To the Graduate Council:

I am submitting herewith a thesis written by Robert C. Wunderlich entitled "Investigation of Factors Influencing the Effectiveness of Railroad-Highway Grade Crossing Warning Devices." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Civil Engineering.

Kenneth W. Heathington, Major Professor

We have read this thesis
and recommend its acceptance:

Donald T. Wheeler

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

INVESTIGATION OF FACTORS INFLUENCING THE EFFECTIVENESS OF RAILROAD-HIGHWAY GRADE CROSSING WARNING DEVICES

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Robert C. Wunderlich

December 1982

DEDICATION

This Thesis is dedicated to my parents, Walter and Ingeborg Wunderlich, whose love, support, and sacrifices have made this and so much more possible.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of the many individuals who contributed to the success of this endeavor. Special thanks goes to Dr. Kenneth W. Heathington, whose guidance and gentle prodding added much to the author's development during the period this research was conducted. The advice and support of the two other committee members, Drs. Jack B. Humphreys and Donald J. Wheeler, are greatly appreciated.

The author acknowledges that the research was sponsored by the Federal Highway Administration, and the assistance provided by both Federal Highway Administration and state transportation agency personnel in obtaining information is appreciated. The assistance provided by Janet Coleman is especially acknowledged.

Special thanks are due to Bette Huber and Judy Wilbur for their help in the preparation of this thesis. The drafting and wisdom of Louis Allen is also acknowledged. Thanks also go to Renee Hall and Kathy Sjodin in Knoxville and Barbara Ward in College Station; their typing speed and accuracy are matched only by their cheerfulness and dedication.

Finally, the author wishes to thank his friends and colleagues for helping him to maintain his perspective during the trying times.

ABSTRACT

This research was concerned with investigating factors believed to influence the effectiveness of railroad-highway traffic control. The objectives of the study were to:

1. Determine the influence of device suitability on railroad-highway grade crossing safety;
2. Determine the influence of conformance to standards on railroad-highway grade crossing safety; and
3. Identify characteristics associated with locations with high and low accident rates.

A sample of 307 grade crossings was selected from the National Inventory of Railroad-Highway Grade Crossings. Accident histories and general crossing characteristics for the years 1975 through 1980 were compiled. A determination of device suitability was made using Federal Highway Administration (FHWA) guidelines and an evaluation was made concerning each warning device's conformance to the Manual on Uniform Traffic Control Devices (MUTCD). An accident rate was defined which accounted for differences in highway and train volumes and the time period. Analysis of variance techniques were utilized to determine the differences in accident rates due to different warning device type, device suitability, and conformance to MUTCD standards. An analysis was also conducted to determine physical and operating characteristics associated with low and high accident rates.

The major findings of this research were:

1. Differences in effectiveness, as reflected by accident rates, were identified for the warning device categories. Generally, gates were found to be most effective and passive devices were least effective.
2. The data did not support a conclusion that conformance or non-conformance of warning systems to MUTCD standards significantly influences device effectiveness.
3. Devices at locations which apparently warranted higher level devices were not found to have higher accident rates than devices judged to be suitable for their location's condition. The results suggest that the analysis based on FHWA guidelines and the available information failed to accurately assess device suitability.
4. High train speeds were associated with low accident rates and low train speeds were associated with high accident rates. This result suggests that driver behavior is influenced by train speed.
5. Low accident rate observations tended to have high train volumes, and high accident rate observations were associated with low train volumes. Apparently, accidents do not vary linearly with train volume. This suggests that driver perceptions of hazard are influenced by the frequency of train arrivals and that these perceptions influence safety.

6. Extensive use of the National Grade Crossing Inventory revealed limitations in that data base in terms of completeness and accuracy.

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CHAPTER 1

INTRODUCTION

Safety at railroad-highway grade crossings has been a concern since the railroad industry became a significant part of the transportation system in this country in the late 1800s. In the last 15 years, federal expenditures to improve safety at crossings has approached two billion dollars (1, p. 1-1). Nearly a third of the total federal highway-safety funding, excluding bridge replacement, has been allocated to the railroad-highway crossing problem (2, p. 4). Although it is apparent that significant gains have been made, safety problems still exist at grade crossings.

In the period between 1968 and 1979, the number of fatalities per year resulting from collisions between motor vehicles and trains declined from about 1,500 to less than 1,000 (3, p. 4). However, since 1975 the number of accidents per year has increased and the number of non-fatal injuries has remained fairly constant at about 4,000 (3, p. 4). The fatalities represent about 2 percent of the total annual highway deaths. Importantly, though, these deaths account for more than half of the railroad related fatalities (4, p. 1).

The severity of these accidents has caused much of the concern. Previous research has noted that "a grade crossing accident is approximately 30 times more likely to produce a fatality than one between highway vehicles" (4, p. 4). The nature of these accidents is such that the severity of vehicle-train collisions is second only to that of airplane crashes as indicated by the ratio of fatalities to injuries (5, p. 2).

Safety problems exist at grade crossings despite the amount of attention the subject has received. In order to understand the nature of the grade crossing problem, it is important to discuss the historical development and current status of grade crossings, their distinguishing characteristics, the measures which have been used to control traffic, and the emphasis of current safety improvement efforts.

Historical Development

The manner in which the railroad and highway systems developed in the United States contributed greatly to the existence of at-grade crossings. The expansion of the railroad system was facilitated by the many towns that allowed tracks to be laid along existing roadways, and new towns were often built along railway lines as the system expanded westward. Many crossings were created in the process (6, pp. 2-5).

The development of a national highway system also contributed to this trend. Road building materials and equipment could be carried by the railroads and rights-of-way were often easier to obtain along existing rail lines. The result was that many highways were built alongside railroad tracks, and, consequently, at-grade crossings were created (6, pp. 2-5).

Currently, there are over 215,000 public at-grade grade crossings. About 140,000 additional at-grade crossings are classified as private and about 3,500 are pedestrian crossings (7, p. 1). The emphasis has been placed on safety at the public at-grade railroad-highway intersections since most of the accidents occur at these crossings. The overall grade crossing situation is a dynamic one as crossings are created by highway development, lightly used ones are closed and some are grade separated. However, the closings and openings tend to balance one another; the number of public at-grade crossings has remained above 210,000 for some time (3, 8).

A substantial reduction in the number of grade crossings is not likely because the elimination of all grade crossings by separating the railroad and highway grades is economically infeasible. In 1969, a cost was estimated of more than $100 billion for grade separating all crossings (9), and the cost would be substantially more today. In addition, grade separations cannot usually be justified by safety benefits alone. In most cases they are built to facilitate traffic movement by reducing delay (8, pp. 32-33).

In summary, the development of the rail and highway systems has resulted in a great many at-grade crossings which cannot, for economic reasons, be eliminated. These crossings present certain safety problems due to the differences in the two modes of transportation that utilize them.

Crossing Characteristics

At its simplist, a railroad-highway grade crossing is the intersection of the travel paths of two different modes of transportation. However, the vastly different operating characteristics of trains and motor vehicles separate grade crossings from other highway intersections and are the root of most of the associated safety problems.

The operating characteristics of trains have been the primary determinant of how the transfer of the right-of-way has been dealt with at grade crossings. Trains travel along a fixed track and cannot take evasive action to avoid accidents. The braking capability of trains is very limited, and, in most cases, it is impossible to stop a train to avoid an accident (4, p. 4). The great mass of a train and its limited braking capability are the characteristics which tend to make grade crossing accidents so severe (4, p. 8).

Requirements that would call for trains to stop at grade crossings or to operate in a manner which would allow stopping are economically unjustifiable. First, a train's acceleration capability is such that stopping before crossings would cause inordinate delay to highway traffic when the train proceeded (10). Secondly, either requirement would seriously hamper the railroad's ability to provide economical transportation services by maintaining a reasonable time schedule.

Motor vehicles, on the other hand, have quite different capabilities. Within certain limitations, highway vehicles may take evasive action in order to avoid an accident. The amount of maneuvering possible is, of course, dependent upon the space available on and alongside the roadway; nonetheless, some changes in direction are possible. Perhaps more importantly, motor vehicles have the capability to decelerate and stop in reasonably short distances (4, p. 4). Automobiles have better braking characteristics than trucks or buses, but even the latter two are capable of stopping to avoid collisions, especially in comparison to trains.

The result of these differences in characteristics is that the right-of-way at a crossing is almost always tranferred to an approaching train. In a few cases, trains are required to halt before proceeding, but at the majority of crossings, the train is given priority of movement. Thus, the responsibility of avoiding a collision rests almost entirely upon the driver of the motor vehicle. The burden of safe operation that has been placed on the driver has been the determinant factor in how traffic has been and is controlled at grade crossings.

Traffic Control

The necessity of aiding motorists in their responsibility by providing warning of trains at crossings was recognized as early as 1877. In that year the U.S. Supreme Court held that the railroads must give a reasonable and timely warning of a train's approach (6, p. 5). As early as 1885, these warnings, which included bells and wigwags, were sometimes supplied by automatic train-actuated devices located at the crossing (6, p. 5).

Previous research has indicated that the information needed by a motorist at a grade crossing can be placed in one of two categories:

1. Whether or not a train is on the crossing; and
2. Whether or not a train which could present a hazard is approaching the crossing (10, p. 33).

Audible warning. Traditionally, one of the methods used to alert drivers has been the train-mounted whistle and, presently, horn. In the past, this warning may or may not have been sufficient, but it cannot be depended on to furnish the needed information today. Present day train horns are ineffective if either the train or the motor vehicle is traveling over 50 mph and there are restrictions prohibiting an increase in the audible output of train horns (6, pp. 35-36). Regardless of speed, present day motor vehicles are highly soundproofed, and external audible warnings must compete with interior sound levels (11). The result is that the audible warning is often not perceivable. Thus, the major focus of traffic control at grade crossings has been placed on signs and signals.

Signs and signals. The visual warning devices used for traffic control at grade crossings can be placed in one of two categories, passive signs or active signals. Passive signs display the same message regardless of conditions and in this case indicate the presence of a crossing and a potential hazard. The driver is responsible for making a determination about the actual existence of a train.

The appearance of an active signal changes according to conditions at the crossing. In this case, a warning is given upon the approach of a train. At crossings where active devices are located, the motorist depends on them to inform him of the existence of a hazard (10, p. 32).

Active devices are usually considered to be better warning devices than passive signs for two reasons. First, the signals require that a simple decision, whether to stop or proceed, be made by the motorist, and they require no additional actions such as looking for a train. On the other hand, drivers are expected to look for trains and determine if a hazard exists at crossings where passive signs are located. Secondly, when actuated, current active devices use flashing lights which are generally more conspicuous than passive signs.

Currently, three levels of warning systems are used at the crossing to control traffic. The first level is of the passive type and consists of reflectorized crossbucks. The second level is the train-activated red flashing light signal, either mast-mounted beside the roadway or cantilevered over the roadway, or both. The third level is an automatic gate which extends over half of the pavement. Each level of warning contains all the previous levels and this creates a hierarchy of systems. For example, an automatic gate installation includes both flashing lights and crossbucks.

In most cases, these warning devices are supplemented by passive advance warning signs and certain pavement markings. Some conditions also call for additional traffic control signs, and the use of standard highway stop signs is also allowed at grade crossings under certain circumstances.

In addition to these standard devices, non-standard signs and signals are sometimes used at crossings. These include highway traffic signals, wig-wags and non-standard stop and other warning signs. It should be noted that almost 7 percent of all crossings have no signs or signals (3, p. 94).

Gate systems are generally accepted as the highest level of warning device for two reasons. First, the system is train activated, and active systems are, as previously noted, regarded as more effective than passive signs. Secondly, the gates, when lowered, are an actual physical barrier in the travel path. This offers a greater visual presence than the flashers alone and provides more than a signal indicating a hazard; it prohibits further movement by blocking the normal travel path.

Application of warning devices. Ideally, the highest level of warning system, gates, would be used at all locations. However, the money available for grade crossing safety is a limited resource and the cost of installing gate systems at all crossings would, as is the case with grade separation, be prohibitive. The average installation cost in 1980 dollars of a gate system is about $52,000 and an additional $34,000 would be required for maintenance over a 30-year life-cycle (12). Since more than 90 percent of all crossings do not have gates, the cost of installing gates at all those crossings would be prohibitive with currently available resources (3, p. 94).

The placement of warning devices has traditionally been guided by attempts to spend improvement funds to maximize safety benefits. This emphasis on cost-effectiveness is partially responsible for the existence of a hierarchy of warning systems. The same level of hazard does not exist at all crossings, and therefore the same amount of expenditure is not warranted at every crossing.

Each level of warning device has a different cost associated with it. Flashing lights average about $37,000 per installation and have additional maintenance costs of $21,000 over a 30-year life-cycle (12). Crossbucks usually cost less than $1,000 per installation and the maintenance cost is nominal (2, p. 2).

Since the different warning devices have greatly different costs, the decisions on which type of device should be located at a particular crossing have been based on an attempt to provide the highest level of device whose benefits justify its costs. It is recognized that, in some cases, other considerations, such as political pressures, have a bearing on the decision on which type of traffic control device is used at a given crossing.

Most organizations and agencies responsible for grade crossings attempt to determine the degree of hazard for each of the crossings under their jurisdiction. Almost all states use some type of priority ranking or hazard index formula to aid the decision-making process of agency personnel (13). These rankings are utilized in determining the expected safety benefit resulting from improving the crossing, and these benefits are then compared to the costs associated with the improvements. Usually the ranking process identifies crossings for further review and inspection by qualified agency personnel for input in the decision-making process.

A wide variety of methods are used by states to determine the improvements at crossings (13) and the U.S. Department of Transportation has also developed a resource allocation model to assist states and railroads in allocating funds effectively (12). Whereas the models serve mainly as aids, their use does indicate the rationale behind the decision-making process. The models are not perfect and final decisions are therefore based on engineering judgment, but the basis of both techniques, cost-effective use of funds, is the same.

The result of these efforts is that different devices are located at different crossings, usually on the basis of cost-effectiveness. The importance of these procedures can be seen when it is realized that the major emphasis of safety efforts at grade crossings involves the installation of active devices.

Emphasis of Current Safety Program

In 1972, the U.S. Department of Transportation published a report on railroad-highway safety which considered the installation of active devices the most cost-beneficial improvement (2). A 10-year program that would improve 3,000 crossings each year at a cost of $75 million per year was proposed (14, p. 90).

The Highway Safety Act of 1973 allocated 17.9 percent of the total highway safety construction funds to railroad-highway safety. The funds applied to crossings on federal-aid highways, and 50 percent of the funds were to be used for installing active devices (2, p. 4).

The Highway Safety Act of 1976 continued this funding and more than doubled the allocation to grade crossing safety. The $419 million accounted for 54.5 percent of the total. Thus, from 1974 to 1978, grade crossing safety funds accounted for 34.1 percent of total federal safety funding. These percentages do not include the bridge replacement program funds (2, p. 4).

The majority of these funds were spent on active device installations. Through June 1977, 23 percent of the funds had been expended equally for grade separations and crossing surface improvements whereas 60 percent was spent on installing active signals (2, p. 20). In the period from 1968 to 1979, approximately 18,000 locations were upgraded to flashing light or gate systems (15, p. 14). About half of these upgrades were made from 1974 to 1978 inclusive.

Thus, the major effort to improve safety at railroad-highway crossings has involved the use of warning devices rather than other measures such as education or enforcement. This emphasis suggests that it would be worthwhile to investigate the performance or effectiveness of these warning devices.

Warning Device Performance

The ability of a warning system to adequately warn motorists of a hazard at a given grade crossing location may be influenced by a number of factors. Factors external to the warning devices which may influence the capability of the system include physical and operational characteristics such as roadway geometrics, sight distances, and train and highway vehicle volumes. Motorist perceptions and capabilities may also affect safety at crossings. The safety problem at grade crossings may stem from the inability of existing warning systems to function adequately under all these conditions.

