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Physical and Operational Characteristics of Rail-Highway Grade Crossings on Low-Volume Roads

RONALD W. ECK AND RAJENDRAN SHANMUGAM

The National Rail-Highway Crossing Inventory and Federal Railroad Administration accident files were analyzed to compare low-volume road grade crossing characteristics with those of their higher-volume counterparts. Other objectives included the determination of accident rates, accident proportions, and effectiveness factors for low-volume road grade crossings and the comparison of these with other grade crossings. Results generally confirmed the hypothesis that low-volume road grade crossing characteristics are significantly different from those of higher-volume road grade crossings. The differences were more evident for physical characteristics than for operational characteristics. Accident rates, in which exposure was incorporated, at low-volume road grade crossings were much higher than those at higher-volume road grade crossings. There were also significant differences in accident proportions between low-volume road and higher-volume road grade crossings. Effectiveness factors for low-volume road grade crossing upgrades were different from those used in the U.S. Department of Transportation Resource Allocation Model. Flashing lights to gates upgrades were more effective for higher-volume road grade crossings (70 percent) than for low-volume road grade crossings (51 percent). However, upgrades from no signs or crossbucks to stop signs were more effective at low-volume road grade crossings (73 percent) than at higher-volume road grade crossings (59 percent).

Potential conflicts can arise in the intersections of any traffic streams. However, the potential for conflicts at rail-highway grade crossings is unique. Because of the size of the train, significant changes in speed through deceleration or acceleration are not possible. Its travel path is limited to the rails. However, automobiles, trucks, and buses can stop, accelerate, decelerate, or turn in reasonable distances. Trains therefore must be given the right-of-way at grade crossings. It is the traffic engineer's responsibility to inform the motorist that a grade crossing exists and to alert drivers to the presence of trains so that drivers can take appropriate action.

Grade crossing warning devices include signs and signals on or adjacent to the highway approach to a rail-highway grade crossing. These traffic control devices can be classified as either active or passive devices (*1*). Passive devices include signs, pavement markings, and crossing illumination that identify and direct attention to the location of a grade crossing. Active devices include flashing lights and gates that are activated by the train to inform motorists of the approach or presence of trains on grade crossings. Gates have proven to be the most effective warning device in use because they provide a visible, if not physical, barrier between motor vehicles and the tracks.

The traffic engineer's job is to select the appropriate warning device for a given situation. Obviously, the ideal solution would be to install gates at all rail-highway grade crossings. However, because budget limitations make this impractical, the use of gates is usually reserved for the most dangerous crossings, and less effective devices are installed at other locations.

Between 1974 and 1985, approximately $900 million in federal aid safety funds were spent to provide active warning devices at nearly 22,000 crossings (*2*). Today, many of the most

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hazardous crossings have been improved and there is concern that a point of diminishing returns is being reached. Under this program, low-volume crossings are rarely reviewed by diagnostic teams. Any work performed at these crossings is usually limited to the installation of crossbucks and advance warning signs. However, recent statistics reveal that approximately half of the annual fatalities occur at low-volume crossings at which active warning devices may never be practicable.

Interest in low-volume crossings has recently grown. Federal Highway Administration Demonstration Project 70, "Railroad Crossing Corridor Improvements," was developed to encourage state highway agencies to expand their current programs to encompass many more crossings each year (*2*). Low-cost improvements are also emphasized at the types of crossings that are not currently being addressed.

The problem of selecting an appropriate warning device applies to all grade crossings, from those located on high-volume urban roads to those on low-volume rural roads. A low-volume road (LVR) is defined as a road with an average daily traffic volume of less than 400 vehicles per day (vpd). Although over 60 percent of the rail-highway grade crossings in the United States are on low-volume roads, the greatest number of grade crossing accidents occur at crossings on higher-volume roads. It is at these locations that exposure (the product of train volume and traffic volume) is the greatest. These crossings therefore have received the most study and funding.

Although traffic volumes are substantially lower, the potential for accidents at low-volume road grade crossings can still be great. Because of the low design standards that are typically used and a lack of maintenance, the crossing surface may be poor, which could contribute to the danger of vehicles stalling on the crossing. The roadway is frequently designed to minimum standards, which can create awkward horizontal and vertical alignments that contribute to sight distance problems. Because of funding constraints, pavement markings and signing at LVR grade crossings may not always meet recommended guidelines.

It has been said (*3*) that safety problems develop because many drivers do not frequently encounter trains at a particular crossing, and therefore expect the absence rather than the presence of trains. Low-volume roads can be especially vulnerable to this problem because the exposure between automobiles and trains is very low. Drivers on low-volume roads rarely expect to see other motor vehicles, let alone a train at a grade crossing.

A great volume of research has been conducted in recent years in regard to this problem (*4-12*). Studies performed have included the development of more effective crossing traffic control devices, formulation of accident prediction equations, and development of models for the optimal allocation of limited grade crossing resources. Virtually all of these studies have dealt with grade crossings in general and have not distinguished between low-volume and higher-volume facilities. However, as was stated earlier, the condition of and associated accidents at LVR grade crossings are not necessarily the same as those of higher-volume road (HVR) grade crossings. Therefore, agencies responsible for local roads may not in fact be maximizing safety and minimizing cost if they base their decisions solely on the information that currently exists on crossings in general. Information must be obtained on the physical and operational characteristics of LVR grade crossings and their associated accident experience. These data should be analyzed to determine if current procedures to predict grade crossing accidents and quantities measured for resource allocation are applicable to low-volume roads. If not, perhaps low-volume roads should be considered a separate category of grade crossing.

