Accident Causation Analysis at Railroad Crossings Protected by Gates

JOHN A. HALKIAS AND LAURENCE BLANCHARD

The purpose of this study was to identify probable causes of and factors responsible for accidents occurring at railroad crossings protected by gates. Two important goals of this study were to (a) compare the results obtained for the two types of warning systems activating the gates: fixed distance and constant warning time systems, and (b) test the hypothesis that extended, or widely variable, warning times create a lack of credibility in warning signals. These objectives were achieved by statistically analyzing accident data obtained from the National Rail-Highway Crossing Inventory and the Railroad Accident/Incident Report files for the period 1975 through 1984. An accident classification by circumstance (movement and position of the car in relation to the tracks and the trains) highlighted some causes and factors responsible for the different types of accidents. The classification indicated results and led to the development of a similar interpretation of the accidents for both types of warning systems. Further analysis confirmed and quantified the small impact of environmental factors (bad weather, poor visibility at crossings, etc.). Trends found in relation to warning times tended to indicate that lack of credibility in warning signals was a factor in the accidents.

More than 7,000 accidents involving grade crossings occur each year in the United States. They are responsible for approximately 600 fatalities and 2,500 injuries annually *(1)*. The high ratio of fatalities and injuries to the number of accidents at rail-highway grade crossings ranks these accidents among the most severe in the public safety area. As a reference, this ratio is approximately 40 times greater than the same ratio for all motorist accidents *(2)*.

In an attempt to reduce railroad crossing accidents, warning devices have been installed on or adjacent to the highway approaches to railroad grade crossings. These devices can be classified as either passive or active. Passive devices include stop signs, crossbucks, and pavement markings. They are used to direct attention to the location of the crossing and thus permit motorists to take appropriate action. Active devices include flashing lights and gates (automatic gates include flashing lights as a part of the warning display) that are train activated. They inform the motorist of the approach or presence of trains at grade crossings.

It should be pointed out that automatic gates are the most sophisticated and restrictive of all the grade crossing control devices: when activated, gates physically separate motor vehicles from the grade crossing. However, while 8 percent of public grade crossings are protected by gates, these crossings still account for about 15 percent of all train accidents involving grade crossings *(1)*. If this disproportion may be partly explained by high exposure (crossings having higher train and vehicle volume are usually equipped with automatic gates), it is still clear that a desirable safety level has yet to be achieved and more research is needed to investigate causes of these accidents.

J. A. Halkias, Department of Civil Engineering, Florida Institute of Technology, Melbourne, Fla. 32901. L. Blanchard, Matra Transport, Paris, France.

WARNING DEVICES

Two basic types of automatic control systems exist at crossings protected by gates: (a) fixed distance warning system, and (b) constant warning time system.

With a fixed distance warning system, trains activate the flashing lights and the gates at a predetermined distance from the crossing. This distance is calculated by using the speed of the fastest train allowed over the crossing and a specified minimum warning time. The major drawback of such systems is that the warning devices operate continuously while the train is on the approach track circuit, regardless of train speed. This leads to inconsistent warning time lengths for crossings used by trains having a wide speed range. Lengthy time intervals (e.g., slow train) between the signal activation and the arrival of the train at a crossing may lead to loss of credibility. Drivers may become impatient in situations where the warning device is active for a long time. Such repeated experiences can lead them to disregard the signals and to maneuver around crossing gates.

Signals activated by a constant warning time system do not present such a drawback. Constant warning time equipment has the capability of sensing a train in the approach section, measuring its speed and distance from the crossing, and activating the warning devices. Thus, regardless of train speed a uniform warning time is provided.

Many studies include lack of signal credibility as a factor in accidents and recommend equipping gates with a constant warning time system. Studies by Wilde et al. *(3)* and Halkias and Eck *(4)* provide useful information and recommendations for further analysis. Wilde et al. studied driver behavior at six crossings protected by gates activated by a fixed distance system *(3)*. Analysis of warning times at those crossings indicated an extreme variability from alarm period to alarm period as defined by standard deviations. The most variable warning times (ranging from 50 to 205 sec) occurred at a crossing at which several accidents involving train-vehicle collisions had occurred in the past. From this, the authors concluded that it can be speculated that the more variable the warning time, the higher the frequency of train-vehicle collisions.