For example, a warning system might not meet the needs of motorists if a higher level device was needed in its place, if the system did not conform to accepted standards, or if the system did not perform or accomplish its intended purpose.

Device suitability. The effectiveness of a warning device is influenced by the suitability of that particular device to the conditions in which it has been placed. For example, a crossing which has a passive device but warrants an active device might be expected to have a higher accident record than a crossing which has and warrants a passive device. Also, a high accident record would be expected for a flashing light signal located where a gate system was appropriate.

Thus, the performance of a given warning system should be less than desirable if it were located where a higher level of warning device was needed.

Conformance to standards. Another condition which may influence the performance of a warning system is its conformance to accepted standards. The use of traffic control devices is governed by the regulations in the Manual on Uniform Traffic Control Devices (MUTCD) (16). A warning system which does not conform to the MUTCD regulations would be expected to not be as effective as one that does. For example, a crossing which had no advance warning signs or pavement markings, even though they were required, might be expected to have a worse safety record than a crossing which did conform to MUTCD standards. The same might be true of devices which did not meet color and reflectivity standards.

These examples demonstrate some of the ways a basically standard device might not meet all the standards. There are also cases where signs and signals that are not one of the three basic standard devices have been used at grade crossings. The use of these devices might also affect safety adversely.

Objectives of Research

There is a need to investigate the ability of existing traffic control devices used at railroad-highway grade crossings to meet the needs of motorists. The different systems now used at grade crossings may not meet motorists' needs because:

1. The system used at a particular crossing is not suited for use at that location;
2. The system does not conform to standards; or
3. The device is simply not adequate for the task required.

The objectives of this research are:

1. To determine the influence of device suitability on crossing safety;
2. To determine the influence of conformance to standards on crossing safety; and
3. To identify characteristics associated with locations with high and low accident rates.

Organization of Report

The research has been reported in six chapters. Chapter 1 presents an introduction to the grade crossing problem and outlines the objectives of the research. Chapter 2 contains a review of previous pertinent research. The procedures utilized to carry out the research are documented in Chapter 3. Chapter 4 presents the results of tests designed to determine the influence of warning device type suitability and conformance to standards. Chapter 5 contains the results of the analysis of high and low accident rate observations. The major findings of the study are summarized in Chapter 6.

CHAPTER 2

PREVIOUS PERTINENT RESEARCH

The recognition that significant safety problems exist at railroad-highway grade crossings has resulted in research directed at understanding and improving the situation. Much of the literature addresses the different factors which influence safety. Some of the prior research was focused on attempts to determine causal factors of accidents; whereas, other reports concentrated on the effectiveness of traffic control devices. There is also information in the literature pertaining to the conformance of devices to standards and also to their suitability.

Crossing Characteristics Influencing Safety

One of the more comprehensive reports on grade crossing safety was presented by Schoppert and Hoyt in National Cooperative Highway Research Program Report 50, Factors Influencing Safety at Highway Grade Crossings (10). The report investigated the nature of the problem and reported that three primary factors, the driver, the vehicle, and the physical conditions interact to influence safety. The driver is responsible for the decision to stop or proceed at a grade crossing. A section on human factors explored both the factors that influence the probability of signal detection and those that influence driver response to detected signals. Any physical or psychological characteristic which impairs the ability to perceive or respond to a hazard or warning has a negative impact on safety. The basic normal human capabilities of perception and reaction were discussed. Age, alcohol and drugs, and fatigue were cited as examples of factors which could significantly reduce these capabilities. The importance of driver vigilance behavior and expectations about hazards at grade crossings was also discussed.

The motor vehicle is important since once a decision to stop or proceed has been made, the vehicle's deceleration or acceleration characteristics become decisive factors. Most automobiles have very similar characteristics. Trucks, however, have poorer performance capabilities, especially in terms of acceleration and deceleration, and evidence was cited that indicated that these characteristics are influential factors.

Physical conditions include roadway geometrics, physical surroundings, and the type of warning device. Roadway geometrics and the surroundings can complicate the driving task by sometimes overwhelming the driver with more inputs than he or she can respond to. Thus, complex alignments and competing distractions, or visual clutter, such as other lights or signs can affect safety.

Ambient weather conditions such as rain, fog, or snow, as well as high humidity which might cause misting up of windshields, were cited as influential factors. All of these conditions may make it difficult to perceive a warning and respond to it.

The characteristics of motor vehicles, though accounted for in the design and location of warning devices, have not been the subject of attempts to improve grade crossings. Basically, the emphasis of most of the research in the area has been aimed at studying crossing characteristics, warning devices, and motorists.

Generally, it is easier to measure and quantify the influence of crossing characteristics than that of motorists. Drivers are complex and often unpredictable, and their behavior is difficult to generalize. Much attention, therefore, has centered on the identification of the physical and operating characteristics of crossings which influence safety.

Crossing characteristics are those operating and physical attributes which tend to distinguish one crossing from another. Some examples of operational characteristics are the number of and type of trains, the number and types of motor vehicles, the speeds of these vehicles, and the accident history of a crossing. Physical characteristics include the type of warning device, the number and type of tracks, the roadway alignment, the sight distances, and the number of lanes. A great deal of the effort to determine the influence of these factors has been made in the course of developing hazard index or accident prediction models.

Hazard index and accident prediction equations. These models usually represent an attempt to quantify the influence of certain parameters so that agencies responsible for crossing safety may use them in their efforts to best allocate funds. Index formulas usually only rank crossings according to hazard; accident prediction models rank crossings and can also indicate the degree of difference in hazard between crossings. These formulas are discussed here to point out the characteristics which are believed to affect safety.

One of the early attempts to correlate characteristics and hazard was made by Schultz and Oppenlander (17). A regression equation was developed which utilized number of track pairs, highway pavement width, train volume, average daily traffic volume, and the number of distractions. The equation only explained 18 percent of the variation in accident occurrence, and it was noted that crossing accidents may be predominantly the result of driver characteristics and chance.

A simple hazard ranking formula is the so-called New Hampshire formula. The equation is of the form H.I. = VTP_t where:

H.I. = Hazard index

V = Average 24-hour traffic volume

T = Average 24-hour train volume

P_t = Protection factor

Automatic gates = 0.1

Flashing lights = 0.6

Signs only = 1.0 (6, p. 87)

A study by Mengert (18) noted the formula was "surprisingly efficient, given its simplicity" and was of value when comparing crossings with the same type of warning device. The Railroad-Highway Grade Crossing Manual (6, p. 86) includes the results of a study that compared 11 hazard indices including the New Hampshire formula. The other formulas considered such factors as accident experience, train speed, alignment, train type, angle of crossing, sight distance, time crossing is blocked, as well as train and traffic volumes. However, the hazard indices all gave approximately the same results. The indication is that train volume, highway traffic volume, and device type have the most significant impacts on safety. The New Hampshire formula suggests that the hazard at a crossing varies in proportion with the product of train and traffic volume. This is logical since the probability of an accident should be related to the number of trains and number of vehicles which may potentially collide. An indication of the difference in effectiveness of the different levels of warning devices is reflected by the P_t parameter.

Coleman and Stewart (19) developed accident prediction equations for groups of crossings. Crossings were categorized according to whether they were urban or rural, single or multiple track, and also by device type. The equation developed was of the form:

$$\mathrm{Log}_{10}\,\bar{A} = C_0 + C_1\,\mathrm{Log}\,\bar{V} + C_2\,\mathrm{Log}_{10}\,\bar{T} + C_3\,(\mathrm{Log}_{10}\,\bar{T})^2$$

where:

$\bar{A}$ = Average number of accidents per crossing year

$\bar{V}$ = Average daily traffic volume

$\bar{T}$ = Average daily train volume

The values of $\bar{A}$, $\bar{V}$, and $\bar{T}$ are the averages for a particular group as delineated by location, number of tracks, device type, and train and traffic volumes. Different values for C_0, C_1, C_2, and C_3 were developed for the different combinations of categories of location, tracks, and warning devices. The equations were able to provide a statistically significant explanation of the observed data. This equation points out the influence of train and vehicle volumes, but suggests other parameters are important, and that the influence of train and vehicle volumes is more complex than the New Hampshire formula indicates. Mengert noted that the two give roughly comparable results (18, pp. 3-7).

Sanford (13) conducted a study of the parameters state highway agencies used in hazard index or accident prediction equations. Table 2-1 shows the different factors that were considered and the number of agencies which considered them. The importance placed on highway and railroad volumes is evident. The type of warning device was also frequently utilized by states in the equations.

A recent Department of Transportation accident prediction model (12) considered:

1. Number of highway vehicles per day;
2. Number of trains per day;
3. Number of day through trains per day;
4. Whether the roadway was paved;
5. Maximum timetable train speed;
6. The highway type;
7. Number of main tracks;
8. Number of traffic lanes; and
9. Number of previous accidents in a given time period.

The model uses these parameters to predict the number of accidents per year for any crossing using data found in the National Rail-Highway Crossing Inventory and in the Federal Railroad Administration's Railroad Accident/Incident Reporting System. Equations were developed using non-linear regression techniques and different equations were developed for different groups of warning devices.

Tustin (20) conducted a study that attempted to determine factors which were not considered in another Department of Transportation

TABLE 2-1

STATE HIGHWAY AGENCY PARAMETERS MOST FREQUENTLY REPORTED IN RAIL-HIGHWAY CROSSING HAZARD INDEX OR ACCIDENT PREDICTION FORMULAE

Parameter	Number of States
Number of Trains per day	42
Number of Vehicles per day	42
Existing Warning devices	27
Visibility and Sight	17
Speed	12
Accidents	12
Angle of Intersection	11
Number of Tracks	10
Highway Approach Grades	6
Highway Alignment	5
Number of Highway Lanes	5
Surface Condition	3
Type of Train	2
Urban/Rural Land Use	2
Nearby Intersections	1

Source: John L. Sanford, Criteria Used by State Highway Agencies to Determine Warrants and Priorities for Warning Devices at Rail-Highway Crossings, Highway Traffic Safety Center, University of Illinois, Urbana, April 1977, p. 13.

accident prediction formula but that evidently had an impact on safety. The formula utilized:

1. The type of warning device at the crossing;
2. The number of daily train movements;
3. The number of day through train movements;
4. The number of train tracks;
5. The population of the surrounding area;
6. Whether the roadway is paved;
7. The functional classification of the roadway; and
8. The number of roadway traffic lanes.

The formula predicted the number of accidents based on these characteristics. The study was concerned with identifying other factors besides those used in the formula which influence safety. Crossings in the national inventory which had experienced, on the average, more than one accident per year above the number of accidents per year predicted by the model were identified as anomalous. One hundred and three crossings so identified were selected for field evaluation. The study found that 45 of the crossings identified as anomalous would not have been identified as such if the inventory and accident data had been correct.

The 56 remaining crossings were studied for similarities. Five anomalies were identified:

1. Restricted sight distance;
2. Intersecting roadways and driveways;
3. Nearby street parking and parking lots;
4. Complex geometry; and
5. Cluttered visual environment.

Ninety-seven percent of the crossings had restricted sight distances where the view of the crossing, signals or track were obscured by such things as buildings, vegetation, roadway signs and signals, utility poles, and parked trains.

Intersecting roadways, parking and complex geometry, found at 95, 86 and 61 percent of the crossings respectively, all tend to make the driving task more difficult and serve to draw the motorists' attention away from the crossing.

A visually cluttered environment was found at 79 percent of the crossings. Signs, structures, vegetation, and other vehicles were cited as creating an area so congested with visual information that the signals were virtually obscured at most of these crossings.

The percentages indicate many crossings had a combination of anomalies, and evidently these charcteristics have a definite impact on safety, although the effects were not quantified. Many of the crossings studied had active devices and this suggests that their performance can be diminished by the presence of these characteristics.

These equations identify a number of characteristics that apparently influence safety at crossings. One item which is not usually considered in these equations but is, as Tustin found, important is sight distance.

Sight distance. Sight distance has been considered by highway engineers to be a significant factor in the design and operations of roadways, and it is also important at grade crossings. Drivers must be able to see a hazard or a warning of one before they can be expected to respond, and the sight distance available after perception should allow drivers to effectively respond to the hazard. However, most efforts to correlate sight distance and safety at crossings have not been successful.

Schoppert and Hoyt (10) explained that this is due largely to the difficulties in uniformly and adequately defining and measuring sight distance. The fact that sight distances vary according to speed and position along the roadway complicates the quantification process. Adequate sight distance is a function of the ability to stop before reaching the crossing or to clear it before the train arrives. The matter is further complicated by the fact that three different sight distances can be identified at grade crossings. Schoppert and Hoyt discussed the three types in their report.

The first is the distance at which the crossing itself, including the warning device, is visible. The second is the quadrant visibility needed to detect the approach of a train. The third is the distance the driver can see down the tracks if his or her vehicle is stopped at the crossing.

Inadequate sight distance of the first type is a problem at all crossings. The second and third types should come into effect only at crossings with passive protection. These inadequacies in the sight distances in the quadrants or along the tracks may indicate a need for active warning devices. Inadequate sight distance to the crossing requires adequate advance warning.

This would seem to suggest that proper advance warning may be important to warn the driver of the impending hazard, especially where passive devices are in use. The driver is responsible for the determination of hazards and must be aware of the crossing to make the determination. If sight distances are such that a driver only becomes aware of a potential hazard at a point where it is too late to safely negotiate the crossing, safety problems may arise. The implication would appear to be that conformance to standards on advance warning devices may affect the safety record of a crossing, especially where passive devices are located.

This premise is also supported in a report by Rowan and Walton (21) on the findings of a diagnostic team's evaluation of 36 grade crossings in Texas. The diagnostic team was composed of individuals experienced in grade crossing matters and the members represented various disciplines and agencies.

Sixty percent of the crossings were reported safe or fairly safe. Forty percent were rated unsafe or hazardous. Missing or improperly located pavement markings or markings in need of maintenance were reported as an unsafe condition at 72 percent of the study crossings. This points out two things:

1. The diagnostic team considered pavement markings an important part of the overall warning system; and
2. A large majority of the locations studied needed improvement in this area.

Implicitly, non-conformance to MUTCD in this regard may be fairly common and also creates unsafe conditions. Forty percent of the unsafe conditions involved the lack of proper advance warning. In 50 percent of the cases, heavy vegetation growth was reported as obstructing driver visibility.

A field study of selected crossings by Tustin (20) revealed that 78 of the 101 crossings investigated apparently needed advance warning signs and pavement markings. Only 37 crossings had both.

Comparison by Berg (22) of accident rates between passively signed crossings with and without advance warning signs revealed a somewhat surprising result. Crossings with advance warning signs had a significantly higher rate than crossings without advance warning signs. This was also found to be true when the crossings studied were stratified by train and traffic volumes. Berg suggested that there were causal factors which were not accounted for. He listed sight distance and driver information load as two examples. Another possible explanation given was that highway agencies tend to place advance warning signs at crossings which have the greatest relative hazard.

Warning devices. The devices used to warn motorists at railroad-highway grade crossings are considered to have a great deal to do with safety. As noted previously, there is a hierarchy of devices in which active signals are considered better than passive signs and gates are considered the most effective of the three levels. Studies have been conducted in an attempt to quantify the relative effectiveness of the three levels.

The California Public Utilities Commission (PUC), which regulates railroad-highway grade crossings in that state, conducted a study to determine the effectiveness of automatic, or train-activated, warning devices (23). The study compared before and after accident histories at a selected sample of crossings which had been upgraded by installing either flashing light signals or flashing light signals with gates.