STUDY OBJECTIVES

A study was undertaken to analyze the National Rail-Highway Crossing Inventory data base and the Federal Railroad Administration (FRA) accident data files. The overall objective of this analysis was to compare the physical and operational characteristics of railroad-highway grade crossings on low-volume roads (ADT $\leq$ 400 vpd) with those of other classes of highways to provide assistance to road agencies involved in LVR grade crossing decision-making. Specific objectives of the research were as follows:

- To compare the physical characteristics of LVR crossings with those of other crossings, namely
    - Angle of crossing,
    - Number of tracks,
    - Highway pavement type,
    - Pavement markings,
    - Advance warning signs, and
    - Crossing surface type;
- To compare the operational characteristics of LVR crossings with those of other crossings, namely
    - Train movement,
    - Train speed,
    - Number of trains, and
    - Proportion of trucks;
- To compare the accident experience at LVR crossings with that of other crossings, namely
    - Vehicle position,
    - Position of train,
    - Circumstances,
    - Hazardous material involvement,
    - Severity,
    - Motorist action, and
    - Visual obstructions; and
- To analyze these results to determine whether currently used procedures and quantities for grade crossing accident prediction and resource allocation are appropriate, or whether crossings on low-volume roads should be considered a separate category. Effectiveness factors were examined as a specific parameter in this regard.

DATA ANALYSIS

The National Rail-Highway Crossing Inventory data base and the FRA accident data files from January 1, 1975, to December 31, 1981, were used in this study. The appropriate magnetic data tapes were obtained from the FRA.

Inventory Data

The original inventory file contained data for 213,907 public, at-grade rail-highway crossings. This file was divided into LVR and HVR crossings based on the highway traffic volume. As was stated earlier, LVR crossings were defined as those with an ADT of less than 400 vpd. New data files were named

LOWVOL and HIGHVOL, respectively. The original inventory data file contained 76 variables that ranged from the most important variables for the purposes of this study, such as crossing identification number, crossing angle, traffic volume (ADT), number of trains per day, and warning device type, to less important variables, such as number of bells and availability of commercial power. The new data sets contained only the 23 variables that were deemed necessary for this study.

Preliminary analysis revealed the data set LOWVOL contained 124,035 public grade crossings, and the data set HIGHVOL contained 89,672 public grade crossings. The LOWVOL data set was further divided into four different classes, A, B, C, and D, that correlated with ADT levels of 0 to 100, 101 to 200, 201 to 300, and 301 to 400, respectively. This subdivision was made to determine if any differences existed between classes of LVR grade crossings. The number of crossings in each volume class is shown in Table 1.

Accident Data

The FRA accident data file contained 93,226 accidents during the period January 1, 1975, to December 31, 1981. The accident data base contained 75 variables ranging from more important variables, such as total killed, total injured, type of accident, and visibility conditions, to less important variables, such as the county and state in which the accident occurred.

In order to create separate accident data sets for LVR and HVR crossings, the accident file had to be merged with the respective inventory data file (LOWVOL and HIGHVOL). New accident data sets were created for LVR and HVR crossings and named LVRACC and HVRACC, respectively. They were also stored on magnetic tape. The LVRACC data set contained 20,790 accidents and the HVRACC data set contained 51,257 accidents. The total number of accidents does not equal 93,226 because the original accident data file contained 7,932 accidents for 1982 (not included in this study) and because the remaining 13,247 accidents occurred either at private crossings or crossings that were not at-grade.

Accident characteristics were established by analyzing the new, merged data sets, LVRACC and HVRACC. The accident characteristics of LVR and HVR crossings were then compared. Accident rates, which included vehicle and train exposures, were also computed for different crossing characteristics, such as angle of crossing, vehicle speed, surface type, and other variables of this nature.

PHYSICAL AND OPERATIONAL CHARACTERISTICS OF LOW-VOLUME ROAD GRADE CROSSINGS

Physical Characteristics

A review of the literature indicated that physical characteristics were the principal contributing factors to grade crossing safety problems. Physical characteristics include angle of crossing, number of tracks, road surface, presence of advance warning signs and markings, and crossing surface type.

Angle of Crossing

The inventory file groups the angle of crossing into three categories: 0 to 29°, 30 to 59°, and 60 to 90°. An analysis of the frequency of the three categories of angle of crossing for the four classes of LVR grade crossings showed little difference between classes in terms of proportion of crossings in each angle category. Approximately 80 percent of the crossings were in the 60 to 90° category, 15 percent were in the 30 to 59° category, and 5 percent were in the 0 to 29° category. Similar results were obtained when the crossing angle characteristics of LVR grade crossings were compared with HVR grade crossings and with all crossings. The large proportion of grade crossings that had an angle of intersection between 60 and 90° was expected because 90° is the preferred angle of crossing in terms of minimizing human error and maximizing sight distance.

Number of Tracks

The inventory file gives the number of tracks for each grade crossing. Although as many as eight tracks per grade crossing exist, crossings with more than four tracks per crossing account for less than 0.5 percent of the total number of grade crossings. For this reason, the analysis considered only the data for grade crossings with up to four tracks. Note that the 0-track category represents crossings that do not have any main tracks. In other words, the tracks that do exist are used only for switching and the passing movement of trains.