By comparing accident rates at crossings before and after upgrading from a fixed distance to a constant warning time system, Halkias and Eck *(4)* found a 28 percent reduction in the accident rate. They concluded that this result tends to confirm the hypothesis that constant warning time systems have greater credibility than do fixed distance systems.

In-depth analysis of warning times appears necessary to test the hypothesis that extended or widely variable warning times contribute to accidents because they create a loss of credibility of the warning signals. Furthermore, although some studies *(3, 5)* have analyzed drivers' behavior at crossings protected by gates and deduced from it possible responsible factors, there are no statistical analyses on the circumstances and causes of the accidents. For this reason, and because it was believed that comparison of accident causes for the two types of warning systems (fixed distance warning and constant warning time systems), as well as any trend related to warning times would be more significant if studied on a large data sample, a statistical approach on a large data base was used for this study.

METHODOLOGY

The National Rail-Highway Crossing Inventory file and the Railroad Crossing Accident/Incident data file for the period January 1, 1975, through December 31, 1984, were obtained from the Federal Railroad Administration on six magnetic tapes. These two files were merged and correlated with the crossing identification number.

Two subfiles were extracted that contained all the accidents that occurred at railroad crossings protected by gates activated by both fixed distance warning system and constant warning time system. These subfiles were analyzed separately using the same procedure (except for the study concerning credibility factor, which was not applicable in the case of the constant warning time device).

Data Analysis

The analysis was divided into two parts: an accident classification by circumstance and an analysis of the accidents that remained unexplained by the circumstances.

Accident Classification by Circumstance

All the parameters available on the motorist action, the relative position of the car with respect to the train or trains (in a case of a second train), and the car movement when the impact occurred, were used to classify the accidents by circumstance. Table 1 gives the list of the parameters used and the type of information they provide. This classification also includes the interpretation of the accidents, the causes of which were understandable by the circumstances.

The data elements (or parameters) are those directly available from the inventory or accident/incident data files. Their definitions are given according to the procedures manual *(6)* and the FRA Guide for Preparing Accident/Incident Reports *(7)*.

TABLE 1 CIRCUMSTANCE PARAMETERS

Parameter	Values
Motorist	Drove around or through the gate Stopped and then proceeded Did not stop Other Unknown
Car position	Stalled on crossing Stopped on crossing Moving over crossing Unknown
Second train: The motorist drove behind or in front of a train and struck or was struck by a second train.	Yes No Unknown
Position of car / unit train: Identify the position within the train of the first locomotive unit or car that struck or was struck by the higher user.	

Analysis of the Accidents Unexplained by the Circumstances

Accidents in which the causes could not be explained by the circumstances were further analyzed to obtain additional information. These accidents were examined by using all of the available parameters that might highlight the causes of the accidents.

It should be pointed out that one important factor was missing—no human factor data were directly available from the file. Indeed, the only data elements available about the motorist were related to the action or more precisely to the movement of the car before impact. Information such as driver's age, location of residence (from which might be inferred the driver's familiarity with the crossing), and condition (whether or not intoxicated?) would have been helpful for a better understanding of the accidents. For this reason, only two parameters available were analyzed: (a) environmental conditions and (b) warning times.

Environmental Conditions

All the environmental elements that might have been contributors to the accident (wet roadway, poor visibility at the crossing, etc.) were regrouped in this category. For each element, a weight (w) of either 0, 0.5, or 1 was given to the probable adverse effect of the driver's response: 0 corresponding to a lack of adverse effect (good environmental conditions at the crossing) and 1 corresponding to a possible adverse effect. For each accident, a summation on (w) for all elements was calculated. An accident obtaining a total of 0 could be considered as not being adversely affected by any of these environmental conditions. The elements used and their corresponding weights are given in Table 2. A weight of 0.5 was given for fog or rain because these weather conditions were judged less dangerous than sleet or snow. Indeed, even if visibility is poor in case of fog or rain, stopping distance will not be severely affected as

TABLE 2 ENVIRONMENTAL PARAMETERS

Element	Weight
View of Track[a]	
Not obstructed	W = 0
Obstructed (permanent structure, standing railroad equipment, topography, highway vehicles, vegetation, other)	W = 1
Weather	
Clear or cloudy	W = 0
Fog or rain	W = 0.5
Sleet or snow	W = 1
Visibility	
Day	W = 0
Dawn, dusk: crossing illuminated by street lights or special lights:	
Yes	W = 0
No	W = 1
Dark: crossing illuminated by street lights or special lights:	
Yes	W = 0
No	W = 0.5

[a]Indicates if the driver's view approaching the crossing was obstructed to the extent that he/she might have been aware that a train was about to occupy or was occupying the crossing.

opposed to sleet or snow conditions where the motorist can completely lose control of the vehicle.