Certain criteria were established to select a sample from the 10,197 crossings then existing in California. The crossings selected for study were new crossings which had automatic devices installed initially or crossings upgraded to automatic devices from devices in the following categories:

1. Crossbuck signs;
2. Cantilevered wigwags;
3. Flashing lights (only when the upgrading involved the addition of gates); and
4. Miscellaneous (including human flagmen, manual gates, two variations of wigwags, and rotating stop barriers).

Crossings which had been opened or upgraded between January 1, 1960, and December 31, 1970, and which had train volumes greater than two trains per day were included. This selection process yielded a sample of 1,551 crossings which represented 44 percent of the total number of crossings with active warning devices.

For each crossing in the sample, several pieces of information were collected. These included:

1. The type of protection immediately prior to the installation of automatic protection, and which type of automatic protection was installed;

2. The accident history prior to installation, including the number of accidents, deaths and injuries, as well as the number of years (10-year maximum) the prior protection was in use; and
3. The accident and casualty history after installation from the time automatic protection was placed in service until August 1, 1972.

Thus, the maximum study period for any given crossing would be 22 years, 1950-1972. The accident and warning device histories were obtained from California PUC records.

Separate analyses were conducted for the upgrading to flashers and upgrading to gates. Each of those two conditions were subdivided according to the category of warning device in place prior to upgrading. For each before-after combination of warning devices, the number of accidents prior to installation was summed over all the crossings in that category. This number was divided by the total number of years the prior warning devices were in place (crossing years). This resulted in an average before-installation value for number of accidents per crossing year. A value for the average after-installation accidents per crossing year was also calculated for each category. The effectiveness of upgrading from one device type to either flashers or gates was determined by subtracting the average after-installation values for accidents per crossing year from the before-installation accident rate and dividing by the average before-installation rate for each combination of devices.

Similar analyses were conducted for fatalities, injuries, and accident severity including deaths per accident, injuries per accident, and casualties per accident. Casualties are defined as the sum of injuries and deaths. The study results are shown in Table 2-2.

In almost all cases, substantial reductions were found in accidents and accident severity after upgrading to flashing light signals or automatic gates. The results indicate the relative differences in effectiveness of the various warning devices and apparently demonstrate that flashing light signals are more effective than crossbucks, and gates are more effective than either of the other two warning device types.

The results led the PUC to conclude that due to their ability to seize the attention of approaching motorists, both flashing light signals and flashing lights with automatic gates offer the ability to drastically reduce the number of vehicle-train accidents and related casualties.

The report noted, however, that both flashers and gate systems were significantly more effective in reducing accidents at crossings that were protected by crossbucks than at crossings at which wigwags or, in the case of upgrading to gates, flashing light signals were in use. The PUC explained this by stating that the crossings previously protected by wigwags and flashing lights were more hazardous than those at which crossbucks were used.

The Commission attributed part of the 41 percent (comparing 1965 to 1972) reduction in vehicle train accidents in California to the installation and subsequent effectiveness of automatic devices. The

TABLE 2-2

RESULTS OF THE CALIFORNIA PUBLIC UTILITIES COMMISSION STUDY

Number of Crossings	Type of Protection Immediately Prior to Installation of Flashing Light Signals	Percent Reduction after Installation of Flashing Lights					
		Accident Factor			Accident Severity		
		Accidents per Crossing Year	Deaths per Crossing Year	Injuries per Crossing Year	Deaths per Accident	Injuries per Accident	Casualties per Accident
75	None--New Crossing	-98.67	*0000.00	*0000.00	*000.00	*000.00	*000.00
245	No. 1--Crossbucks	-64.00	-83.33	-84.21	-45.45	-54.05	-53.13
98	No. 3--Wigwag	-50.00	0.00	-53.33	+66.67	-9.80	-5.56
16	Miscellaneous	-43.24	-50.00	-58.33	-42.86	-24.24	-27.50
434	Subtotal	-62.96	-75.00	-76.47	-40.00	-39.06	-40.00
	Type of Protection Immediately Prior to Installation of Automatic Gates	Percent Reduction after Installation of Automatic Gates					
91	None--New Crossing	*0000.00	0.00	*0000.00	0.00	*000.00	*000.00
243	No. 1--Crossbucks	-87.50	-100.00	-93.33	-76.00	-40.00	-51.11
248	No. 3--Wigwag	-66.67	-75.00	-88.89	-54.55	-61.70	-60.34
498	No. 8--Flashing Light	-65.85	-83.33	-78.95	-57.14	-28.89	-33.90
38	Miscellaneous	-73.77	-100.00	-80.00	-33.33	-26.83	-23.26
1,118	Subtotal	-70.27	-89.00	-83.33	-64.29	-42.86	-47.62
1,552	Grand Total	-68.60	-85.60	-80.05	-54.00	-38.46	-41.75

*Not measurable.

Source: The Effectiveness of Automatic Protection in Reducing Accident Frequency and Severity at Public Grade Crossings in California, California Public Utilities Commission, June 30, 1974, p. 30.

report also claimed that an additional benefit of automatic devices was a reduction in accident severity, in terms of casualties per accident.

The report also compared effectiveness at rural and urban crossings. Urban crossings were designated as those located within a community of 2500 persons or greater. The remainder were classified as rural. Generally, urban crossings had significantly higher accident rates than rural crossings, both before and after upgrading. The rural crossings had 28 percent fewer accidents but 55 percent more casualties per accident before installation of active devices. After installation, the rural crossings experienced 35 percent fewer accidents and approximately the same casualty rate as urban crossings. Accidents were more frequent at urban crossings but more severe at rural locations.

The California PUC study reported that automatic gates reduced the number of accidents per year by 87.5 percent at crossings which had crossbucks and by 66 percent at flashing light crossings. Flashing lights were reported to reduce, on the average, the number of accidents per year by 64 percent. These values of effectiveness were criticized by some as being too high considering the accident statistics for active devices (24, p. 3). A study was conducted by Morrissey (25) to investigate the validity of some of the PUC findings and to establish new effectiveness factors. The procedure utilized was similar to that employed in the California PUC study. However only three groups of before-installation devices were used. All passive devices, stop signs, crossbucks, other signs, and no warning devices, were grouped together. The second group was made up of flashing lights, wigwags, bells, highway signals, and special devices. Flashing lights with gates constituted the third group.

The data were obtained from the DOT-ARR National Railroad-Highway Inventory and the Railroad Accident/Incident Reporting System (RAIRS). The period chosen for study was January 1, 1975, through December 31, 1978. The DOT-AAR inventory data base contains update information from both railroads and state departments of transportation. The program is voluntary. This study approximated that 50 percent of all crossings which were actually upgraded during the study period were included in the data. No stipulations were reported that restricted the sample due to train volume.

The effectiveness was determined by the same method employed in the PUC study. The results are shown in Table 2-3. The PUC results are apparently validated for they lie within the 95 percent confidence limits of the Morrissey study.

These two studies do not report if any conditions such as the number of vehicles or trains changed during the periods studied. It must be assumed that all other conditions except the type of warning remained constant. If this is true, the studies indicate that, on the average, each higher level of warning device is more effective than the previous level or levels under the same conditions. This suggests that the different types of warning devices should be considered when studying grade-crossing safety. It also suggests that locations which do not have the suitable level of warning device will have higher rates than they would have had if higher level devices were located there. The study did not indicate, however, that unsuitable devices were

TABLE 2-3

RESULTS OF THE MORRISSEY STUDY
ON ACTIVE DEVICE EFFECTIVENESS

Upgrade Category	Effectiveness Factor (Percent)	95 Percent Confidence Interval (Percent)	California Findings (Percent)
Passive to Flashing Lights	65	57-73	64
Passive to Flashing Lights with Gates	84	80-89	88
Flashing Lights to Flashing Lights with Gates	64	56-71	66

Source: J. Morrissey, The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossings 1975-1978, Federal Railroad Administration, U.S. Department of Transportation, Report No. FRA-RSS-80-005, April 1980.

located at these crossings before upgrading. It should be noted that the studies determined the average improvement and did not analyze individual locations.

These two studies demonstrate the relative effectiveness of the warning systems, and active signals were shown, on the average, to improve safety at crossings previously having passive devices. However, there is some question if active signals, especially flashing lights, are effective alerting devices under all conditions at all locations.

Hopkins and White, in a study reporting on an attempt to develop more effective warning systems, described some of the limitations of present day flashing lights (4). They reported that the basic flashing light warning signal has been used for over 50 years and has been developed primarily by the railroad industry. The highway engineering community has had very little input in the development process.

This process has been an evolutionary one, and the basic alternating light pattern can be traced to a man swinging a lantern. The current standard flashrates of 35 to 55 flashes per minute simulates this motion (4). Other research (24) has indicated that a faster rate would have a greater alerting capability.

There has been an emphasis on reliability which has served to constrain the effectiveness. Generally, the systems are required to be able to run from one to seven days on battery power in the event of a commercial power failure. This has restricted the amount of power the system may consume and ultimately has resulted in the use of 18 or 25 watt bulbs. In comparison, highway traffic signals use bulbs from 60 to 150 watts (4).

In order to obtain adequate intensity, the beam of light must be tightly focused. Hopkins and White noted that, "considered in terms of effectiveness as a motorist warning device, serious limitations arise from the requirements for light focusing" (4, p. 15). The problems are twofold. First, adequately intense light should be provided for all the positions which a driver may occupy. The authors noted that even the use of several pairs of lights may not be adequate, especially if the driver directs his attention to a pair which are not aimed at his position (4).

The second problem stems from misalignment. The authors noted that "very little deviation is required to degrade seriously the effectiveness of the warning" (4, p. 18). The misalignment may be the result of improper installation or movement caused by vandalism or accident. Other factors which might cause the lights to become misaligned are extremes of weather and continual vibration.

The limitations of the signals may become especially important if adverse environmental conditions are present. Longrigg (26) pointed out that snow, heavy fog or condensation on the windshield may render flashing light signals virtually ineffective.

The true impacts on safety of these limitations are not known. The number of accidents caused by the failure of active signals to effectively alert drivers is not known and may in fact be impossible to determine. However, the fact that 50 percent of crossing accidents occur at the 25 percent of crossings which have active devices (27) suggests that signal conspicuity may be a problem. Russell (5, p.2) pointed out that, although other factors such as train and vehicle volumes influence the number of accidents, present flashing light signal systems are less effective than desirable. Considerable research (4, 24, 28, 29) has been conducted to develop more effective signal systems. Most of this work has involved the use of strobe lights to supplement existing incandescent flashing signals.

The ability of passive signing to convey the intended warning message to motorists has also been questioned. The same passive sign, crossbucks, are used regardless of the conditions. However, passively signed crossings have a wide range of operational and physical characteristics.

Schoppert and Hoyt (10) recommended that signing be tailored to crossings by using different combinations of signs to denote different conditions. The authors felt that a motorist should be informed of his or her obligations at a crossing in terms of whether a signal was located at the crossing that would indicate the approach of a train or whether the driver himself was responsible for determining the existence of a hazard. Basically, this called for different advance signing for active and passive warning systems. The authors also felt additional signing was required for passively signed crossings with restricted sight distances. Some of these principles were applied in a study reported on by Rowan and Walton (21). Signs were utilized that indicated the different conditions at a crossing in terms of signal type and limited visibility. A team composed of representatives from the Texas Highway Department, Federal Highway Administration, Texas Transportation Institute, and the railroad industry studied the signs after implementation in the field and reported that the new signs were more effective than current standards.

Koziol and Mengert (30) conducted a study on new passive signing configuration. Four combinations of advance and at-crossing signs were tested. The new signs tested were similar to the signs reported on by Rowan and Walton (21). The study determined that the combination of new advance and at-crossing signs achieved an improvement in the looking behavior but did not result in any differences in speed profiles when compared to a standard configuration. The authors recommended that the new signs be installed in two phases at hazardous passive railroad crossings. The first phase would change the advance sign. If that sign proved effective, the new at-crossing sign should also be installed.

All of these studies advocate the creation of a hierarchy of passive signing which is more responsive to the differences between crossings. Two of the studies cited here also recommended that different advance signing be used for active and passive warning devices.

In general, active devices have been shown to be more effective relative to passive signs. However, in absolute terms, active signals have limitations and may not always provide an adequate warning to the motorist. Improvements also seem to be possible within the passive category. The studies suggest that drivers should be warned of more than the existence of a crossing; they should also be given an idea of its relative hazard and what their obligation is. It must be noted that the effectiveness of any railroad crossing warning device is greatly dependent on the attitudes drivers have about crossings in general and specifically their perceptions of warning devices.

Driver Attitudes and Perceptions

Driver characteristics that influence behavior and subsequently safety at crossings are difficult to specify. It is hard to determine exactly why people behave as they do and harder still to correlate the behavior to safety in a quantitative fashion. However, driver attitudes, perceptions, and behavior have been studied, and some important characteristics have been identified.

Heathington and Urbanik (31) conducted a survey of 259 drivers in an attempt to determine their attitudes. Railroad grade crossings were compared to signalized intersections, yield-controlled intersections, crossroads, and curves. The researchers found that the drivers considered grade crossings to be relatively more hazardous than the other highway situations. However, none of the conditions were perceived as being very hazardous by the respondents.

Tidwell (32) conducted a survey of 829 drivers to investigate their knowledge relative to grade crossings. Thirty-five percent of the respondents believed that all grade crossings had active warning devices. An additional 19 percent thought that only crossings rarely used by trains did not have active devices. Some of the drivers did not distinguish any difference between crossbucks and non-activated signals. It was pointed out that there is very little difference between the appearance of unactivated flashing light signals and passive devices. The major element in both is the crossbuck sign, and the advance warning sign is the same for either condition.

The author noted that the implication was that if these drivers did not observe an activated signal, they would believe there was no hazard. The perception of those questioned was that all, or at least non-hazardous crossings, have an active device. Another finding was that approximately 30 percent of the drivers did not recognize the signs and markings used at crossings. Most drivers correctly associated the advance warning signs and the crossbuck sign with crossings, but 15 to 21 percent of the drivers questioned could not identify which of the signs was placed at the crossing and which was placed in advance of the crossing.

Tidwell's study indicated that there are some fundamental misconceptions about warning devices used at grade crossings. The author also attempted to correlate knowledge and behavior in another part of his research. He reported that a certain level of knowledge is needed for safe operation at crossings but that possessing that knowledge did not guarantee safe performance.

Sonefeld (27) believed that grade crossings are more likely thought of in terms of roughness and delay than of a potential hazard. The results of a study by Sanders, Kolsrud and Berger (33) seem to support this idea. They found that drivers who did not look for trains or were otherwise categorized as unsafe drivers cited crossing roughness as the motivation for speed reduction. The authors also stated that drivers reported to incur long delays at grade crossings tended to act less safely. This suggests that not only do some drivers have these attitudes but that they may also adversely impact crossing safety.

Rowan and Walton (21) stated that the problem at grade crossings is not that drivers do not "respect" trains but that they do not "expect" them. This is not surprising since 63 percent of all crossings have five trains a day or less and 47 percent have two or less trains a day (4). Thus, seeing a train is a rare event; encountering a potential hazard situation is even less likely. An article which discussed research conducted by Lebowitz (34) pointed out the result. The perceived risk of an event is related to its frequency, not its severity. Since railroad accidents are fairly rare events, the hazard associated with crossings is probably not perceived to be great.

These attitudes probably have a detrimental effect on safety, especially at crossings with passive signs. Russell (5, p. 7) reported that the signs located at crossings become meaningless to some drivers because they rarely, if ever, encounter a train. Since the signs always give the same message regardless of conditions, they become associated with no hazard rather than trains. Thus, the warning is often given unnecessarily and drivers tend to disregard the warning. However, if the perception is that a particular crossing is hazardous, safe behavior may result. Sanders, et al, (33) reported that there was a strong relationship between train volume and safe behavior which was apparently explained by a high level of familiarity with the crossing by the drivers that were observed and questioned in their study.