Some differences existed between the volume classes in terms of proportion of number of tracks. The proportion of single-track crossings decreased with an increase in volume class, and the proportion of two-track crossings increased with an increase in volume class. As was expected, single-track crossings were

TABLE 1 NUMBER OF PUBLIC GRADE CROSSINGS IN DIFFERENT ROAD CLASS CATEGORIES IN THE NATIONAL RAIL-HIGHWAY CROSSING INVENTORY FILE

Low-Volume Road Crossing Category	Average Daily Traffic Volume	Number of Grade Crossings
A	0-100	76,279
B	101-200	19,939
C	201-300	19,330
D	301-400	8,487
Subtotal	--	124,035
Higher-Volume Crossings	>400	89,672
Missing Data	--	200
Total	--	213,907

predominant in the LVR grade crossing category. A difference also existed between vehicle volume categories and the number of tracks per crossing. Eighty-four percent of the LVR grade crossings had one track compared to 68 percent of the HVR grade crossings; this difference was significant. Note that the 0-track category occurred twice as frequently for HVR grade crossings as LVR grade crossings. This is because only switches are associated with many urban crossings that fall under the HVR category.

Road Surface

A notable finding of this analysis was that only 47 percent of the LVR grade crossing surfaces were paved, compared to 96 percent of the HVR grade crossings. An analysis of the LVR crossing data indicated that as the ADT increased, the proportion of crossings with paved surfaces also increased, which was expected. For Class A crossings, 29 percent of the road surfaces were paved, compared to 86 percent for Class D crossings. Such differences, though not necessarily of this magnitude, were expected and are consistent with the hypothesis that more HVR grade crossing surfaces are paved than LVR grade crossing surfaces, as shown in Figure 1. Several reasons exist for this situation. Higher-volume roads need to withstand more wheel passes and generally higher loads than low-volume roads. Low-volume roads also are usually of secondary importance when funds are allocated for construction or improvement. Whether or not a crossing is paved is taken into account in the DOT formula; it was found to be a significant factor only for crossings with passive devices.

Crossing Surface Type

Like road surfaces in general, a rough crossing surface can cause changes in driver behavior, such as a reduction in speed to negotiate the crossing. Although nine different types of grade crossing surfaces were defined in the crossing inventory, section timber, full wood plank, asphalt, and unconsolidated type of surfaces comprise 98 percent of all grade crossing surfaces. Therefore, data summarized in this discussion and the accompanying figures relate only to the four previously mentioned surface types.

The frequency of surface type by volume class for LVR crossings was then determined. Asphaltic surfaces predominated in the LVR grade crossing category. However, for Class A roads, the unconsolidated type (32 percent) was about as common as the asphalt surface (31 percent). This is because most Class A roads are unpaved and carry lower loads and volumes than roads of a higher class.

The frequency of crossing surface type by highway volume condition is shown in Figure 2. In the higher-volume category, asphalt surfaces are once again the dominant surface type. The difference is significant not only between the low-volume and higher-volume road categories, but also between the different classes in general. Such differences were expected.

Advance Warning Signs

Advance warning signs are intended to inform the motorist in advance of the existence of the grade crossing. The absence of advance warning signs would probably increase the likelihood of an accident at the grade crossing. The *Manual on Uniform Traffic Control Devices* (MUTCD) states that an advance warning sign should be used on each roadway in advance of every grade crossing, except on low-volume, low-speed roadways that cross minor spurs or other tracks that are infrequently used (*13*).

An analysis of the inventory data indicated, as expected, that a large proportion of higher-volume road grade crossings (55 percent) are equipped with advance warning signs compared to only 37 percent for LVR grade crossings. The difference of 18 percent is significant.

At least some of the difference in the percentages of crossings with advance warning signs could be attributed to the fact that different jurisdictions have maintenance responsibility for the highways. A smaller jurisdiction, which is more likely to maintain a low-volume road, is less likely to do as much signing as a state or a large municipality that normally maintains a higher-volume road or street.

The use of highway pavement markings is another way to provide drivers with advance warning at grade crossing approaches. Two types of markings exist at grade crossing approaches: a stop line and a railroad (RR) symbol. The inventory file lists the markings under the four categories of

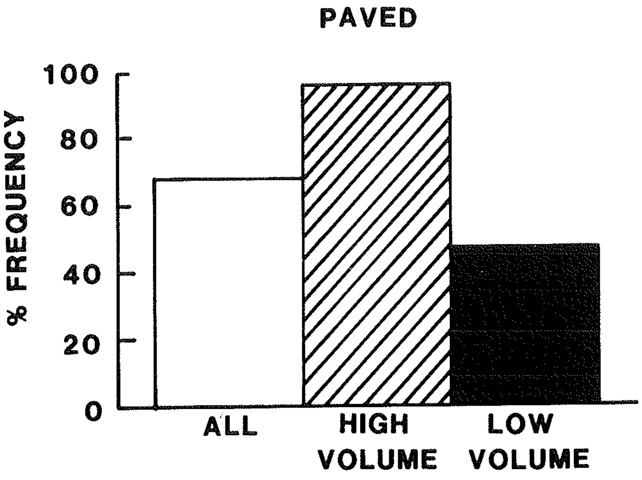

FIGURE 1 Frequency of paved road surface by highway volume condition at grade crossings.