When the crossing was not illuminated by street lights or special lights, dark conditions received a weight of only 0.5 because they were considered less dangerous than dawn or dusk conditions. Red flashing lights offer more contrast with black background and are thus more conspicuous and visible. Furthermore, visibility at twilight is likely to be more diminished because of the continuously changing luminosity and the associated need for visual adaptation. When the crossing was illuminated by street lights or special lights, dark, dawn, and dusk conditions were judged similar to day conditions (weight of 0).

Warning Times

Warning times were obtained from the following data elements:

Maximum timetable speed (*MxTTSp*): The maximum train speed permitted over a crossing;

Typical minimum train speed (*MinSp*): The typical minimum train speed over a crossing; and

Train speed (*TrnSp*): The train speed when the accident occurred.

The concept of a fixed distance warning device is the provision of minimum warning time (*MinWT*) for the fastest train speed (*MxTTSp*) permitted over the crossing. To accomplish this requirement a train detection track circuit system is placed at a certain distance (*d*) from the crossing such that

$$d = MxTTSp \times MinWT \quad (1)$$

The minimum warning time (*MinWT*) corresponds to the interval of time between the arrival of the train at the track circuit—beginning of the signal's activation—and the arrival of the train at the crossing, for the case of a train traveling at the maximum timetable speed. This minimum warning time should be long enough to enable vehicles to stop or clear the crossing *(8)*. It was set to 24 sec for all of the crossings.

Furthermore, with maximum timetable speed and the typical minimum train speed known for each crossing, it is possible to work out the typical maximum warning time (*MaxWT*), which corresponds to the same interval of time as defined previously, but for a train traveling at the typical minimum speed.

$$d = MxTTSp \times MinWT$$

$$d = MinSp \times MaxWT \quad (2)$$

Hence

$$MaxWT = (MxTTSp)/(MinSp) \times MinWT \quad (3)$$

$$MaxWT = (MxTTSp)/(MinSp) \times 24 \text{ sec} \quad (4)$$

From the warning times a ratio was developed, the object of which was to enable the plotting of the actual warning time (*WT*) with respect to the minimum and maximum warning times (*MinWT* and *MaxWT*) for each accident. The following scheme explains the calculation of the ratio. Considering a line with three points A, B, and X of respective coordinates *MinWT*, *MaxWT*, and *WT*;

____*A*__________*X*__________________*B*_____

the location of *X* is given by the parameter *r* such that

$$AX = r \times AB \quad (5)$$

$$r = AX/AB \quad (6)$$

Because

$$AX = WT - MinWT \quad (7)$$

$$AB = MaxWT - MinWT \quad (8)$$

$$r = (WT - MinWT)/(MaxWT - MinWT) \quad (9)$$

As an example, $r = 0$ corresponds to an actual warning time equal to the minimum warning time, and $r = 1$ corresponds to an actual warning time equal to the maximum warning time. The sketch below shows the relative scale adopted and the plotting of two actual warning times (*WT*1 and *WT*2 as examples):

0	*MinWT*	*WT*1	*MaxWT*	*WT*2	
	$r = 0$	$r = 1/2$	$r = 1$	$r = 2$	(10)

The idea was to highlight the credibility problem, if any, by finding a correlation or trend between the frequency of accidents and the warning times calculated or the ratio developed, or both.

It should be noted that this procedure is not applicable in the case of constant warning time systems because, regardless of the train speed, the warning time remains constant and, in general, equals 24 sec.

RESULTS

The results obtained for both types of warning devices (fixed distance and constant warning time devices) were similar and led to identical classifications and interpretations of the accidents (except for the accidents related to the credibility factor). The data in Tables 3 and 4 show the distribution of accidents for both types of warning devices. The data in Table 5 and Figure 1 compare the results obtained for the two types of warning devices by using the valid percentage.