Conditioning from low train volume crossings applies to both at-crossing signs and advance warning signs. Drivers are expected to become alert when they encounter an advance sign. However, drivers may come to believe that no hazard actually exists and simply not respond to the sign at all (5). Since the same advance warning signs are located at all crossings, the experience from non-hazardous conditions could be transferred into behavior at crossings with a substantial amount of train traffic and hazard even if active devices were present.

The research cited here suggests that drivers do not consider railroad crossings to be a serious hazard and that some drivers have inaccurate knowledge of the warning devices themselves. Apparently these beliefs are related to the operational characteristics of crossings and tend to reduce the credibility of passive warning devices.

Active warning devices also have credibility problems. Some of the lack of credibility stems from extended warning time and part is based on a lack of trust in the warning.

Extended warning times result from the manner in which most active signals are activated. At the majority of crossings, the signals are activated when a train reaches a certain point on the track. The distance is set so that adequate warning time, a minimum of 20 seconds, is given for the fastest train that utilizes the crossing. The problem comes about when trains operate over the crossing at speeds less than that of the fastest train, and this is often the case. Unfortunately, the resulting warning time is usually too long for most motorists and even though the signals are activated, drivers proceed over the crossing (34). There are indications that some drivers believe they have at least one minute before a train arrives (4). Obviously, when conditions differ from those that are expected, accidents have a greater possibility of occurring.

This is further complicated by the fact that even if drivers see a train, they may misjudge its speed. Large objects often appear to be going more slowly than smaller ones, and drivers may also assume the train is going the same speed as other trains they have seen on the crossing (34). Another factor which may be associated with misjudging train speed is that drivers have had very little experience with trains in general, and they are less adept at judging train speed than highway traffic speed (4).

Problems may also arise from a lack of trust in active signals. If signals are activated but no train ever arrives at the crossing, drivers may come to believe that the signals simply are not indicating a hazard at all. This situation may result from nearby switching operations of trains that activate the signals but never use the crossing or may result from signal malfunction (35). Whatever the reason, a signal activated without a subsequent arrival of a train may not directly cause an accident, but it is probable that it causes signals to be less credible.

It is important to note that there is usually no penalty for unsafe behavior or disregard of warnings at railroad-highway grade crossings. Since accidents are rare events, unsafe behavior does not usually result in an accident. In most cases that a driver acts in an unsafe manner, the action is actually reinforced because no penalty is incurred (5, p. 7).

Device Suitability

A few studies have addressed device suitability directly and others contain information which can be used to infer the status of device suitability. The diagnostic team reported on by Rowan and Walton in 1970 considered device suitability (21). One-half of the crossings studied were protected by passive devices; 30 percent of the team's recommendations were concerned with or involved the installation of active warning devices, but not all of these recommendations dealt with installing active signals at the passive crossings. For example, the need for actuated advance warning signs at some locations was included in the 30 percent. The report implies that device suitability was not the major problem found at crossings. However, some locations with passive devices were apparently in need of a higher level of device.

In 1972, the United States Department of Transportation (DOT) submitted a report to Congress which included recommendations for improving safety at grade crossings (14). As part of this study, a benefit-cost analysis of improvements warranted in terms of safety gains was conducted. One of the restraints required that any justified improvement return at least one-half of the upgrading cost in safety benefits. The improvements studied were flashing lights, automatic gates, and grade separation. The improvement was selected which had the largest net benefit. Grade separations were not considered for rural crossings with two or less trains per day or urban crossings with ten or less trains per day.

Accident prediction equations were used to estimate the number and severity of accidents per crossing for approximately 223,000 public at-grade crossings. Costs were assigned to accidents, fatalaties, and injuries. The analysis determined that 26,121 crossings warranted immmediate improvement at a cost of $665 million. It was also estimated that 4,000 accidents could be prevented and 450 lives could be saved annually by implementing these improvements.

Since 1972, a considerable amount of federal funds has been allocated to grade crossing safety as was noted in the introduction. A large part of the funds has been used for the installation of active devices. In 1982, John Hopkins (15) reported on the results of these improvements. His study investigated the reduction in grade crossing fatalities from 1968 to 1979. Hopkins found that fatalities, after adjusting for changes in vehicular and train traffic, had declined 7.4 percent per year. Hopkins then estimated the impact of the installation of over 18,000 active warning devices on the fatality rates.

The study reports that the theoretical benefit derived from these installations accounts for 4.5 percent of the annual reduction and Hopkins noted that this is approximately the rate that crossing safety is improving relative to highway fatalities in general. Hopkins attributed the remaining reduction, 2.9 percent, to the decline in the severity of crossing incidents, presumably through improved automobile crashworthiness and seatbelt usage. Other factors credited by Hopkins for improving safety included public education efforts, elimination of crossings, improved signal effectiveness, better maintenance, and increased attention to passive signing.

Hopkins' study (15) reports that about 14,000 upgrades have been made since 1971. Presumably, most of these crossings were included in the crossings identified in the DOT's 1972 Report to Congress. This would seem to indicate that improvements are still warranted at some crossings. It is important to note the number of new improvements involving active devices has increased by 300 every year since 1974

(15). Thus, the trend has not only been to install active devices but to increase the rate at which they are being installed as well.

There is little doubt that the installation of these devices has had a positive impact on safety. However, there is evidence that there may still be crossings in need of upgrading. In 1978, the Comptroller General submitted a report to Congress on the federal program for railroad-highway safety (2). The report was critical of the Federal Highway Administration for not setting a uniform level of safety that the states could conform to. According to the report, this resulted in widely divergent policies in different states. Thus, a crossing with the same characteristics might be treated differently in different states, and this was demonstrated in the report to be the case.

The report also noted that funds were not apportioned according to safety needs. This was pointed out as a barrier to meeting a uniform safety goal and implies that suitability may vary across the country. A report on state programs by Gertler in 1977 (36) indicated that crossings on both the federal and state highway system were most likely to be improved, and crossings off both systems may not receive the same degree of attention.

Both of these reports suggest there may be crossings which warrant higher levels of devices because the crossing safety programs have been administered and funded differently in different states. It must be noted that the 1978 Surface Transportation Act changed the formula by which funds are appropriated for grade crossing safety to include a factor based on the number of public crossings (37). Until then, the number of crossings in a state had no impact on the amount of federal funds received for railroad-highway grade crossing improvements.

A great deal of effort has been made to install higher level devices at crossings with conditions which warrant their use. This effort has, as Hopkins (15) reported, improved safety at grade crossings. There is evidence, however, that some crossings may still have devices which are not suited to the situation if judged solely on the basis of safety needs and not in terms of available funds.

Summary

A good deal of research has been conducted on railroad-highway grade crossing safety. A number of factors which seem to influence safety have been investigated.

The research on grade crossing characteristics has identified a number of physical and operating attributes which are apparently related to, if not actually causal factors of, accident occurrences. Two items which have been identified in almost all of the studies are highway and railway traffic volumes. Logically, the probability of an accident should be related to the number of trains and motor vehicles which utilize a crossing. However, as the research on driver behavior indicates, these operational characteristics also influence driver perceptions of grade crossings.

Sight distance is considered important, but the impact is difficult to quantify. The same is true for characteristics such as complex geometry, visual distractions, and other conditions which may make it difficult to perceive a hazard. However, the need for adequate warning devices that compensate for these conditions was indicated.

The ability of warning devices to meet the needs of motorists has been questioned. There are operational limitations which may prevent active warning devices from effectively alerting motorists. Both passive and active devices have credibility problems that may prevent them from functioning as effective traffic control devices. It is recognized that active control devices have been shown to be more effective than passive devices. However, on an absolute basis, there are indications that active devices do not provide an adequate warning under certain conditions for some drivers.

In terms of device suitability, there is reason to believe that there are locations in need of a higher level device. As has been noted, there is a possibility that, even if suitable devices were located at all crossings, safety problems would still exist due to the limitations of the devices.

The conformance of devices to MUTCD standards in terms of advance warning requirements has been discussed, but the effects have not been quantified. Therefore, it is not known how many, or if any, grade crossing safety problems can be attributed to the non-conformance of devices with the MUTCD. However, there are indications that a substantial number of crossings are not in conformance with MUTCD standards.

CHAPTER 3

RESEARCH PROCEDURES

This chapter details the methods utilized to meet the objectives of this research. The data base used, the selection of a sample, and the acquisition of the needed information are detailed first. The discussion on the methods used to determine device suitability and conformance to standards for each crossing is followed by an explanation of the methods used to determine the influence of suitability and conformance. The manner in which high and low accident rates were identified and analyzed are also detailed. A discussion of the limitations of the data is followed by a summary of the procedures utilized for this research.

Data Base

In 1972, the National Inventory of Railroad-Highway Crossings was initiated by the U.S. DOT. The inventory was developed by the Federal Railroad Administration (FRA), Federal Highway Administration (FHWA), and the Association of American Railroads (AAR). The AAR-DOT inventory, as it is known as, is now maintained by the FRA. In 1977 the inventory contained information on some 402,000 crossings, about 215,000 of which were public-at-grade, 142,000 were private, 3,750 were grade separated, and 3,500 were pedestrian. At present there are 215,428 public-at-grade crossings. Thus, a comprehensive listing of the grade crossings which were of interest was available.

The FRA also maintains an accident history for all crossings in the Railroad Accident/Incident Reporting System (RAIRS). Major changes in reporting requirements went into effect January 1, 1975, and this precludes direct comparison of data taken before and after these changes (3, p. 1). RAIRS now includes all impacts between railroad on-track equipment and highway users. Before the changes, all collisions were not reported.

Thus, since 1975 sources have existed which contain comprehensive and consistent information on crossing characteristics and accident histories. Crossings on both data bases are identified by the same code number, and the information from the two can be easily linked.

Time Period Studied

Since railroad-highway grade crossing accidents are fairly rare events in terms of any single crossing, it was desired to have as long a time period as possible to study, especially since the analysis was conducted on individual crossings. As has been noted, RAIRS reporting requirements were changed on January 1, 1975. These changes preclude comparison of data taken before the date to those taken after that date. The beginning point of this study period was therefore set at January 1, 1975. The last complete year of accident data available was 1980. Thus, the period selected for study was from January 1, 1975, to December 31, 1980, a period of six years.

Selection of Crossings to be Studied

A computer tape was obtained from the FRA which contained the current information for all public-at-grade crossings. Since the individual analysis of each crossing selected in the sample involved a subjective manual evaluation, some limitation had to be placed on the number of crossings selected.

The largest number of crossings which seemed reasonable in terms of time and effort was chosen. It was felt that around 300 crossings could be evaluated with reasonable effort. There were 215,428 crossings listed on the inventory. Since they are in random order on the tape, a systematic sample was taken by selecting every 700th crossing. This resulted in a sample size of 307 crossings.

Data Acquisition

After selecting a sample, the complete inventory and accident history for the crossings chosen was obtained from the FRA. These histories contained any and all updates which were received for these crossings by the FRA. Either state transportation agencies or railroads can initiate updates to the inventory. However, the program is voluntary and not all changes are reported. Still, it represents the best aggregated data base available. Forms for all reported accidents were also received. The accident and inventory records were then compiled and sorted by state in order to facilitate the evaluation.

Previous experience with the inventory had created doubts about the validity of entries for Average Daily Traffic (ADT). Since ADT is a very important parameter in determining device suitability, it was decided to obtain supplementary information on it.

A request for additional highway traffic information was sent to each state which had crossings listed in the sample. These states are listed in Table 3-1. A form was provided for each crossing. Space was provided for the years of interest, 1975 through 1980, inclusive and for a growth factor if all ADT's or all years were not known. The AAR-DOT crossing number, city, street, and railroad were listed to aid

TABLE 3-1

STATES WITH CROSSINGS IN THE SAMPLE

Alabama	Montana
Arkansas	Nebraska
California	Nevada
Colorado	New Hampshire
Connecticut	New Jersey
Delaware	New Mexico
Florida	New York
Georgia	North Carolina
Idaho	North Dakota
Illinois	Ohio
Indiana	Oklahoma
Iowa	Oregon
Kansas	Pennsylvania
Kentucky	South Carolina
Louisiana	South Dakota
Maine	Tennessee
Maryland	Texas
Massachusetts	Utah
Michigan	Virginia
Minnesota	Washington
Mississippi	West Virginia
Missouri	Wisconsin

the states in determining the requested information. The forms were sent through FHWA division offices, and, in some cases, the division or local FHWA offices furnished the information. The remainder were completed by state transportation agencies. Information was received from all states from which information was requested except Arkansas, Idaho, and New Hampshire.

Compilation of Information

A tabulation was made of pertinent information from the available sources. The FHWA or state and AAR-DOT inventory ADT's were recorded. An average was calculated for the six years of traffic data. Growth factors were used to provide estimates for missing years. If growth factors were not given, constant growth was assumed between the years for which ADT values were given. In every case, a determination was made using the best available information. The inventory value for ADT was utilized if no FHWA or State data were available.

The number of trains per day was derived by summing the number of day and night through trains and day and night switching trains listed on the inventory. The average ADT value was multiplied by the number of trains per day to obtain an average exposure value. FHWA or state values for ADT were used whenever possible.

The number and type of tracks at the crossing, the number of highway traffic lanes, the maximum timetable train speed, the highway functional classification, the skew angle, and whether or not passenger trains used the crossing were recorded using inventory information. Other pertinent data such as whether the roadway had a paved or unpaved surface were also noted. Any changes in crossing characteristics listed on updates were recorded. The accident history was determined using the RAIRS information. The date, circumstances and conditions surrounding the accident, and type of warning devices were recorded.

The warning device in place was recorded along with any changes that had been noted in inventory updates. RAIRS also includes warning device information. The two sources were not always in agreement. These inconsistencies are discussed in more detail in another section of this report. All different warning device types reported by both sources and the dates during which they were present were recorded.

Determination of Device Suitability

In order to assess the suitability of a crossing's warning device to its application, guidelines for determining the need for active devices listed in the FHWA's Railroad-Highway Grade Crossing Handbook (6, pp. 203-204) were utilized (referred to hereafter as FHWA guidelines or criteria). These guidelines, listed in Table 3-2 do not constitute a standard or regulation. However, these guidelines were developed by a task force appointed by the National Advisory Committee on Uniform Traffic Control Devices (NAC) to develop modifications to the MUTCD (16). In 1976, the NAC recommended that a new Part VIII, including these criteria and other standards for railroad-highway grade crossings, be included in the MUTCD. In 1977, the FHWA approved the new Part VIII for inclusion in the MUTCD (16). The criteria listed in Table 3-1 eventually did not become part of Part VIII of the MUTCD (39).

The selection criteria appear to provide an acceptable basis for determining the need for active control devices. An evaluation of the

TABLE 3-2

FACTORS USED IN DETERMINING THE NEED FOR ACTIVE TRAFFIC CONTROL DEVICES AT RAILROAD-HIGHWAY GRADE CROSSINGS
(Analysis includes these factors and their interrelationship)

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1. Volume of vehicular traffic--an ADT of less than 1,000 would require other significant warrants.
2. Volume of railroad traffic--less than six trains per day would normally represent light exposure except where passenger train operations exist.
3. Maximum speed of railroad trains--speeds in excess of 50 miles per hour (80 km/hr) in rural areas or 35 miles per hour (56 km/hr) in urban areas deserve careful consideration.
4. Permissible maximum speed of vehicular traffic--speeds in excess of 35 miles per hour (56 km/hr) in rural areas or 25 miles per hour (40 km/ hr) in urban areas deserve careful consideration.
5. Volume of pedestrian traffic--pedestrian volume of 150 or more per hour may be a significant determinant.
6. Accident record--occurrence of a train-involved accident within a 3-year period indicates a need for careful analysis.
7. Reduced sight distances--limited view of tracks should be checked for approaching driver reaction.
8. Potential for complete elimination of grade crossings without active traffic control devices--closing lightly used crossings and installing active devices at other more heavily used crossings.