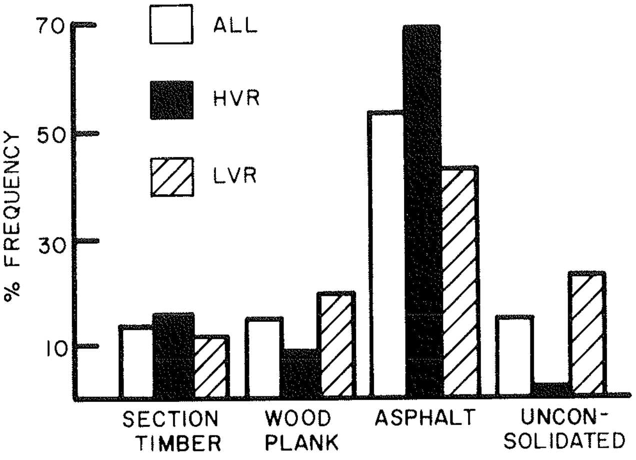

FIGURE 2 Frequency of crossing surface type by highway volume condition at grade crossings.

stop line, railroad symbol, no markings, and stop line and railroad symbol.

As shown in Figure 3, 91 percent of the LVR crossings do not have markings, compared to only 68 percent for the HVR grade crossings; the difference is significant. A number of possible explanations exist for this finding. Most grade crossings in the LVR category tend to be unpaved and therefore do not have any markings. Approach speeds are also less likely to meet the MUTCD standard of 40 mph or greater, and active devices are much less likely to be present at a low-volume crossing. Finally, the jurisdiction with maintenance responsibility may once again play some part.

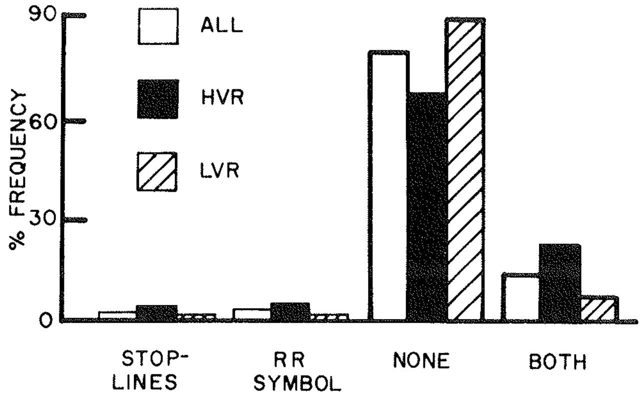

FIGURE 3 Frequency of highway marking by highway volume condition at grade crossings.

Operational Characteristics

A review of the literature indicated that operational characteristics such as train volume, train speed, warning type, and truck volumes are some of the most significant characteristics in regard to accidents at rail-highway grade crossings. The study examined the important operational characteristics of LVR crossings and compared them with those of HVR crossings.

Train Volume

A motor vehicle and a train obviously must be present at a grade crossing for an accident to occur. The higher the volumes of either or both, the greater the chance for a conflict. This fact has been well recognized by researchers; almost every accident prediction formula and hazard index formula uses train and vehicle volumes as basic inputs (*1*).

The inventory file groups train volume data in four separate categories: day through trains, day switch trains, night through trains, and night switch trains. Through trains do not start or terminate at or near the vicinity of the grade crossing. Switch trains start or terminate at or near the vicinity of the grade crossing.

The analysis indicated that zero to nine trains travel over 90 percent of the crossings a day. A chi-square goodness-of-fit test indicated no significant differences between the data for LVR crossings and those for HVR crossings. Statistical tests for various aggregations of train movement data yielded similar results. This implies that accident prediction and hazard index formulas based only on train movement for all grade crossings can be applied equally well to LVR grade crossings.

Train Speed

Train speed is one of the most important operational characteristics that determine the severity of a grade crossing accident. In order to simplify access to the inventory data, train speeds were grouped into units of 10 (i.e., 0 to 9 mph, 10 to 19 mph, etc.). For HVR grade crossings, 30.8 percent had a maximum train speed of 10 to 19 mph; this was the largest single speed group. For LVR grade crossings, 30 to 39 mph was the largest single maximum speed group, with a frequency of 22.8 percent. In the minimum train speed group for both low-volume and higher-volume road grade crossings, 0 to 9 mph (almost standing) was the single largest speed group (42.8 and 60.6 percent, respectively).

A chi-square goodness-of-fit test was performed to compare the train speed distributions between LVR, HVR, and all grade crossings. The results indicated no significant differences between the train speed distributions.

Proportion of Trucks

Truck volumes are considered to be one of the important operational characteristics that influence grade crossing safety. Crossings with a high proportion of trucks should be given careful consideration because of mandatory stopping laws (for trucks carrying hazardous materials) at grade crossings and because of the contributing role truck characteristics play in grade crossing accidents.

The inventory file contains truck data as a proportion of the traffic volume. For all three highway volume categories, crossings with truck proportions over 20 percent were negligible compared to crossings with truck proportions of less than 20 percent. A chi-square goodness-of-fit test indicated no significant differences in truck proportions for the three highway volume categories.

Warning Device Type

Warning devices are used at rail-highway grade crossings to identify and direct attention to the location of the crossing. Some devices detect the presence of a train at or near the crossing, which allows motorists and pedestrians to take appropriate action. The inventory file contains the warning device type data under eight classes. These classes and the proportion of grade crossings under each class, by highway volume category, are shown in Figure 4.