TABLE 3 ACCIDENT CLASSIFICATION BY CIRCUMSTANCE-FIXED DISTANCE WARNING DEVICES

Circumstances	Frequency	Percent
Accidents remaining unexplained	2,585	43
Stopped	1,058	18
Stalled	1,136	19
Struck or was struck by a second train	175	3
Struck a car other than the leading car	451	8
Missing or unknown	569	9
Total	5,974	100

- Twenty percent of the accidents that occurred at railroad crossings with fixed distance warning systems (21 percent for constant warning time systems) involved motorists stopped on the crossing. The presence of a highway intersection within 75 ft of the crossing was found to contribute to these accidents. Another factor believed responsible for these accidents was motorists' lack of driving experience.
- Twenty-one percent of the accidents that occurred at railroad crossings with fixed distance warning systems (22 percent for constant warning time systems) involved motorists stalled on the crossing. The cause of these accidents was believed to be engine failure or automobile malfunction.
- Eight percent of the accidents that occurred at railroad crossings with fixed distance warning systems (9 percent for constant warning time systems) involved motorists who drove around or through the gate and struck a train car other than the leading car. The environmental factor did not have a strong adverse effect because more than 50 percent of these accidents occurred during good weather and good visibility conditions (Tables 6 and 7). Alcohol and drug intoxication, brake failure, or inattentiveness were believed to contribute to these accidents.
- Forty-eight percent of the accidents that occurred at railroad crossings with fixed distance warning systems (45 percent for constant warning time systems) involved motorists who drove around or through the gate, and while moving over the crossing, struck or were struck by the leading train car (accidents classified as remaining unexplained by the circumstances). This last category of accidents was further analyzed

TABLE 4 ACCIDENT CLASSIFICATION BY CIRCUMSTANCE (CONSTANT WARNING TIME DEVICES)

Circumstances	Frequency	Percent
Accidents remaining unexplained	723	36
Stopped	342	17
Stalled	359	18
Struck or was struck by a second train	54	3
Struck a car other than the leading car	135	7
Missing or unknown	375	19
Total	1,988	100

TABLE 5 COMPARISON OF ACCIDENT CLASSIFICATION BY CIRCUMSTANCE (VALID PERCENT) FOR FIXED DISTANCE AND CONSTANT WARNING TIME DEVICES

	Valid Percent	
Circumstance	Fixed Distance	Constant Warning Time
Accidents remaining unexplained	48	45
Stopped	20	21
Stalled	21	22
Struck or was struck by a second train	3	3
Struck a car other than the leading car	8	9

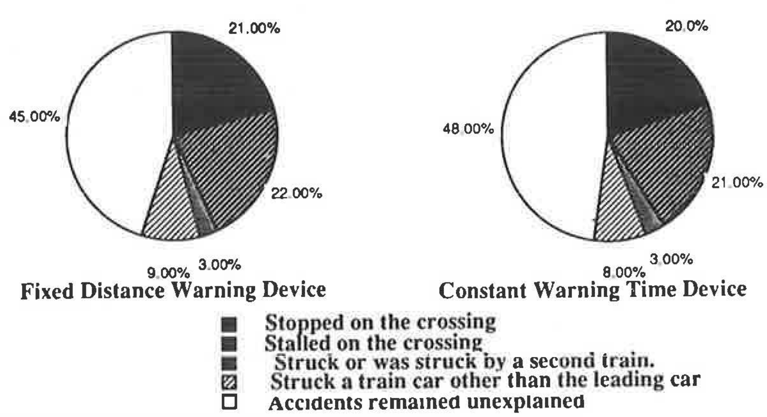

FIGURE 1 Comparison of the accident classification by circumstance for fixed distance and constant warning time systems.

TABLE 6 ACCIDENTS BY ENVIRONMENTAL FACTOR WEIGHT (VEHICLE STRUCK A TRAIN CAR OTHER THAN THE LEADING CAR, FIXED DISTANCE WARNING DEVICES)

Weight	Frequency	Percent	Valid Percer
0.0	168	37	51
0.5	85	19	26
1.0	58	13	18
1.5	12	3	4
2.0	3	1	1
Missing	125	27	Missing
Total	451	100	100

TABLE 7 ACCIDENTS BY ENVIRONMENTAL FACTOR WEIGHT (VEHICLE STRUCK A TRAIN CAR OTHER THAN THE LEADING CAR, CONSTANT WARNING TIME DEVICES)

Weight	Frequency	Percent	Valid Percent
0.0	61	45	54
0.5	22	16	19
1.0	19	14	17
1.5	8	6	7
2.0	1	1	1
2.5	3	2	2
Missing	21	16	Missing
Total	135	100	100

TABLE 8 ACCIDENTS BY ENVIRONMENTAL FACTOR WEIGHT (FIXED DISTANCE WARNING DEVICES)