Additional Factors Should Be Used for Automatic Gates.

9. Multiple main line railroad tracks.
10. Multiple tracks at or in the vicinity of the crossing which may be occupied by a train or locomotive so as to obscure the movement of another train approaching the crossing.
11. High-speed train operation combined with limited sight distance at either single or multiple track crossings.
12. A combination of high speeds and moderately high volumes of highway and railroad passenger or freight traffic.
13. High-speed passenger trains, substantial numbers of school buses or trucks carrying hazardous materials, or continuing accident occurrences.

TABLE 3-2 (continued)

14. Recommendations of a multidisciplinary diagnostic inspection team.
15. Any combination of the conditions listed above.

Source: Railroad-Highway Grade Crossing Handbook, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1978.

type of warning device needed at each location was performed by comparing available crossing characteristics to the FHWA guidelines. The need for active devices was determined by considering train and highway traffic volumes and speeds, pedestrian traffic, accident history, and sight distance. Unless the factors for gates were also met, these factors indicated the need for the basic active device, flashing light signals.

Complete information was available for Factors 1, 2, 3, and 6, listed in Table 3-2, concerning vehicular traffic volume, railroad traffic volume, maximum train speed, and accident history.

The speed of highway traffic was not listed on the inventory form and was not known. However, the cutoff points for consideration are 25 mph in urban areas and 35 mph in rural areas. It is very likely that all but local streets in both areas have permissible maximum speeds greater than these values. The inventory included information on highway classification and crossing location, rural or local.

Pedestrian traffic volumes are also not reported. However, the interest was in the highway vehicle and train problems so this information was not critical to this determination of suitability.

Sight distance information was also not available on the inventory, and a site visit would have been necessary to make this determination. It was not economically feasible to visit each crossing. The RAIRS form listed a "view of the track obscured by" condition. The categories were:

1. Permanent structure;
2. Standing railroad equipment;

3. Passing train;
4. Topography;
5. Vegetation;
6. Highway vehicles;
7. Other; and
8. Not obstructed.

Of course, this information was known only for those crossings which had accidents during the study period. Therefore, in almost all cases, no information was available on sight distance.

The determination on the need for gates required information on the number and type of tracks, passenger train operation and school bus and hazardous material truck volumes in addition to the information required for flashing light signals. All of the needed additional information was available except the numbers of school buses or trucks carrying hazardous materials. No information was available on the results of multidisciplinary diagnostic team investigations of any of the crossings. Therefore, Factor 14 could not be utilized.

Application of FHWA Guidelines

The application of these criteria involved a subjective examination of each crossing. Due to data limitations, only Factors 1, 2, 3, and 6 were utilized to distinguish between crossings requiring passive devices and those requiring flashing light signals. Since the criteria state that less than 6 trains per day and an ADT of less than 1,000 indicate low exposure and thus a low hazard, a breakpoint was established at an exposure value of 6,000. If no other factors, including the criteria for gates, were met, and the exposure value was less than 6,000, a need for only passive warning was indicated. If one value, either trains per day or ADT, was very high and the other low, a need for flashing lights might be indicated, especially if the train per day volumes were very high. If the exposure value was substantially more than 6,000 and both the ADT and train per day minimum values were exceeded, flashing light signals were considered to be needed, especially if any other factors were met. If the exposure was near but above 6,000 and either Factor 1 or 2 was not met, other factors were investigated. If these were also not met, a decision based on engineering judgment was made based on the perceived hazard of the crossing.

The differences between rural and urban locations was considered. The Railroad-Highway Grade Crossing Handbook states that traffic volumes of over 3,000 ADT for rural and 5,000 ADT for urban may be categorized as high (6, p. 205).

Train speed was a very important consideration. The consequences of a high speed accident are usually very severe and only if exposure values were very low, would high speed crossings not warrant at least flashing light signals. Highway type was considered as an indicator of motor vehicle speed. Since definite determinations could not be made, this characteristic was considered supplementary to other characteristics.

Accident histories were evaluated. More than one accident in a three-year period strongly indicated the need for active signals.

It is important to note that it was these factors and their interrelationships which were considered. The factors were not considered independently, but as a whole. In the absence of determinate characteristics, passive devices were usually deemed appropriate if the decision was between passive and flashing light signals.

Factor 8, which considers the potential for complete elimination of the crossing, was not applied. To make a determination based on this factor, other crossings in an area must be considered. Since this is an analysis of device suitability and not one of potential elimination of crossings, this factor was not utilized.

The additional factors for gates listed in Table 3-2 were applied to each crossing. Factors 9, 10, 12 and the accident and passenger train sections of Factor 13 were considered. Multiple main lines were an important but not absolute criteria. If train and highway traffic were both very low, the determination might be that gates were not needed, especially if no other factors, including the basic active device factors were met.

The application of Factor 10 included consideration of the type of tracks. The number and type of tracks give a good indication of the likelihood that the view will be obscured by another train. Locations with passing and/or multiple sidings are likely to have these types of problems. One main and one siding was usually not considered to meet Factor 10, but if passing or multiple sidings were located in conjunction with a mainline track, gates were determined to be necessary. If both Factors 9 and 10 were met, gates were considered to be needed.

A combination of high train speed and substantial highway and train volumes was a strong indication by itself to indicate the need for gates. The determination of what constituted substantial volumes was made according to the criteria discussed for flashing light signals. More than 6 trains per day and an ADT of 3,000 for a rural crossing and 5,000 for an urban location were considered substantial. If the highway volume was less than these cutoffs but more than 1,000, other factors were examined. Train speed was judged according to the limits set in Factor 3.

High speed passenger trains may indicate the need for gates, but other factors such as vehicular train and traffic and volume were considered. A continuing accident history was usually accompanied by other factors. More than two accidents during the study period or more than one in a year indicated a need, but other factors were also considered.

Again, it is important to note that the interrelationships of these factors were considered. Decisions about device suitability were made by considering all of these factors and then using engineering judgment to determine the degree of hazard present and the device needed. In most cases, several factors were met and the decision on the appropriate device was clear. In some cases, the decision was not clear and the best judgment was made. In borderline cases, the lower of the two devices in question was usually selected. For example, if the decision was between gates and flashers, and the factors for gates were not clearly met, then flashing light signals were deemed appropriate.

The device type determined to be needed was then compared to the device located at the crossing. The type of device needed according to the FHWA criteria and the suitability of the device located at the crossing were recorded.

Conformance to MUTCD Standards

A determination on the warning system's conformance to national standards for grade crossings was made by comparing the information available in the inventory with the appropriate section of the MUTCD. The requirements for Traffic Control Systems for Grade Crossings are given in Part VIII of the MUTCD. The inventory provides information on signs and train activated devices located at the crossing, special warning devices not train activated, pavement markings, and advance warning signs.

Not all of the provisions given in the MUTCD are mandatory. Some practices are considered advisable and are recommended but not mandatory. Other practices included in the manual are allowed but not required for design or application. Only the practices which are mandatory were considered for the determination on device conformance.

Crossbucks. Section 8B-2 of the MUTCD governs use of crossbucks at grade crossings. Basically, a minimum of one crossbuck sign is required on each roadway approach to every grade crossing. The manner in which the crossbuck information was recorded in the inventory allowed a determination to be made on whether enough crossbuck signs were present to meet MUTCD requirements.

The MUTCD requires that all signs shall be reflectorized. It was possible to make a distinction between reflectorized and non-reflectorized crossbucks from the inventory information. Therefore, a determination of conformance based on that requirement was possible.

It had to be assumed that the crossbuck signs were located according to the location requirements in the MUTCD. Under certain conditions crossbucks are required on both the right and the left sides of a roadway approach. The information necessary for a determination on that requirement was not available.

Multiple track sign. Section 8B-2 requires that an inverted T-shaped sign listing the number of tracks be mounted below the crossbucks at crossings with multiple tracks. These signs are not required at crossings that have gates. A separate category is not provided in the inventory for this sign, and no determination was made concerning this requirement.

Advance warning signs. Specifications for the use of railroad advance warning signs are given in Section 8B-3 of the MUTCD. Basically advance warning signs are required to be used in advance of every grade crossing on each roadway approach. Certain exceptions are permitted. They are:

1. low volume, low speed roadways crossing minor spurs or other tracks which are infrequently used and which are flagged by train crews;

2. in the business districts of large cities where active grade crossing traffic control devices are in use; or

3. where physical conditions do not permit even a particularly effective display of the sign. (37)

Information necessary to apply the first exception was available. Information on city size or business district location was unavailable. Thus, this exception was not applied. It was assumed that a partially effective display of the sign was possible at all locations. The result was that advance warning signs were deemed necessary to meet MUTCD requirements except in rare instances.

The information available from the inventory record only distinguishes between the case where at least one approach has an advance warning sign and the case where no advance signs are present on any of the approaches. It could not be determined if both approaches had the signs. Thus, it was assumed that both approaches had advance warning signs if the inventory record indicated that at least one approach had an advance warning sign. It was also assumed that the advance signs reported in the inventory met MUTCD provisions on location and reflectivity.

Pavement markings. Section 8B-4 contains provisions for pavement markings. The basic requirement is that identical markings be placed on all paved approaches to crossings where active devices are located and at all other crossings where the speed of highway traffic is 40 mph or greater. Inventory information was available on pavement markings. It could be determined if stoplines, railroad crossing symbols, or both were located at the crossing, or if no markings were present.

The inventory record did not give a separate account for each approach; therefore, it was assumed that the information applied to both approaches. Since highway speed data were not available, the 40 mph requirement for passive crossings could not be applied. However, any crossing which had some but not all of the markings used at grade crossings was classified as not conforming to MUTCD requirements. This would be the case if stoplines were present but the railroad crossing symbols were not, for example.

The inventory record also provides information on whether the roadway surface is such that pavement markings can be effectively maintained. Obviously pavement markings cannot be required at locations where they cannot be placed due to the type of surface.

The requirements also call for non-passing markings to be used on two-lane roads with two-way traffic. No information was available on no-passing markings. Certain location requirements are also specified; however, only the presence or absence of markings could be determined from the available data.

Stop signs. The use of standard highway stop signs is covered in Part II, Section B-5 of the MUTCD. Basically, stop signs should only be used as an interim measure before active signals can be placed at the site and then only after an engineering study has been performed. In this study, crossings with standard highway stop signs were classified as not meeting MUTCD requirements. This was a reasonable decision, especially for locations with active control devices or passively signed crossings where the stop signs had been in use for several years. An assumption was made that the standard stop signs used at any crossing were not an interim measure and, therefore, the warning devices did not meet the requirements of the MUTCD.

Non-standard signs. Any signs used at a crossing which are not approved for use at grade crossings were categorized as non-conforming. Signs such as non-standard stop signs or "dangerous crossing" signs are examples. The inventory record contained information on these types of signs, and, therefore, a determination could be made.

Active devices. The requirements for active traffic control devices are given in Section 8C-1 through 8C-7 of the MUTCD. The inventory record reported all flashing lights which are not in accord with the latest AAR Bulletin on Railroad-Highway Grade Crossing Warning Systems as other flashing lights. Since the AAR Bulletin and the MUTCD requirements are virtually identical, the determination of conformance was based on this information (40).

The MUTCD does not contain any absolute criteria upon which the use of cantilevered flashing lights depend. Basically, cantilevered flashing lights are recommended to supplement mast-mounted flashing light signals to provide better visibility of the warning to approaching traffic, especially on multi-lane roadways. Information on the use of cantilevered signals at a crossing was available; however, since the provision is not mandatory, no crossings were categorized as not conforming to MUTCD requirements because cantilevered flashing light signals were not located there.

The inventory records differentiate between red and white reflectorized gates and other colored gates. The MUTCD requirements of Section 8C-4 call for red and white striped gate arms which are fully reflectorized. The use of any other colored gates would constitute non-conformance.

The MUTCD recommends that devices which provide reasonably uniform warning times should be installed at crossings where train operating speeds vary considerably. Speed range information, as well as whether the train detection devices allowed for speed selection, was available. Since this is a recommended practice and not a mandatory one, no determination was based on uniform warning capability. Other provisions such as flash rate and gate arm descent and ascent timings and train detection are also given in the MUTCD. No determination based on these items was possible.

Wig wags. The MUTCD does not contain any provisions for wig wag signals. At one time they were considered to be acceptable warning devices; however, they do not conform to present-day standards. For this reason, wig wag signals were judged not to be in compliance with MUTCD standards.

Other MUTCD provisions. Provisions are also given in the MUTCD for items which are used to supplement the basic warning systems. These include signs relating to exempt crossings, turn restrictions, and stopping on track prohibitions. The illumination of crossings is also covered. No determination was made based on these provisions. For the most part, these are recommended practices, not mandatory ones, and the information needed to judge the need for these items was not available.

RAIRS information. The RAIRS record also contained information on warning devices. Categories for gates, cantilevered flashing light signals, standard flashing light signals, wig wags, highway traffic signals, audible warnings, crossbucks, stop signs, watchmen, crew flagging, other devices (and description), and no warning devices were included on the record. The location of the device was specified as: (1) both sides; (2) side of vehicle approach; and (3) opposite side of vehicle approach. For those locations that had accidents during the study period, the RAIRS information was also used to determine the type of warning device located at the crossing and its conformance to standards.

Changes During Study Time Period

It is important to note that this evaluation accounted for all the different conditions a crossing may have had during the six-year study period. If any changes occurred in the characteristics that were considered in the evaluation process, a separate determination was made for the different conditions which were represented. For example, if crossbucks were located at a crossing for part of the period studied, and flashing lights were installed at some point, two different evaluations were made. Any differences reflected by updates to the inventory that were used in the suitability and conformance evaluations were considered. Thus, one crossing might represent more than one condition. The suitability or conformance might be for different time periods because of a change in device type, train or highway volumes, speed, advance warning, pavement markings, or other crossing characteristics. The appropriate time period was determined for each different set of conditions found at each crossing. The time periods were determined by using the effective dates of the updates that reflected the changes. However, the effective date of the updates may not necessarily accurately reflect the time the changes were made. Secondly, if

RAIRS information reflected a change, usually in terms of the warning system, the date the change occurred could not be known. However, both information sources allow an approximation of the time period to be made. For example, if an accident record indicated that the warning device was different from the inventory, points in time were known for which the conditions were different. For these cases, an estimation of the time period was made. The dividing of the base time period due to changes means that crossing conditions rather than crossings become the observations used for the analysis. Analysis of the data identified 356 different conditions for the 307 crossings in the sample.

Measure of Effectiveness

The desire was to make a determination of the effectiveness of the warning devices used at grade crossings. Therefore, some measure of effectiveness, or response variable, had to be defined. This measure of effectiveness should reflect how the system has performed; the demand or stress placed on the system should also be taken into account. The response variable should reflect the performance in terms of the demand; one such measure is the ratio of the performance divided by the demand. The measure of performance chosen for this study was the accident history during the appropriate time period for which conditions at a crossing were constant. The ADT and the number of trains per day utilizing the crossing constituted the stress. The appropriate time period should also be accounted for in the stress measure so that the total stress over time is reflected. Due to the manner in which the response variable was defined, some adjustments were necessary.

The zero accident condition for a given time period must be adjusted. The measure of effectiveness is the ratio of performance to demand. A performance value of zero, (e.g., no accidents), does not allow accounting for demand since zero divided by any value is still zero. There is a difference in the effectiveness of a warning device located at a crossing with no accidents and a high value of stress and one at a crossing which had no accidents and a low stress level.