As expected, there was a significant difference of over 5 percent in warning device type distribution between LVR and HVR grade crossings. Eighty percent of the LVR grade crossings are protected by crossbucks only, whereas only 39 percent of the HVR crossings are protected by crossbucks only. Only 6 and 3 percent of the LVR grade crossings are protected by flashing lights and gates, respectively, whereas the corresponding values for HVR crossings are 31 and 15 percent, respectively. Overall, 48 percent of the HVR crossings are

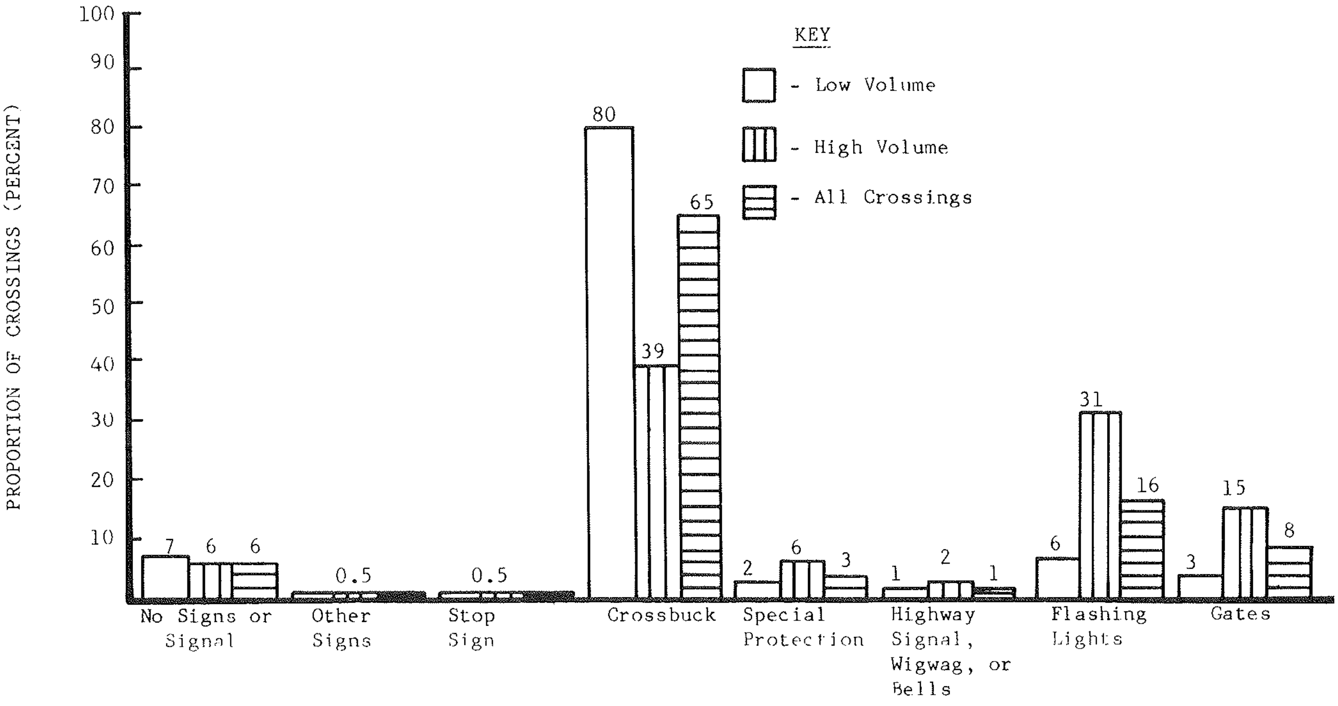

FIGURE 4 Proportion of crossings, by warning device type, for various highway volume conditions.

protected by active devices compared to 10 percent of the LVR crossings. Such great differences are significant and are a result of the importance placed on HVR grade crossings over LVR grade crossings in reducing accidents. These results indicate that when working with aspects of crossings in which the warning device type is significant, such as in the use of the hazard index or accident prediction formulas, attention should be given to stratifying LVR and HVR grade crossings. Results that are based on all grade crossings in general may not be valid because of the significant differences between the type of grade crossing protection used at LVR and HVR grade crossings.

ACCIDENT CHARACTERISTICS AND EFFECTIVENESS FACTORS

Accident Rates

Most literature in the area of rail-highway grade crossings presents accident data in terms of accidents/crossing/yr. Although this could be loosely interpreted as an accident rate, strictly speaking it is not, because the ratio does not incorporate a measure of exposure. Exposure refers to data about the population at risk, such as train and traffic volume. Exposure data are important because they are critical to the calculation of the actual likelihood of an accident. The accident rates presented in this section therefore include vehicle and train exposure; the units are expressed as accidents per vehicle-train per day (acc/v-t/d) times 10^{-8}.

Accident rates can be computed for any physical or operational characteristic at grade crossings. Based on a preliminary analysis, accident rates appeared to represent accident patterns very well for physical characteristics, but not so well for operational characteristics. Physical characteristics, such as angle of crossing, vary between grade crossings, which makes it possible to compare accident rates between grade crossings. However, operational characteristics, such as speed of train at time of accident, vary within a grade crossing. Comparisons therefore are made within the grade crossing instead of between grade crossings, as was desired. Therefore, accident rates for LVR grade crossings were computed for some of the most important physical characteristics, such as angle of crossing, crossing surface type, and presence of advance warning signs and pavement markings. These accident rates were then compared with those of HVR grade crossings.

In general, the accident rates at HVR grade crossings were considerably lower than those of LVR grade crossings. This was expected because of the superiority that HVR crossings have in terms of geometry, physical conditions, and warning device type.

Accident rates for LVR and HVR grade crossings for the three crossing angle groups are shown in Figure 5. Accident rates for the HVR grade crossings were about the same (2.2×10^{-8} acc/v-t/d) for each of the three groups of angles. Accident rates were somewhat different between the three angle groups for LVR grade crossings. Angle group 60 to 90° had the highest accident rate of 20.8×10^{-8} acc/v-t/d.