Weight	Frequency	Percent	Valid Percent
0.0	826	32	47
0.5	363	14	21
1.0	445	17	26
1.5	63	2	4
2.0	39	2	2
2.5	4	0	0
Missing	845	33	Missing
Total	2,585	100	100

TABLE 9 ACCIDENTS BY ENVIRONMENTAL FACTOR WEIGHT (CONSTANT WARNING TIME DEVICES)

Weight	Frequency	Percent	Valid Percent
0.0	295	41	51
0.5	104	14	18
1.0	150	21	26
1.5	16	2	3
2.0	10	1	2
Missing	148	21	Missing
Total	723	100	100

by examining the environmental conditions and the warning times.

Environmental Conditions

For approximately 30 percent of these accidents (results similar for both types of warning systems), bad weather or poor visibility at crossings might have had a likely or strong adverse effect (weight larger or equal to 1) on motorists' action and decision (Tables 8 and 9). Although the relative weights given to some environmental factors such as fog and rain versus sleet and snow and variable luminosity can be questioned, the results indicate that a small change in the relative weights would not have affected the conclusion that most of the accidents occur during good weather and good visibility conditions.

Warning Times

The >>*x*% sign to the right of Figures 2 and 3 indicates that *x* percent of the accidents had an actual warning time larger than the extreme value plotted. These cases were largely spread on the time scale, and for reasons of scale, do not appear on the figures.

For fixed distance, several conclusions were drawn from the analysis of warning times.

- Warning times have an extreme variability. They range from less than 20 sec up to 16 min (Figure 2). This variability is much larger than the one found by Wilde et al. *(3)*. It should be noted that their research was based on the study of only six crossings. It can be assumed that these few crossings were not representative of the whole crossing population.
- Three percent of the accidents occurred because of warning times that were too short (smaller than the minimum warning time) to enable motorists to clear the crossing before the arrival of the train (Figures 2 and 3). This was believed to be a result of the introduction of high-speed rail service at existing facilities without any corrective action having been undertaken to provide a minimum required warning time at the crossing. It should be noted that this percentage might have been biased by incorrect data, such as maximum timetable speed smaller than the true value or overestimation of the actual train speed.
- Comparing different groups of crossings (classification based on the value of the typical maximum warning time), a general trend was found: the larger the typical maximum warning time, the less the accidents are spread on the time scale, and the more concentrated they are near the minimum warning time. In other words, the more variable the warning times (the larger is the train speed range), the more accidents occur when the actual warning time is short and close to the minimum warning time (e.g., actual train speed close to the maximum timetable speed). Also, the smaller the warning time range, the more accidents occur when the actual warning time is large and beyond the typical maximum warning time (actual train speed smaller than the typical minimum speed).

The distributions obtained for the first two charts in Figure 4 (maximum warning times less than 0.75 min and maximum warning time between 0.75 and 1.5 min) are unexpected in terms of the large percentage of accidents occurring out of the typical warning time range (61 and 48 percent, respectively). Indeed, because most of the trains can be expected to provide a

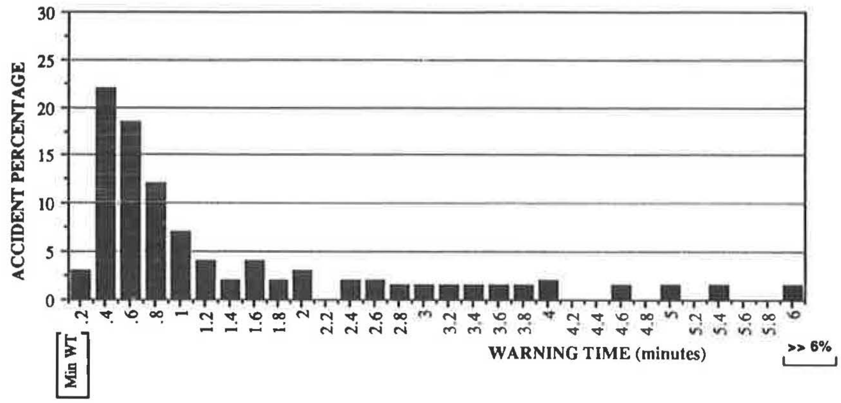

FIGURE 2 Accident percentage versus actual warning time.