Therefore, an adjustment was made to the no accident condition. Since crossings accidents are rare events for any one crossing, the fact that no accidents were reported during any given time period may only indicate the time period was not long enough to reflect the actual performance, as measured by accidents, of the warning device.

The adjustment factor used was based on the average accident rate for all public crossings in the United States. The national average is approximately 0.055 accidents per crossing per year (3). Thus, any given crossing would experience, on the average, 0.33 accidents during a six-year period. Since there was evidence that the crossings had less, none in fact, than 0.33 accidents for the time period, a conservative measure was used. Thus, each zero accident condition was assigned a value of 0.2 accidents. Further rationale for the 0.2 value was found by examining the accident history of the sample crossings. The 307 crossings had experienced 73 accidents over the six-year period. This represents a rate of about 0.24 accidents per crossing over the six-year period. Again, a conservative measure could be 0.20. This adjustment was made only to crossings with no accidents.

This adjustment implies that, if the study period were longer, the crossings which did have accidents would have had the same number of accidents per year as they did for the six-year period. In other words, the relationship between all the conditions in terms of the number of accidents would be the same for any time period.

An appropriate measure for stress also had to be determined. Traditionally, the product of the ADT and the number of trains per day, or exposure, is used to reflect demand or stress. This implies that hazard increases as exposure does, which is an implication of much of the hazard-index formula research.

Initially, exposure was used as the measure of demand or stress. Thus, the response variable, or accident rate, was defined as accidents divided by the product of ADT, trains per day, and the appropriate time period in years. By defining the response variable in this manner, the variation in the number of accidents due to different exposure values should be accounted for.

However, a plot of this response variable versus exposure indicated that as exposure increased, the value of the response variable decreased. It is desirable to have a linear band of values with no positive or negative slope when the response variable is plotted against exposure. A linear band would indicate that the variation in accidents due to differences in exposure levels had been accurately accounted for. However, in this case, the performance measure, accidents, was obscured by the demand or stress measure, exposure, since regardless of the value for accidents, the rate decreased as exposure increased. Thus, an adjustment of the demand, or stress, measure was needed.

Several different adjustments were tried. The best results were obtained when the response variable was accidents divided by the product of trains per day, the natural logarithm of ADT, and the appropriate time period in years. Rationale for this was also given by recent research noted by Hopkins (15) that suggests hazard at a crossing increases as the square root of ADT increases. Taking the natural logarithm was similar in that, in both cases, the actual ADT level is deemphasized.

Thus, the accident rate equation used in this study was:

$$AR = \frac{A}{(T)\ (LNADT)\ (CY)}$$

Where = AR = Accident Rate

A = Adjusted Accidents

T = Trains Per Day

LNADT = Natural Logarithm of Average Daily Traffic

CY = Number of Years Rate is Based On

Two additional adjustments had to be made to the data. First, some crossings had an average train volume of less than one train per day. It was impossible to determine the actual train rate. For example, it could have been two trains per week or two trains per month or any value less than an average of one train per day. Since it is necessary to know the train rate for the response variable calculation, the data for these conditions were deleted from consideration.

Secondly, if a particular crossing condition existed for less than one year and there were no accidents, the observation for that condition was also deleted. It was felt that the time period was too short to include the observation in the evaluation process. These crossings tended to have very high rates because the denominator of the response variable had a term of less than one. These rates did not reflect the situation accurately and, therefore, the observations were deleted.

Statistical Analysis of Factors

The objective of part of this research was to determine the influence of a device's suitability and conformance to standards on its effectiveness. Different categories were defined for warning device type, suitability, and conformance to standards.

Three warning device levels were defined. The first level contained all passively signed crossings and crossings with no signs or signals. This level will be referred to as passive. The second level is made up of flashing light signals and wig-wags. This will be referred to as flashing light signals. Gates constituted the third level.

The two levels of suitability were defined as yes, if the device met or exceeded FHWA criteria, and no, if it did not. Two levels of conformance to standards, yes and no, were used. Yes was indicated if the warning system was determined to be in accordance with MUTCD requirements, and no was indicated if any part of the warning system did not meet these standards. The defining of these levels grouped the crossing conditions data into specified categories or cells for further analysis. A separate cell was defined for each combination of levels of all the factors.

The method chosen to determine the differences in effectiveness for the different levels of warning device, suitability, and conformance to standards was analysis of variance. Analysis of variance is an appropriate technique for determining differences in the response variables for different levels of a factor. The total variance of the data is split into two components, the variation of the response variable within each cell and the variation between cells. The within cell variance is an estimate of the random error, and the between cell variance is an estimate of the combination of the systematic variation caused by differences between factor levels and the random error. An analysis of variance compares the two variation terms to see if the between cells variance is significantly greater than the within cell variance. If this is the case, the implication is that a significant part of the variation in the data is associated with the difference in the factors.

The overall test used in this research was a one-way analysis of variance wherein the different cells were treated as different levels of one factor. If overall significance is found, the implication is that there is a significant difference between at least two of the cells. When the cell sizes are unequal and some are missing data, as was the case here, the clearest method is to conduct a one-way overall test followed by procedures which allow specific comparisons of interest to be made.

The procedure utilized to make specific comparisons was the Bonferroni Method. The Bonferroni procedure allows comparisons to be made between cells or groups of cells. It was used here to make comparisons between the different levels of device type, suitability and conformance to standards. Any comparison between two cells or groups of cells can be made using this procedure.

This method compares two cell means or the average of the means of two different cell groups. Each cell mean is considered representative of the rate for the crossings in that cell.

A sum of squares is calculated based on the differences between these means and the number of observations in the cells used in the comparison. When this sum of squares is divided by the mean square error of the data, a statistic results whose square root follows a t-distribution under the null hypothesis that there is no difference between the groups being compared.

In this case a critical t-value was calculated for each comparison and the corresponding confidence coefficient was identified. These confidence coefficients were then compared to identify differences in factor levels which the data supported. For example, a large confidence coefficient would support the conclusion that a difference was real and a low confidence coefficient would indicate that the data did not support a conclusion that there was any difference between the cells being compared.

The use of analysis of variance techniques required a transformation of the response variable. The within-cell error is calculated as the average of the individual cell response variation. One assumption is that these within cell variations are essentially the same for the different cells. A plot of the standard deviation of each cell versus the cell means revealed that the variation in each cell, as reflected by the standard deviation, was proportional to the cell mean. This tended to obscure the differences in the factor levels by inflating the within cell variation. The traditional solution for this problem is to take the natural logarithms of the response variable (40). This transformation stabilizes the variation but retains the relationship of the responses within each cell. This transformation was applied, and the desired effect was obtained.

Identification and Evaluation of High and Low Accident Rates

Another objective of this research was to examine crossing conditions with high or low accident rates in an attempt to discover any trends or similarities within each group and any differences between the low and high rates. The accident rate used was the same as the response variable developed for the analysis of variance procedure. Separate analyses were conducted for all the observations considered together and for the observations within each level of device type identified for the analysis of variance.

The high and low rates were identified by separating out the crossings that were one standard deviation greater than the mean or one standard deviation less than the mean for each of the different groups under consideration. The observations identified with high rates which had no accidents during the time period were deleted from consideration. In those cases, the high rate indicated a very low stress measurement or a short time period rather than a low performance record. This analysis was intended to compare conditions which had a poor performance record in terms of the stress level to ones which had a good performance record in terms of their stress level. The no accident condition observation would not be appropriate for consideration in this case since there was no actual evidence of a poor safety record.

Several characteristics were considered in the analysis. Device suitability and conformance to MUTCD requirements, maximum train speed, whether the crossing was in an urban or rural location, whether the roadway was classified as a local street, and train and vehicle volumes were investigated. Separate analyses were conducted for the crossings as a whole, passive crossings, flashing light signal crossings, and gate crossings. In each case, the characteristics of the crossings with high rates were compared to those with low rates. The characteristics of all crossings within the category of interest were used as a reference.

The distribution of train speeds was analyzed. For each category, the percent of crossings with maximum train speeds of less than 35 mph, from 35 to 49 mph, 50 to 59 mph, and greater than or equal to 60 mph was determined. The percent of rural crossings with train speeds greater than 50 mph and urban crossings with speeds greater than 35 mph was also calculated.

Train volumes per day were classified as 6 or less, 7 to 10, 11 to 19 or 20 or more. The percent of crossings in each category was determined. ADT values were categorized into five groups. The percentages were determined for ADT levels of less than 1000, 1,000 to 2,999, 3,000 to 4,999, 5,000 to 9,999, and 10,000 or more.

Data Limitations

The analyses conducted in this study were partially constrained by the limitations of the data. These limitations generally were one of two types. The first concerned the absence of information on some parameters pertinent to the evaluation and the second type concerned the questionable accuracy of some of the information which was available.

Completeness of data. The lack of data for some items affected the evaluation of device suitability and conformance to MUTCD standards and also the comparisons of crossing characteristics for high and low accident rate observations. The analysis of device suitability based on FHWA guidelines was hampered since some guidelines could not be applied and determinations could not be made on all aspects of the MUTCD requirements due to the lack of certain information. In terms of crossing characteristics, only those for which information was available were analyzed, although a comparison of other characteristics may have proved valuable.

FHWA guidelines. The determination of device suitability based on FHWA guidelines was restricted by the lack of information for some of the guidelines. No information was available on the speed of highway traffic at the crossing, nor was any information available on sight distance. These two factors were probably the most important of the guidelines which could not be applied. Additionally, no information on school buses, trucks carrying hazardous material, pedestrian traffic, or the findings of a multidisciplinary diagnostic inspection team was available. Pedestrian traffic and the diagnostic team findings were not critical to the study; however, the school bus and hazardous material data would have aided in the evaluation.

Conformance to MUTCD. A truly complete inventory of all the information relevant to MUTCD standards would probably be cumbersome and impractical. However, some information which would be valuable and would be practical to obtain and catalog is missing from the available data. Specifically, the two approaches to a grade crossing are not reported on separately. The lack of detail due to this makes a complete determination of conformance difficult in some cases. This is especially true of an analysis of advance warning conformance in terms of signs and pavement markings. A separate accounting of the warning devices for each approach would allow for a better determination of complete conformance to MUTCD requirements.

Specific information is lacking on the location of all signs and signals. Such information would make data collection more difficult but would be valuable for the analysis. Especially valuable would be information on the distances at which advance warning signs and pavement markings were located from the crossing.

Information on the "number of tracks" sign and on whether flashing light signals are in accordance with standards is lacking. A separate category for supplementary signs such as the "number of tracks" sign would be helpful. More detailed information on flashing lights, such as whether back-to-back pairs are present, would aid in the determination of compliance.

Certain information on crossing characteristics would also be useful. Currently, one-lane streets are not specifically reported as one-way or two-way although this has a bearing on conformance. Highway speed information is needed for the pavement marking determination.

The information contained in the RAIRS record on warning devices does not match the inventory information and is generally less detailed. If both sources were the same, a better determination of actual conditions and changes could be made. The differences tend to confuse rather than illuminate at present.

Changes in conditions. Although inventory changes are documented in updates to the inventory, the date of the change is not given. Thus, it is impossible to determine precisely the time period of any given set of conditions unless no changes occurred between updates. Since the inventory records are not updated on a regular basis, the date that a condition changed is difficult to determine. This is especially critical in terms of warning devices. Presumably, updates were made soon after an upgrade or change in warning system; however, updates are not mandatory, and it is not known if this is the case. All that is known is the date of the first report of a change through an inventory update.

Accuracy of Data. Examination of the available information created concerns about the accuracy of some of the data. Most of this concern was based on the discrepancies between data sources for some parameters. Basically, these amounted to differences between inventory and RAIRS information or inventory records and information supplied by state highway agencies. Some concern was related to the number of inventory updates for some crossings.

RAIRS and inventory discrepancies. At least 20 instances were noted where the RAIRS record and the inventory record on warning devices were inconsistent. The 20 cases do not include instances where the RAIRS data may have reported a change in the warning system that was not reported in an inventory update. Only those cases for which the two information sources did not report logically consistent information were noted. This indicated that one or both of the sources was inaccurate. In one case, the RAIRS record listed the cause of an accident as driving around gates but did not list gates as a warning device.

The accuracy of all the data becomes suspect after discovering some of the inconsistencies. Since about 20 of the 73 RAIRS records indicated that either or both sources were incorrect, the validity of all the crossings which did not have accidents and, therefore, RAIRS information is questionable. The lack of updates for many crossings also caused concern about inventory record validity.

Inventory updates. Many of the inventory records for the crossings in the sample had not been updated since 1972. In fact, over 49 percent of all crossings in the sample had only one inventory record. Thirty-six percent had two inventory records or, in other words, one update. The remaining 14 percent had between two and four updates. The crossings which did not have any updates may or may not have had changes since the inventory was created; however, the lack of confirmation from inventory updates raised concern about the validity of the information for those crossings. Some changes in the crossing characteristics, if not in the warning devices themselves, would be expected in the period since 1972. It cannot be said that records which have not been updated are inaccurate, but the degree of confidence in their validity is lessened by the absence of subsequent updates confirming that no changes had indeed taken place. There were some cases where the RAIRS information reported logical changes in warning devices which were not reflected in the inventory or any updates. Thus, the inventory date was possibly incorrect in at least some of the cases for which there were no updates. Other information suggested that some of the inventory information was incorrect even if updates had been made.

Crossing closures. The information received from the state highway agencies and FHWA district offices indicated that nine crossings in the sample had been closed and one was grade separated. However, this information was not reflected in the inventory. Some of the crossings had been closed after the study period was over and were included in the analysis. The four which were not were eliminated from consideration. In either case, the inventory did not reflect the closing.

Highway volumes. Previous experiences with the inventory prompted the collection of information from state transportation agencies through the FHWA about ADT's for the crossings in the sample. A comparison of the values reported in the inventory and by the transportation agencies revealed that many of the values differed. About 25 percent of the inventory values differed from the state agency values by 500 or more vehicles per day and about 17 percent differed by 1,000 or more vehicles per day. Almost half, 40 percent, had ADT values which differed by 100 or more. The state values were used in this analysis, but the differences demonstrate the potential for inaccuracy in the inventory.

Summary

This chapter has documented the procedures followed to conduct the analysis. A sample of 307 grade crossings was selected from the National Inventory of Railroad-Highway Crossings. Accident histories and general crossing characteristics for the years 1975 through 1980 were compiled using the National Inventory. RAIRS and ADT data were provided by FHWA.

For each crossing, determination of device suitability was made by comparing the warning devices located at the crossing to the warning device warranted according to FHWA guidelines. An evaluation was also made of each warning device's conformance to MUTCD standards.

An accident rate was defined which accounted for differences in levels of ADT and train volumes and the length of time the accident rate included. Adjustments were made to the number of accidents for those observations which had no accidents during the study period.

Analysis of variance techniques were utilized to test for differences in accident rates due to different types of warning devices, device suitability, and conformance to MUTCD standards. An analysis was also conducted to determine which physical and operating characteristics are associated with low and high accident rates.

Finally, constraints were placed on the analyses by the limitations of the data. These limitations were primarily concerned with either the accuracy or the completeness of the data.

CHAPTER 4

INFLUENCE OF WARNING DEVICE TYPE, CONFORMANCE TO STANDARDS, AND SUITABILITY ON WARNING DEVICE EFFECTIVENESS

The classification of observations into categories according to warning device type, suitability and conformance to standards allowed comparisons to be made which tested the differences in accident rates associated with the classification. It was expected that warning device type, suitability, and conformance to standards would have an effect on effectiveness as measured by the accident rates. This chapter contains the results of the tests performed to determine the extent of these influences.