Of the four dominant crossing surface types, section timber (24.7×10^{-8} acc/v-t/d) and unconsolidated crossing surfaces (22.7×10^{-8} acc/v-t/d) had the highest accident rate in the LVR category. Accident rates for rubber and concrete type crossing surfaces in the LVR grade crossing category were very high perhaps because of the fact that drivers can traverse them at high speeds. However, these conditions comprise less than 1 percent of all LVR grade crossings. For the HVR category, section timber (2.7×10^{-8} acc/v-t/d), full wood plank (2.7×10^{-8} acc/v-t/d), and asphalt (2.5×10^{-8} acc/v-t/d) crossing surfaces had the highest accident rates.

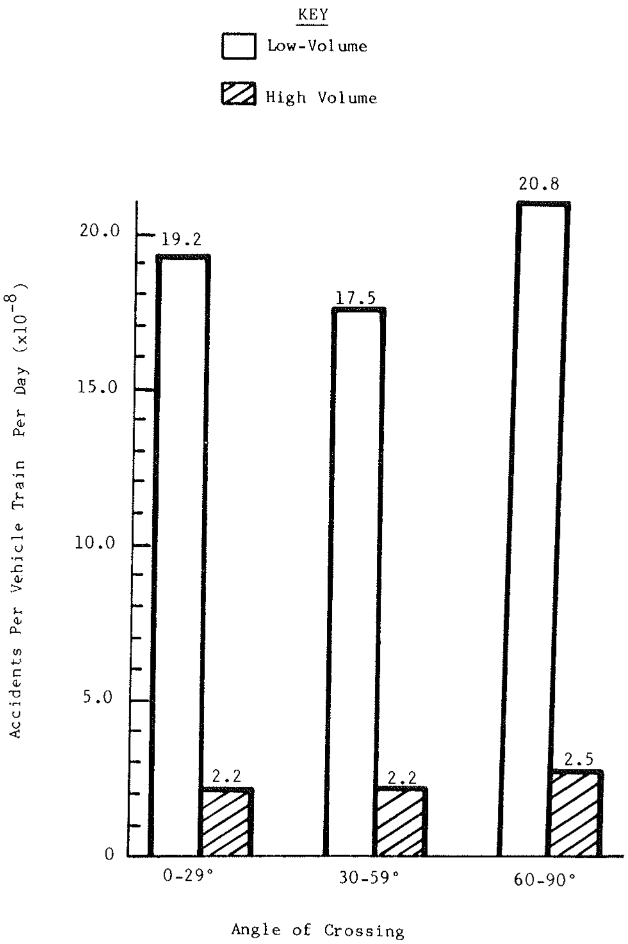

FIGURE 5 Accident rates for low-volume and higher-volume road grade crossings by crossing angle.

Accident rates were higher at LVR crossings at which no advance warning signs were present than when advance warning signs were present (22.5 vs. 16.4 × 10^{-8} acc/v-t/d). It is likely that grade crossings on many low-volume roads may not be clearly visible to motorists for reasons that were outlined earlier. Motorists therefore place more reliance on advance warning signs on low-volume roads than on higher-volume roads. The absence of advance warning means that the crossing might not be detected as readily and more accidents might be expected.

Accident rates were about the same for HVR grade crossings, regardless of the presence or absence of advance warning signs (about 2.5 × 10^{-8} acc/v-t/d). Similar results were found for pavement markings. However, crossings with both types of pavement markings (stop line and RR symbol) had higher accident rates than those with only one type of pavement marking.

Accident Proportions

Accident proportions are another way of representing accident patterns for most operational characteristics and some physical characteristics at grade crossings. Low-volume road grade crossing accident proportions were computed for type of vehicle, position of vehicle, vehicle speed, train speed, type of accident, number of people killed or injured, visibility at the crossing, obstruction to view, and presence of hazardous materials. These proportions were compared with HVR grade crossing accident patterns. As part of this analysis, tests for the differences between two proportions were performed to determine significant differences between LVR and HVR and grade crossing accident proportions.

An analysis was made of grade crossing accidents by type of motor vehicle involved. Although there are eight different vehicle categories, two categories, automobile and truck, accounted for nearly 90 percent of all accidents. Seventy-one percent of HVR crossing accidents involved automobiles compared to 63 percent of the LVR crossing accidents. Eighteen percent of HVR crossing accidents involved single-unit trucks compared to 25 percent of LVR crossing accidents. Both differences are significant. Contrary to initial expectations, truck-trailer combinations had a low accident proportion for both LVR and HVR grade crossings. It was expected that truck-trailer combinations would have high accident proportions because of the greater time required for a long vehicle to negotiate the crossing at slow speeds.

The pedestrian accident proportion at HVR crossings was twice as great as that for LVR crossings. This may be because many HVR grade crossings are located in urban areas and tend to have more pedestrian movement than LVR crossings, which are primarily located in rural areas.

As was expected for both LVR and HVR grade crossings, moving vehicle accidents comprise the largest proportion of accidents at 70 and 75 percent, respectively. The moving vehicle accidents for HVR crossings are significantly higher than those for LVR crossings. As was expected, stalled and stopped accidents on LVR crossings (15 percent for both) were significantly higher than those for HVR crossings (9 and 13 percent, respectively). This is probably a result of the large proportion of unpaved road surfaces and poor geometric conditions at LVR grade crossings, which force the vehicle to suddenly reduce speed and change gears, thereby increasing the chances for the vehicle to stall.