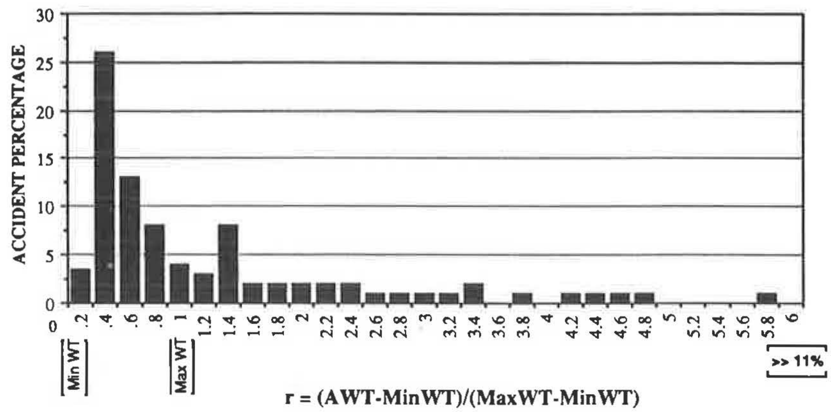

FIGURE 3 Accident percentage distribution with respect to the minimum and typical maximum warning time.

warning time between the minimum and the typical maximum times, most of the accidents should be expected to occur within this range of warning times. From this result, it can be inferred that, in the case of crossings providing a small range of warning times (e.g., typical minimum speed close to the maximum timetable speed), larger warning times are dangerous. These large warning times, being out of the typical range, are by definition infrequent. They are, however, involved in a high percentage of accidents. If it is considered that the driver involved in the accident was familiar with the crossing *(2, 9, 10)*, it is likely that he experienced short warning times at the crossing. A longer alarm period without an approaching train might have led drivers to distrust the signal, and, getting impatient, they might have proceeded without looking for a train.

The trend leading to a concentration of accidents when the typical maximum warning time increases is optimal for the last chart in Figure 4 (maximum warning time greater than 6 min), with 40 percent of accidents occurring when the actual warning time is close to the minimum warning time. Referring to the probable familiarity of the driver with the crossing, this trend can be explained by a lack of driver trust in the signal. The larger the typical maximum warning time, the higher the probability that the driver familiar with the crossing has experienced a long alarm period at the crossing. The driver might have finally developed the expectancy to have to wait a long time at the crossing and decided that there was enough time to proceed before the arrival of the train. Changes in the train pattern (faster train providing a shorter warning time) may be responsible for this large number of accidents.

Although it was impossible to quantify the importance of the lack of credibility in warning signals, the trends found indicate that it is a factor in accidents.

In the case of accidents occurring at gates activated by a constant warning time system, the credibility factor should not be involved because the warning time provided at these crossings is short, constant, and approximately 24 sec. However, crossings equipped with fixed distance warning systems are much more numerous than crossings equipped with constant warning time systems. In 1984, 12,483 crossings were equipped with fixed distance warning systems compared with 3,953 crossings equipped with constant warning time systems. The probability that a driver will encounter a crossing equipped with a fixed distance warning system is therefore much higher. Furthermore, drivers do not have any knowledge about warning devices that would enable them to differentiate between crossings equipped with constant warning time systems and those equipped with fixed distance warning systems. Thus drivers might in some cases have carried over their expectancy of extended or inconsistent warning times developed at cross-