Results of the Classification Process

The results of the classification of the crossings in the sample by device type, conformance to MUTCD standards, and device suitability are shown in Table 4-1. The table shows the cells formed by the classification process. The mean accident rate and the number of observations in each cell are shown. The total number of observations included in the analysis was 287. The original sample contained 356 observations based on the sample of 307 crossings. Due to the changes in crossing characteristics, 69 observations were deleted by the elimination of observations which had either of the following characteristics:

1. Train volume of less than one per day; and
2. Less than one year of the same conditions and no accidents during that period.

TABLE 4-1

MEAN ACCIDENT RATES AND NUMBER OF OBSERVATIONS
FOR CROSSING CLASSIFICATIONS

FHWA	MUTCD	Passive	Flashing Light Signals	Gates
Yes	No	[1] 0.00275 (149)	[2] 0.00166 (49)	[3] 0.000689 (16)
	Yes	[4] 0.00222 (26)	[5] 0.00299 (7)	[6] 0.000417 (7)
No	No	[7] 0.00110 (19)	[8] 0.000560 (7)	[9] --
	Yes	[10] 0.00170 (6)	[11] 0.00791 (1)	[12] --

Key: [3] = Cell Number; 0.000689 = Cell Accident Rate Average; (16) = Observations in Cell

As can be seen from Table 4-1, cells 9 and 12 had no observations since, by definition, all locations with gates met FHWA guidelines. Cell 11 had only one observation and was not included in the analyses because of the possibility that the cell mean was not representative of the actual accident rate. More than half of the observations were included in the cell containing the observations with passive devices that met FHWA guidelines but did not conform to MUTCD standards. Seventy percent of the crossings had passive devices or no signs or signals, 22 percent had flashing light signals, and 8 percent had gates. Eighty-nine percent were determined to be in accord with FHWA guidelines, and 84 percent were judged not to be in conformance with MUTCD standards.

The results of the classification process were used in the analysis of variance. An overall test of significance was performed to determine if any of the cells had significantly different mean accident rates. A one-way test was performed wherein each combination of categories, or cells, was considered a separate "treatment." The results are shown in Table 4-2. An F-value of 7.86 was calculated. This value is significant at the 0.001 significance level which indicates that at least two of the cells have significantly different means. The mean square error value of 1.0444 was used in subsequent analysis of variance calculations.

Bonferroni procedures (40) were utilized to test differences in the accident rates of the different levels of device type, device suitability, and conformance to standards. A number of comparisons were identified and tested in order to determine the influence of each level

TABLE 4-2

OVERALL ANALYSIS OF VARIANCE RESULTS

Source	Degree of Freedom	Sum of Squares	Mean Square	F Value
Model	9	73.857	8.206	7.86*
Error	277	289.297	1.0444	
Total	286	363.154		

*Significant at the 0.0001 level.

of each category. Cell 11 was not used in any of the comparisons. The results are shown in Tables 4-3, 4-4, and 4-5. Each comparison is described, and the cells which were used for each comparison are identified. The t-statistic calculated for each comparison and the corresponding confidence coefficient range are listed. The confidence coefficient range is an indication of how strongly the data support a conclusion that the differences in the accident rates of the compared cells are truly different.

A t-statistic preceded by a (+) indicated that the cells identified by a (t) in the comparison had a lower rate than the cells identified by a (-). The opposite is true for cases in which the t-statistic is preceded by a (-). The associated confidence coefficient range provides an indication of how much confidence can be placed in the conclusion that a difference is significant. The closer the confidence coefficient is to one, the more likely it is the difference is truly significant. The ranges may also be thought of as percentages, indicating the percent of confidence that can be placed in the conclusion that the differences are significant. Since the comparisons are not independent, the confidence coefficients are not absolute; however, they do serve as indications of which results the data support as being significantly different.

Comparisons of Accident Rates for Categories of Device Type

Seven comparisons were used to determine the differences in accident rates for different device levels. The results are shown in Table 4-3. Comparisons 1-A, 2-A, and 3-A compared different levels of devices for all observations that met FHWA criteria. Comparison 1-A

TABLE 4-3

COMPARISONS OF THE ACCIDENT RATES OF DIFFERENT WARNING DEVICE TYPES

	Comparison +		Comparison -	Meets Criteria						Does Not Meet Criteria						t Statis-tic	Confidence Coefficient Range
			FHWA	Meets Criteria						Does Not Meet Criteria							
			MUTCD	Does Not Meet			Meets			Does Not Meet			Meets				
			Device	P	FLS	G	P	FLS	G	P	FLS	G	P	FLS	G		
			Cell	1	2	3	4	5	6	7	8	9	10	11	12		
1-A	All Passive FHWA--Yes	vs	All FLS FHWA--Yes	+	-		+	-								-0.44	0.30-0.40
2-A	All Passive FHWA--Yes	vs	All Gates FHWA--Yes	+		-	+		-							-5.97	>0.99
3-A	All FLS FHWA--Yes	vs	All Gates FHWA--Yes		+	-		+	-							-4.43	>0.99
4-A	All Passive MUTCD--No	vs	All FLS MUTCD--No	+	-					+	-					-2.45	0.98-0.99
5-A	Passive FHWA--Yes MUTCD--No	vs	FLS FHWA--Yes MUTCD--No	+	-											-3.01	>0.99
6-A	Passive FHWA--No MUTCD--No	vs	FLS FHWA--No MUTCD--No							+	-					-1.49	0.80-0.90
7-A	Passive FHWA--Yes MUTCD--Yes	vs	FLS FHWA--Yes MUTCD--Yes				+	-								+0.13	0.10-0.20

Note: The cells marked (+) were compared to cells marked (-) in each comparison. The sign of the t-statistic indicates which cells (+ or -) had the lower accident rate.

P = Passive; FLS = Flashing Light Signal; G = Gates

TABLE 4-4

COMPARISONS OF THE ACCIDENT RATES OF LEVELS OF MUTCD CONFORMANCE

	Comparison +	vs	Comparison -	1	2	3	4	5	6	7	8	9	10	11	12	t Statis-tic	Nominal Confidence Coefficient Range
			FHWA	Meets FHWA Criteria						Does Not Meet FHWA Criteria							
			MUTCD	Does Not Meet MUTCD Requirements			Meets MUTCD Requirements			Does Not Meet MUTCD Requirements			Meets MUTCD Requirements				
			Device	P	FLS	G	P	FLS	G	P	FLS	G	P	FLS	G		
1-B	Passive FHWA--Yes MUTCD--No	vs	Passive FHWA--Yes MUTCD--Yes	+			-									-1.00	.60-.70
2-B	Gates FHWA--Yes MUTCD--No	vs	Gates FHWA--Yes MUTCD--Yes			+			-							-1.09	.70-.80
3-B	FLS FHWA--Yes MUTCD--No	vs	FLS FHWA--Yes MUTCD--Yes		+			-								+1.43	.80-.90
4-B	Passive FHWA--No MUTCD--No	vs	Passive FHWA--No MUTCD--Yes							+			-			+0.91	.60-.70
5-B	All Passive MUTCD--No	vs	All Passive MUTCD--Yes	+			-			+			-			+0.42	.30-.40
6-B	All Crossings FHWA--Yes MUTCD--No	vs	All Crossings FHWA--Yes MUTCD--No	+	+	+	-	-	-							-0.20	.10-.20

Note: The cells marked (+) were compared to the cells marked (-) in each comparison. The sign of the t-statistic indicates which cells (+ or -) had the lower accident rate.

P = Passive; FLS = Flashing Light Signal; G = Gates

TABLE 4-5

COMPARISONS OF THE ACCIDENT RATES OF LEVELS OF DEVICE SUITABILITY

			FHWA	Meets FHWA Criteria						Does Not Meet FHWA Criteria						t Statis-tic	Nominal Confidence Coefficient Range
			MUTCD	Does Not Meet MUTCD Requirements			Meets MUTCD Requirements			Does Not Meet MUTCD Requirements			Meets MUTCD Requirements				
			Device	P	FLS	G	P	FLS	G	P	FLS	G	P	FLS	G		
			Cell	1	2	3	4	5	6	7	8	9	10	11	12		
	+ Comparison		−														
1-C	All Passive FHWA--Yes	vs	All Passive FHWA--No	+			+			-			-			-2.25	.95-.98
2-C	FLS FHWA--Yes MUTCD--Yes	vs	FLS FHWA--No MUTCD--No		+						-					-2.63	>.99
3-C	All FLS FHWA--Yes	vs	All Passive FHWA--No		+			+		-			-			-1.54	.80-.90
4-C	Gates & FLS FHWA--Yes	vs	All Passive FHWA--No		+	+		+	+	-			-			+0.78	.50-.60
5-C	Gates FHWA--Yes MUTCD--No	vs	FLS FHWA--No MUTCD--No			+					-					-0.45	.30-.40

Note: The cells marked (+) were compared to the cells marked (-) in each comparison. The sign of the t-statistic indicates which cells (+ or -) had the lower accident rate.

P = Passive; FLS = Flashing Light Signal; G = Gates

compared crossings having passive devices to those having flashing light signals. A t-statistic of 0.444 which corresponds to a confident coefficient range of 0.30 to 0.40 was calculated which indicates that there is no difference between the two. Comparison 2-A compared the accident rate of crossings with passing devices to those with gates for situations where FHWA guidelines were met. A confidence coefficient of greater than 0.99 was found, which indicated that the observations with gates had a lower accident rate. Comparison 3-A, which investigated the difference between flashing light signals and gates, and resulted in a confidence coefficient greater than 0.99, indicated that the crossings with gates had a lower accident rate.

Comparisons 4-A, 5-A, and 6-A were additional comparisons of passive devices to flashing light signals for observations which did not conform to MUTCD standards. Comparison 4-A compared rates of all passive sites not conforming to MUTCD standards to all flashing light signal rates that did not meet MUTCD criteria. The results of comparison 4-A indicate that the flashing light signals had a lower rate than passive signs. Comparisons 5-A and 6-A, which make the comparison for the two different levels of suitability also indicate this difference. Comparisons 5-A and 6-A are subsets of comparison 4-A.

Comparisons 4-A, 5-A, and 6-A all indicated that there was a difference between the accident rates of flashing light signals and passive devices; however, comparison 1-A did not. Examination of comparisons 5-A and 7-A provided insight into why this was the case. These comparisons subdivided further the comparison made in 1-A.

Comparison 5-A indicated that there was a difference between passive devices and flashing light signals that met FHWA criteria but did not conform to standards. However, there was no difference when both the devices conform to MUTCD standards. The non-significant differences between cells 4 and 5 cancelled out the difference between cells 1 and 2 in comparison 1-A. This indicates that there was an interaction between the two factors of device suitability and conformance to standards. It is important to note that, in each of the comparisons that indicated there was a difference, flashing light signals had a lower accident rate average than passive devices.

The comparisons performed to test the differences in accident rates for the three levels of warning devices, passive signs, flashing light signals, and gates, suggested that the different device types do indeed have different accident rates. Specifically, gates appeared to have lower accident rates than either flashing light signals or passive signs. It was also indicated that, in most cases, flashing light signals had lower rates than passive signs. However, this was not always the case. One comparison indicated that there was no difference in the accident rates of flashing light signals that met FHWA guidelines and conformed to MUTCD standards and passive signs with the same characteristics of conformance and suitability.

These results were, for the most part, expected since the studies reported on in the literature review generally considered or found gates to be more effective than flashing light signals, and both of these automatic signals to be more effective than passive signs. This study indicates, however, that in some cases, flashing light signals are apparently no more effective than passive devices. The effectiveness, as measured by the accident rate, of flashing light signals which met MUTCD standards and FHWA criteria was no better than that of passive devices with the same conformance and suitability characteristics.

Comparisons of Accident Rates for Categories of MUTCD Conformance

The six comparisons used to examine the differences in accident rates corresponding with the conformance of devices to MUTCD standards are shown in Table 4-4. The first three comparisons, 1-B, 2-B, and 3-B compare the two different levels of MUTCD conformance, yes and no, for the different levels of device type that met FHWA criteria.

Comparison 1-B, which investigated the difference in rates for passive devices meeting FHWA criteria, had a t-statistic of -1.00 and a corresponding confidence coefficient range of 0.60 to 0.70. This result does not strongly indicate a true difference, although there is some chance that those which conformed to standards had lower rates. Comparison 2-B, which made the comparison for gates does not strongly suggest that there is a difference due to conformance to MUTCD standards. A stronger indication, 0.80 to 0.90, is given by comparison 3-B, which suggests that flashing light signals that did not meet MUTCD standards had a lower accident rate than flashing light signals that meet the MUTCD standards. Comparison 6-B compared the two levels of conformance for all crossings that met FHWA criteria. The 0.10 to 0.20 confidence coefficients range indicates that there was no difference in the accident rates. However, it should be noted that for the passive and gate levels, the MUTCD-yes condition had a lower rate; whereas, in the flashing light signal case, those crossings not meeting MUTCD standards had the lower rate. Comparison 6-B combined these cases, which tend to cancel each other out, and the result was the low confidence range. These results indicate an interaction effect between flashing light signals and the conformance to MUTCD standards.

An interaction effect can also be seen for passive devices. Comparison 1-B indicated that if there was actually a difference, the MUTCD-yes condition would have a lower rate. However, when the passive crossings did not meet FHWA criteria, the opposite was true. However, since neither comparison strongly suggests a true difference, the rates may really not be different for meeting or not meeting MUTCD standards. This is what comparison 5-B indicated. But the fact that in one case the crossings meeting MUTCD standards had a lower rate and in one case they had a higher rate tend to cancel the effect when all passive crossings were compared, resulting in the 0.30 to 0.40 confidence coefficient range.

None of the comparisons performed indicated that the data strongly support a conclusion that meeting or not meeting MUTCD standards had an effect on accident rates. The strongest indication was in the case of crossings with flashing lights that met FHWA criteria. In this case, the crossings not meeting MUTCD standards appeared to have a lower rate than the ones that did. There were probably some interaction effects involving conformance to MUTCD standards and device type. There also may have been some interaction between device suitability and conformance to standards in the passive device cases. However, if conformance to MUTCD standards has no effect, which is entirely possible, there may actually be no interaction effect.

The results found in this study gave some indication that crossings that met MUTCD requirements had a lower rate than crossings which did not. This was true for passive signs and gates, although the results did not strongly support this conclusion. Indeed, the strongest indication of an effect due to conformance indicated that flashing light signals which did not conform to MUTCD standards were more effective than systems which did conform.

It was expected that warning devices not in conformance with standards would have a higher rate than those which did conform. The fact that there were no strong indications of this may be attributable to the way in which conformance was classified. Certain types of non-conformance may have a more significant impact on effectiveness than others. In this study, any type of non-conformance resulted in a classification of not conforming to standards. Perhaps a more detailed analysis which examined different types of non-conformance would reveal more information on the effects of non-conformance on accident rates.

The need for more detailed information on this factor is underscored by the result which indicates that a large majority of warning systems are not in compliance with the standards. The standards represent good engineering practice, and efforts should be made to bring grade crossing warning systems into compliance. Information on which types of non-conformance affect safety most would aid in prioritizing improvements so maximum safety benefits can be realized.

The indication that flashing light signals complying with MUTCD standards had a higher rate than flashing light signals that did not conform suggest that, under certain circumstances, even flashing light signals which conform to standards do not meet the needs of motorists. Perhaps crossings with flashing light signals which were overly hazardous were given special attention in terms of compliance to standards. If this was the case, the indication is that the flashing light signals were unable to compensate for the extra hazard of the crossing, whatever the source.

The data do not strongly suggest that the safety problems at grade crossings are attributable to non-conformance, although there are some indications of an effect. The high degree of non-conformance which was found indicates the need for more detailed research into this aspect of grade crossing safety.