A significant number of grade crossing accidents (about 47 percent overall) occurred at low vehicle speeds (0 to 9 mph). However, the proportion of LVR crossing accidents at low vehicle speeds was significantly higher than that of HVR crossing accidents. This is probably a result of the poorer physical condition of the road and grade crossing.

Accident proportions for LVR crossings were more or less equal for train speeds up to 50 mph. The greatest proportion of accidents for HVR crossings (37 percent) occurred at train speeds of 0 to 9 mph. Accident proportions were significantly lower for LVR crossings at train speeds less than 20 mph. For train speeds of over 20 mph, the accident proportions of LVR crossings were significantly greater than those of HVR crossings. Accidents at LVR grade crossings tended to be more severe than those at HVR crossings.

The proportion of accidents that resulted from an obstruction of the driver's view was significantly higher at LVR crossings than at HVR crossings. This tended to confirm the hypothesis that sight distance restrictions are more prevalent at LVR crossings than at HVR crossings.

Although only about 5 percent of the accidents at both LVR and HVR grade crossings involved the presence of hazardous materials, the potential severity of such accidents must be recognized. The accident proportion at LVR grade crossings in which hazardous materials were present (6 percent) was significantly higher than that of HVR crossings (4.7 percent). Hazardous materials carriers might use low-volume roads either because of the presence of terminals or to deliver certain products such as agricultural chemicals, propane, or heating oils.

Effectiveness Factors

Effectiveness factors for different safety improvements are required in order to use the U.S. DOT rail-highway crossing resource allocation model. The effectiveness of a warning device is defined as the fraction by which accidents are reduced after it is installed. The resource allocation model considers three categories of warning device upgrades: passive to flashing lights, passive to flashing lights with gates, and flashing lights to flashing lights with gates. Previous effectiveness factor studies have considered all grade crossings in general (*5, 14-16*). However, because of differences in geometric design, road and crossing surface types, presence of advance warning, and other such variables between LVR and HVR crossings, the effectiveness factors for LVR crossings were expected to be different.

One of the limitations in examining the upgrade effectiveness of LVR crossings is the amount of data available. Because very few LVR crossings are equipped with active warning devices, the sample size is very small and the confidence intervals are very large. Two other primary upgrade types for LVR crossings are no signs to crossbucks, and no signs or crossbucks to stop signs. These may be more important types of upgrade, because most LVR crossing upgrades come under these two categories. The importance of these two primary upgrade types has been recognized in recent studies (*14, 15*).

Effectiveness values and confidence intervals for these five types of upgrades were calculated for LVR grade crossings, HVR grade crossings, and all grade crossings. The results are summarized in Table 2. Effectiveness factors for all grade crossings can be used as the base value because this is what is used by the resource allocation model for the three main categories of upgrades. Effectiveness factors for the LVR and HVR grade crossings can be compared with these base values to determine if any differences exist. Although some differences exist in the effectiveness factors of the first two categories, passive to flashing lights and passive to flashing lights with gates, they are within the confidence interval (CI) of all grade crossing effectiveness factors. The third category, flashing lights to flashing lights with gates, shows a variable effectiveness factor. An effectiveness factor of 51 percent for LVR crossings is very low compared to the 70 percent value for HVR crossings. The HVR grade crossing effectiveness factor falls within the CI of all grade crossing effectiveness factors of 69 percent (CI = 66 to 73 percent). However, the LVR effectiveness factor does not fall within the CI of all grade crossing effectiveness factors.

Such significant variation in the effectiveness factors can make a noticeable difference in how the resource allocation model is used. This illustrates the importance of analyzing LVR crossings separately from HVR crossings. Note that the CI for the LVR crossing effectiveness factor (30 to 72 percent) is very high, because the number of changes in this category is very low.

TABLE 2 SUMMARY OF RESULTS OF EFFECTIVENESS FACTORS BY HIGHWAY VOLUME CONDITION AND WARNING DEVICE UPGRADE CATEGORY

	Upgrade Category	Number of Crossings	Number of Before Accidents	Number of After Accidents	Number of Before Years	Number of After Years	Effectiveness Factor	95 Percent Confidence Interval
Low-Volume	P to FL	792	204	47	1896.6	1757.4	75.2	67.5-82.9
	P to G	967	432	52	2662.5	2091.6	84.7	80.4-89.0
	FL to G	200	70	27	556.7	435.5	50.7	29.7-71.7
	No Sign to C	2641	363	96	11575.9	3530.7	13.7	--
	No Sign/C to SS	110	17	2	382.4	164.0	72.6	--
	Total	4710	1086	224	17074.2	7979.1	--	--
Higher Volume	P to FL	1824	780	173	4854.1	3807.3	71.9	75.4-76.4
	P to G	1642	1128	137	4559.1	3643.1	84.8	79.7-89.9
	FL to G	1805	1307	321	5053.7	4122.9	70.1	66.7-73.5
	No Sign to C	1177	405	106	4884.3	1698.6	24.8	--
	No Sign/C to SS	44	19	3	124.7	47.1	59.1	--
	Total	6492	3639	740	19475.9	13319.0	--	--
All Grade Crossings	P to FL	2616	984	220	6750.6	5564.7	73.0	69.2-76.8
	P to G	2609	1560	189	7221.7	5738.7	84.9	82.7-87.1
	FL to G	2005	1377	348	5610.3	4558.3	69.2	65.8-72.6
	No Sign to C	3818	768	202	16460.1	5229.3	17.2	4.6-29.8
	No Sign/C to SS	154	36	5	507.0	211.1	66.8	36.2-97.4
	Total	11202	4725	964	36549.7	21298.1	--	--

P-Passive FL-Flashing Lights G-Gates C-Crossbucks SS-Stop Sign
--data not applicable

As was expected for all three highway volume conditions, stop signs were much more effective than crossbucks. Stop signs are also more effective at LVR crossings (73 percent) than HVR crossings (59 percent).