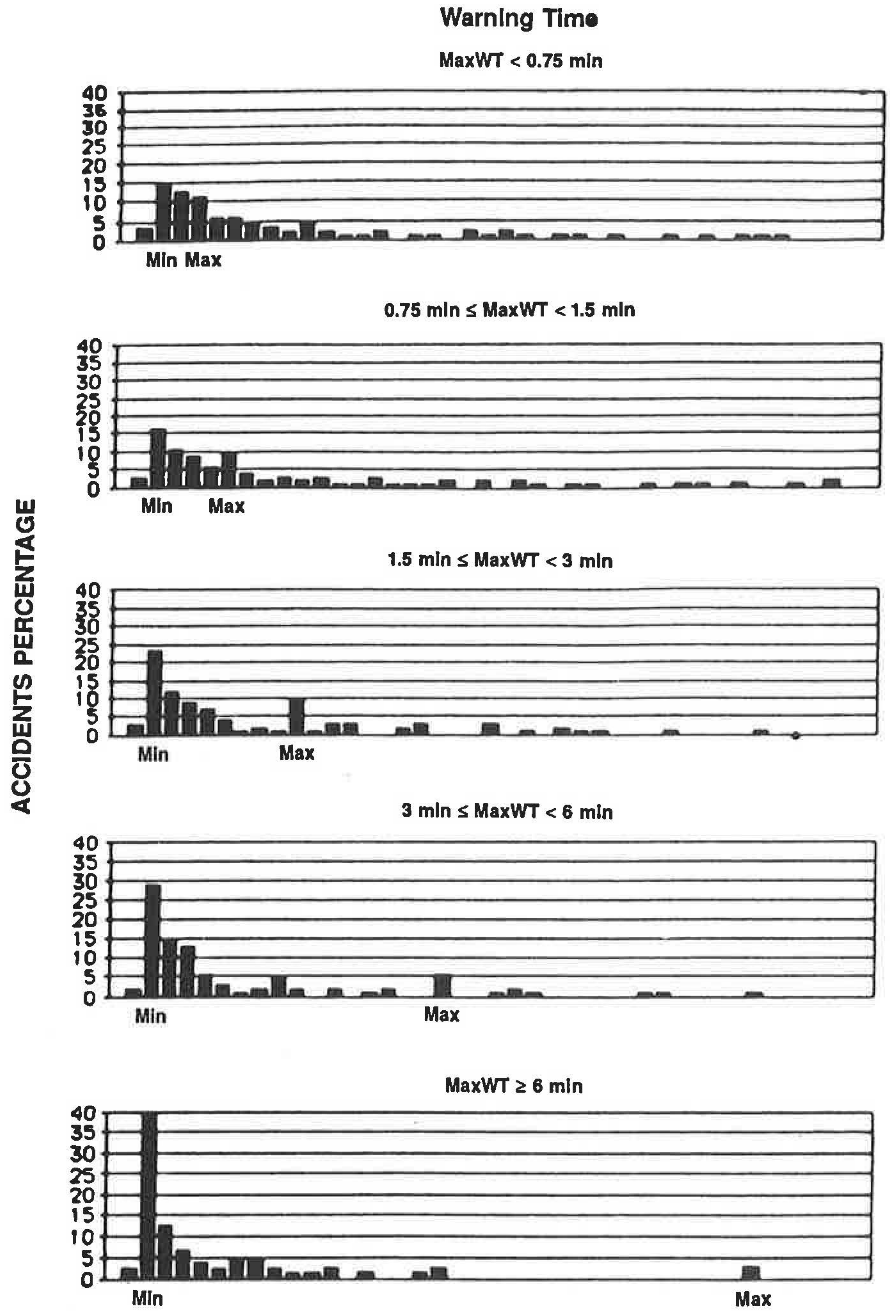

FIGURE 4 Summary of accident percentage distribution for five ranges of typical maximum warning times.

ings equipped with fixed distance warning systems to crossings equipped with constant warning time systems. In other words, it might be inferred that the effectiveness of constant warning devices is influenced by the inconsistency of warning times at the numerous crossings equipped with fixed distance warning systems. In this case, the warning signal's lack of credibility would also be a factor in accidents occurring at crossings equipped with constant warning systems. The similarity of the results for both types of warning systems and the high percentage of accidents remaining unexplained by the circumstances and environmental factors, would tend to confirm this theory. An analysis of driver familiarity with crossings equipped with constant warning time systems might have allowed this problem to be highlighted; for drivers involved in these accidents, a lack of familiarity with such crossings will reinforce the hypothesis developed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study highlighted some causes of and factors that are responsible for accidents at railroad crossings. Unlike previous studies, it analyzed a large data base and provided primary statistical data on accidents occurring at railroad crossings protected by gates. The study might be useful as a base for the development of necessary countermeasures for improving safety at railroad crossings protected by gates.

Some of the conclusions reached are as follows:

- Results from the present large data sample confirm the theory generally adopted that the majority of accidents occurs during good weather and good visibility conditions.
- Physical and environmental conditions are not sufficient to explain accidents. For a large percentage of cases, the cause of the accidents remained obscure or uncertain essentially because of a total lack of data elements on the driver.
- Study of warning times led to two main conclusions. (a) Inconsistency in warning time length leads motorists to distrust signals. At railroad crossings that have a narrow typical warning time distribution, most of the accidents occur beyond the typical maximum warning time. (b) Extended warning times lead motorists to ignore warning signals and cross the railroad.

From these results, it was concluded that lack of credibility in warning signals was a factor in accidents occurring at crossings equipped with fixed distance warning systems.