CONCLUSIONS AND RECOMMENDATIONS

The results of this study generally confirmed the hypothesis that low-volume road grade crossing characteristics are significantly different than those of higher-volume road grade crossings. The differences were more evident for physical characteristics than for operational characteristics. The only physical characteristic for which there was no significant difference between the two types of crossings was the angle of crossing. Operational characteristics such as number of trains, train speed, and truck volumes at grade crossings showed no significant differences between the two types of crossings.

The fact that there was no difference in the angle of crossing between LVR and HVR crossings should not be interpreted as meaning that the effect of angle of crossing in determining crossing safety should be the same for both volume classes. Many low-volume roads achieve a great crossing angle by introducing sharp horizontal curvature on the approaches. Although the crossing is recorded as a 90° angle, it does not function as one.

In general, accident rates at LVR grade crossings were much greater than those of HVR grade crossings. There were also significant differences between the two types of grade crossings for several different accident categories.

There were differences in effectiveness factors between LVR grade crossings and all grade crossings for several types of upgrades. These differences should be taken into consideration by low-volume road decision-making agencies. Because effectiveness factors are one of the major inputs in resource allocation, differences in effectiveness factors can make a difference in the outcome of a decision.

Based on the results of this study, two recommendations are made to assist road agencies involved in LVR grade crossing decision-making:

- Because of the great differences that were noticed in the physical and accident characteristics between LVR grade crossings and all other grade crossings, it appears appropriate to analyze LVR grade crossings separately.
- The application of accident prediction formulas and hazard formulas, which are derived by using all grade crossing characteristics, to LVR grade crossings should be approached with a considerable amount of engineering judgment.

During the course of this study, it was noticed that one of the most important grade crossing characteristics, sight distance, was not included in the inventory data. However, data for sight obstruction were available in the FRA accident data file. Additional useful data could be developed if information was available on the sight distances and directions of approach of vehicular and train traffic at grade crossings. Further study is warranted, perhaps involving field investigations, to determine the influence of these variables on accident experience. The development of a simple but meaningful way to incorporate such factors into the inventory data base appears to be appropriate.

It would also be desirable to record the width of the crossing surface. Each crossing surface should be at least as wide as the approach roadway and shoulders. One of the most common deficiencies observed during the corridor review process that was described earlier was that crossing surfaces were too narrow (*2*). The resulting exposed tracks could cause a low-speed vehicle to become stuck on the tracks or a high-speed vehicle to go out of control.

One limitation of this study was that the accuracy of the data base was not checked. Experience in several states indicates that the data base is in error in many cases, especially in regard to highway information. The principal reasons for the deficiencies include the number of data items in the inventory file, failure to update data in response to new signs and markings, and the poor quality of volume data on local roads. It is recommended that the accuracy of the data base be checked in any future studies of this type.

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Rock and Debris Slide Risk Maps Applied to Low-Volume Roads in Nepal

ALEXIS WAGNER, RAYMOND OLIVIER, AND EDUARDO LEITE

A discussion is provided of rock and debris slide risk mapping along low-volume road corridors in the foothills of Nepal. First, the results of a data compilation of the main factors leading to the failure of rocky and semi-rocky terrains are described. This research was conducted in Nepal on over 100 rock and debris slides. These data were developed into a rock and debris slide risk mapping method that was experimented with success along 300 km of road corridor sections in Nepal. The method is based on a superimposition of the geological, morphostructural, and slope maps of the road corridor in association with "weights" in percent to the most relevant factors leading to failure. The initial results are of a computerized risk mapping system that was applied to low-volume roads in mountainous developing countries. Because the initial data compilation revealed the structural factor to be a very crucial one, a test of a computerized structural risk map was operated on an already mapped road project section. This test was found to be consistent with the original risk map and revealed, with more accurate limits, similar locations of the risk areas in which slides actually occurred as predicted. Other advantages of the computer map are the systematic aspect of the process and the simulation flexibility of the unique parameters according to the observed field data and the local imposed conditions.

A synthesis is presented of geological research concerning techniques for mapping the risks of rock and debris slides along low-volume road corridors in Nepal, and hydrological work in which digitalized elevations were combined with hydric data to yield hydrological balance maps (*1-6*). The goal is to create a computerized system for landslide risk mapping that is geared especially to low-volume roads and other alignments in mountainous developing countries. This work was commissioned by the Swiss National Fund for Scientific Research.

It is well known that careless construction of low-volume roads in mountainous developing countries causes heavy environmental damage and high maintenance costs. This presents constant challenges to the efficiency and liability of the projects themselves. For example, 5 percent of the total surface of landslides in Nepal is created by road construction (*7, 8*). The roads themselves cover a surface of about 15 km^2 in the Nepalese foothills, whereas the area sensitive to landslides is about 60,000 km^2. In Nepal, the construction of roads therefore creates conditions 200 times more likely to cause land movement than the average of other human activities and the natural tendency of the terrains to slide. The goal of the present work is to contribute to the alleviation of this worrying situation. It is hoped that by implementing a reliable method of accurately identifying alternate, safe alignments and pointing out sections in which specified techniques should be applied for construction and maintenance, significant progress will be made in this direction.

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