For crossings equipped with constant warning time systems, it was hypothesized that the effectiveness of this warning device was biased by the inconsistency of warning times at the numerous crossings equipped with fixed distance warning systems. From this, it was concluded that the warning signals' lack of credibility might also contribute to the accidents occurring at crossings equipped with constant warning time systems.

Recommendations

Based on the work undertaken for this research, the study of the data sources, and the results obtained, several suggestions are presented. They concern two important subjects: (a) the data available in the U.S. Department of Transportation Crossing Inventory and the FRA Rail-Highway Crossing Accident/Incident files, and (b) areas in which further research could prove helpful.

The following recommendations are made:

- For better quality and reliability in the data, it is important to minimize inconsistencies. This can be achieved by running programs to check the consistency of the values entered in the data file. Programs as simple as the one that checks whether a field declared as numerical contains only digits might enable the correction of mistyped characters. Other checking programs should detect incompatibilities such as a vehicle stopped on the crossing with a speed other than zero.
- More precise information is needed on the motorist's action when the accident occurred. The phrase "motorist drove around or through the gate" has to be reviewed. For a better understanding of the accidents, it is important to be able to distinguish the cases in which the motorist drove around the gate from those in which he drove through the gate. Furthermore, these two motorist actions involve two different approaches of solving the problem. For example, a countermeasure to stop drivers from driving around the gates would be to install four half-gates (instead of two) to completely separate the motorist from the tracks. However, this countermeasure would probably not have any impact on the accidents in which the motorist drove through the gates. For these cases increasing the conspicuousness of the gates might improve safety.
- Information about the motorist is indispensable for accident causation analysis. Motorist data elements that may prove valuable are age, alcohol and drug intoxication, and location of residence (from which can be inferred driver familiarity with the crossing).
- Additional data on the train speed pattern at crossings (such as median train speed) will enable a more accurate definition of the warning time distribution at crossings and thus will provide more information on the effect of warning times on accidents.

Further research could prove valuable in two areas:

- A further causation analysis of these accidents is needed. This analysis should concentrate on the possible contributing factors about which information was not available in the data source used for this research. The important factors to be examined are alcohol and drug intoxication, advanced age, lack of driving experience, and automobile malfunction.
- The results obtained lead to the development of the hypothesis that the credibility factor might also be involved in accidents occurring at crossings protected by constant warning time systems. An analysis of driver familiarity at these crossings might provide valuable information. For drivers involved in the accidents at these crossings, a lack of familiarity with the crossings would reinforce the hypothesis developed.

REFERENCES

1. *Rail-Highway Crossing Accident/Incident and Inventory Bulletin 5*. FRA, U.S. Department of Transportation, 1983.
2. J. H. Sanders, G. S. Kolsrud, W. G. Berger. *Human Factors Countermeasures to Improve Highway-Railway Intersection Safety*. DOT-HS-190-2-300. U.S. Department of Transportation, 1973.
3. G. J. S. Wilde, L. J. Cake, and M. B. McCarthy. *An Observational Study of Driver Behavior at Signalized Railroad Crossings*. Report 75-16. Canadian Institute of Guided Ground Transport, Kingston, Ontario, 1975.
4. J. A. Halkias and R. W. Eck. Effectiveness of Constant Warning Time Versus Fixed Distance Warning Systems at Rail-Highway Grade Crossing. In *Transportation Research Record 1010*, TRB, National Research Council, Washington, D.C., 1985, pp. 101–116.
5. T. Ikeda. A View of Level Crossing Accident in JNR. *Japanese Railway Engineering*, No. 12, 1971, pp. 12–15.
6. *Procedures Manual, National Railroad-Highway Crossing Inventory*. FRA, U.S. Department of Transportation, 1973.
7. *FRA Guide for Preparing Accident/Incident Reports*. FRA, U.S. Department of Transportation, 1982.
8. *Railroad-Highway Grade Crossing Handbook*. FHWA, U.S. Department of Transportation, 1978.
9. D. W. Shoppert and D. W. Hoyt. *NCHRP Report 50: Factors Influencing Safety at Highway-Railway Grade Crossings*. TRB, National Research Council, Washington, D.C., 1968.
10. E. C. Wigglesworth. Epidemology of Road-Rail Crossing Accidents. *Journal of Safety Research*, Vol. 22, No. 4, 1979, pp. 162–171.

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