Comparisons of Accident Rates for Categories of Device Suitability

The effect of meeting FHWA guidelines, which was utilized to determine device suitability, was tested by the comparisons listed in Table 4-5 (p. 90). Comparisons 1-C and 2-C tested the difference between crossings that met and did not meet FHWA guidelines which have the same devices. The three remaining comparisons examined the differences in accident rates of crossings with one type of warning device which did not meet the guidelines to crossings with higher level devices which did meet the guidelines. For example, passive crossings that did not meet FHWA guidelines were compared to flashing light signal crossings that did in comparison 3-C.

The results of the first comparison, 1-C indicate that passive crossings not meeting FHWA guidelines had lower rates than passive crossings that did. A similar result was discovered for flashing light signals in comparison 2-C. The crossings which did not meet FHWA guidelines had lower rates than the flashing light signal crossings which did meet the guidelines.

The comparison of flashing light signals that met FHWA guidelines to passive devices which did not, 3-C, resulted in a confidence range of 80 to 90 that the passive devices had lower accident rates. Low confidence coefficients were found for the last two comparisons, 4-C and 5-C. Apparently, there is little difference between the combined average rates for gates and flashers meeting the guidelines when compared to passive crossings not meeting the FHWA guidelines. Similarly, no difference was found between gates which met the criteria and flashing light signals which did not.

The meaning of the results of the comparisons that tested device suitability is not obvious. It was expected that for a given device type, the observations with devices which met FHWA guidelines would have lower accident rates than those which did not. This was not found to be the case. Locations with passive signs which apparently did not warrant higher level devices had higher rates than those passively signed crossings which were judged in need of higher level devices.

The same situation was found for observations with flashing lights. In both cases, there were strong indications that the crossings whose devices had been determined to be unsuitable had lower rates than the observations with apparently suitable devices.

It was also expected that locations judged to be in need of a higher level device would have a higher accident rate than crossings with the higher level devices that did meet the guidelines. Again, this was not the case. There was either no difference between the rates, or the locations which were judged to be in need of higher level devices had lower rates.

The true explanation of these results is not obvious. There are several possible reasons for these phenomena. First, due to data limitations, the determination of device suitability may not have been valid. The FHWA criteria, as they were applied in this study, may not have accurately determined device suitability. If all the information necessary for applying all the factors had been available, different results may have been obtained. However, it should be noted that the additional information would have tended to classify more crossings as needing higher level devices since the crossings which were determined to need higher devices did not meet those guidelines which could be applied. Certainly, there was no evidence that those crossings with warning devices which did not meet the criteria had higher rates than those observations with suitable devices. Perhaps some observations which should have been classified as needing higher devices tended to increase the average accident rate of the observation with suitable devices and obscure the differences between the two categories.

However, if the crossings classified as needing higher level devices were actually more hazardous, it would be likely that this would be reflected by the analysis. Perhaps the criteria themselves do not accurately identify hazardous crossings. The results found here imply that crossings with the characteristics which are thought to indicate hazard actually have lower accident rates than the crossings without those characteristics. Perhaps drivers recognize the potential hazard of these crossings by these characteristics and exercise more caution than at other grade crossings. The greater care taken in negotiating the crossing may compensate for the increased hazard.

The possibility also exists that the guidelines separate crossings with a high accident potential from other crossings. The potential hazard may not have been reflected by the accident history during the time period studied. Since accidents are rare events, accident histories may not accurately reflect the true hazard of a crossing. Indeed, this is at least part of the reason that factors other than accident experience are included in the guidelines.

Another explanation is that hazard is associated not only with accident frequence, but with severity as well. Some factors, notably those involving speed and passenger train traffic, address the probability of severe consequences, since higher speeds usually result in greater injury. Thus, crossings which have the potential for high accident severity may indeed warrant higher level devices although the probability of an accident is not greater than at other locations.

Summary

Although different accident rates were expected for different categories of device type, suitability and conformance to standards, the results of this study do not indicate clear trends in all of the cases. Differences were found between the different warning device categories, but the influence of device suitability and conformance to standards were not clear.

In terms of warning device types, gates were found to be the most effective, as reflected by the accident rate, and passive devices were found to be least effective. However, under certain circumstances, there were indications that flashing light signals were no more effective than passive devices. Within each device category, there were variations in the accident rate; however, this variability was not explained by the categorization according to conformance to MUTCD standards or device suitability.

This analysis did not strongly suggest that the variability in accident rates was attributable to conformance or non-conformance of warning devices to MUTCD standards, although in some cases, there was an indication of an effect. However, individual types of non-conformance were not analyzed and certain areas of non-compliance may be more important than others. One clear result of the classification process was that most, about 84 percent, of the crossings analyzed had warning device systems which in one form or another did not comply with MUTCD standards.

Device suitability, as determined by application of FHWA guidelines, also did not seem to explain the variability in accident rates.

Locations which were determined to warrant higher level devices were expected to have higher accident rates, or, in other words, less effective warning devices than locations with suitable devices. However, the opposite result was found in some cases. Certainly, no consistent trend which related device suitability to conformance was found. These results suggest that the application of FHWA criteria in this analysis did not accurately assess device suitability.

CHAPTER 5

EXAMINATION OF THE CHARACTERISTICS OF HIGH AND LOW ACCIDENT RATE OBSERVATIONS

This chapter reports on the results of the analysis which compared the characteristics of crossings which were classified as having high accident rates to those which had low rates. Separate analyses were performed for crossings with passive devices, flashing light signals, gates, and for the sample as a whole. In each category, a high accident rate was defined as being at least one standard deviation greater than the mean accident rate in that category, and a low accident rate was defined as being at least one standard deviation less than the mean in that category. The characteristics examined were:

1. Device suitability;
2. Conformance to MUTCD standards;
3. Train speed;
4. Location--urban or rural;
5. Type of roadway--local or non-local;
6. Train volume; and
7. Highway traffic volume.

In each case, these same characteristics were examined for all the crossings in the category in question. For example, the conformance to MUTCD standards was compared for passive crossings with high and low rates and the conformance to the standards for all passive crossings was used as a reference.

Observations with Passive Devices

Seventeen crossings were identified as having high accident rates and 20 were identified as having a low rate in the passive category. Only 17 were classified as high because any high accident rate location which had no accidents during the study was deleted for the analysis. Characteristics of crossings with higher rates, crossings with low rates, and passive crossings as a whole were compared.

Device suitability. The percent of observations that did meet FHWA guidelines, which were used as a measure of device suitability, are shown in Figure 5-1. The percent of observations with high rates that did conform to the criteria is nearly identical to the percent of all passive observations. This value, 88 percent, is substantially more than the approximately 72 percent of observations with low rates that were determined to have met the criteria.

Conformance to MUTCD standards. Figure 5-2, shows the percent of observations in each category which did conform to MUTCD standards. Both high and low accident rate categories had a greater percentage of observations meeting the MUTCD standards than all passive observations had. The high accident rate crossings had the highest degree of conformance but only slightly higher than the low rate category. Most of the observations in any category did not conform.

Train speeds. Three comparisons were made concerning the train speed characteristic. A comparison was made on the distribution of train speeds based on speed ranges of less than 35 mph, 35 to 49 mph,

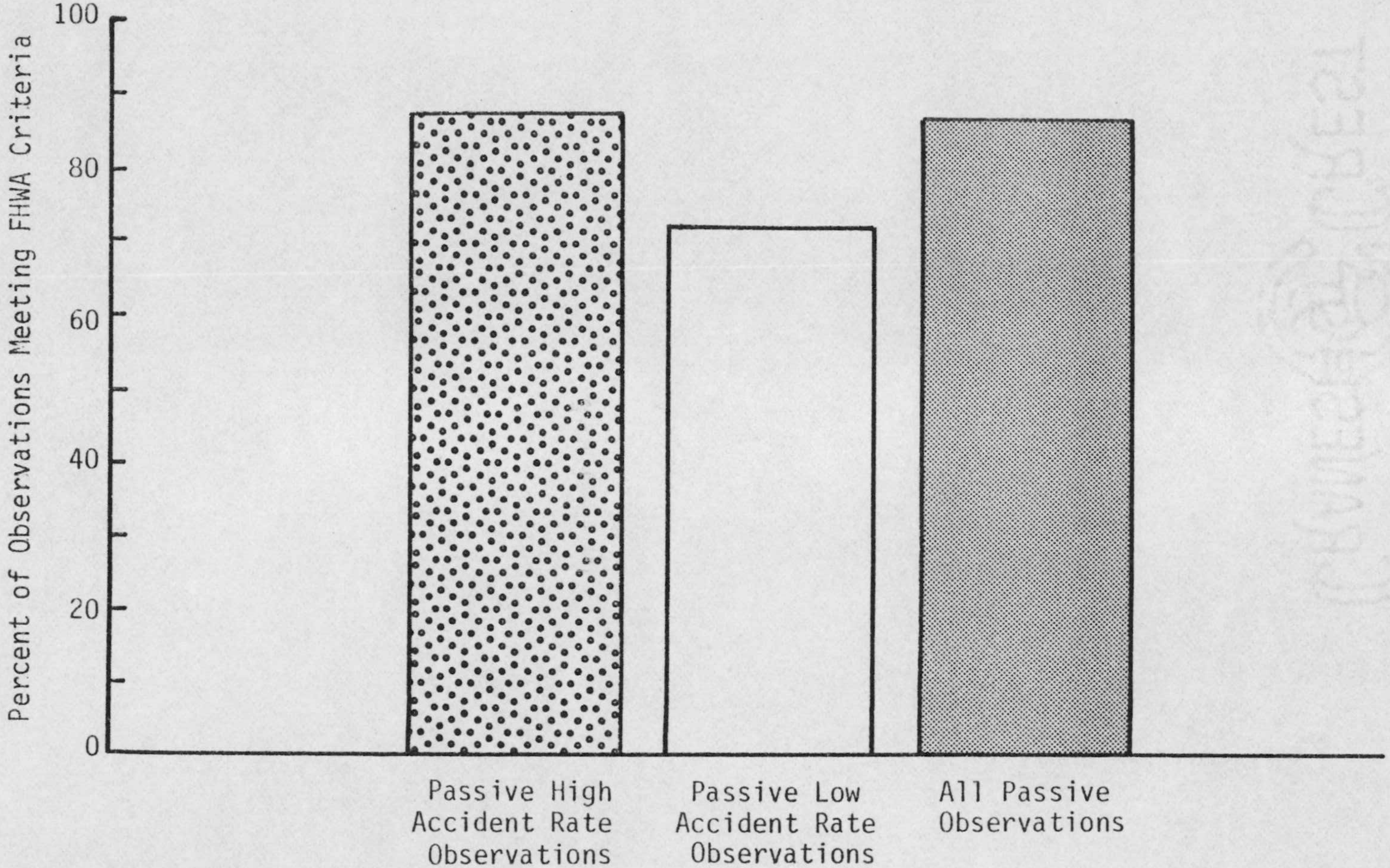

FIGURE 5-1

COMPARISON OF THE PERCENT OF OBSERVATIONS MEETING FHWA CRITERIA OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

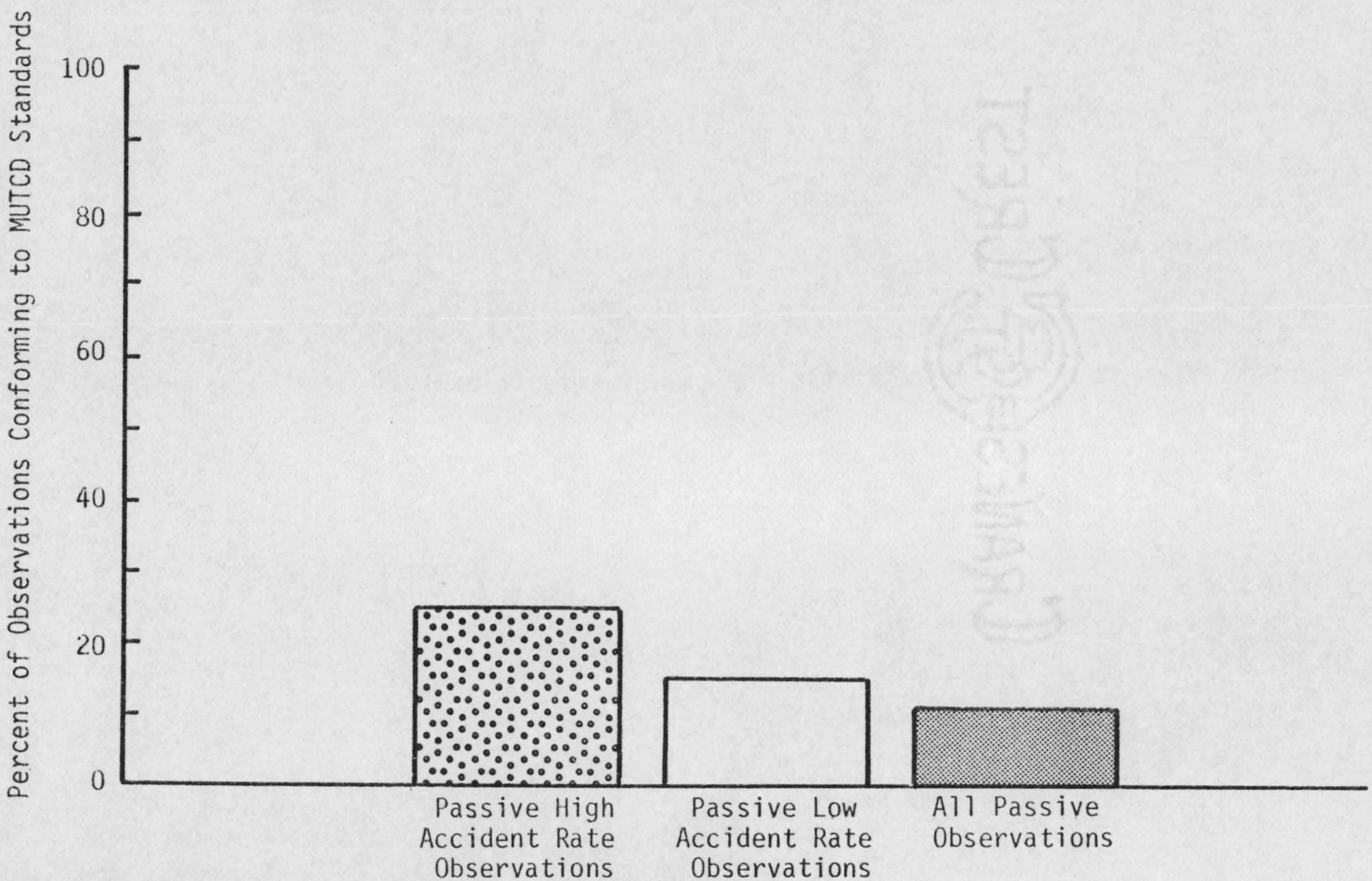

FIGURE 5-2

COMPARISON OF THE PERCENT OF OBSERVATIONS CONFORMING TO MUTCD STANDARDS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

50 to 59 mph, and 60 mph or greater. The percent of observations in urban areas which had train speeds greater than 35 mph and the percent of rural crossings which had train speeds in excess of 50 mph were also analyzed.

The train speed distribution is shown in Figure 5-3. The high rate observations generally have lower train speeds than the observations with low rates. The distribution of speeds for high rates is similar to the overall passive distribution with the exception of very high train speeds, greater than 60 mph. None of the high rate crossings had train speeds in that range; however, a substantial percentage, about 35 percent, of the observations with low rates had speeds in excess of 59 mph.

The crossings with low rates had lower percentages with low and medium speeds, less than 50 mph, than either the higher rate crossings or passive crossings overall. The observations with low rates had greater percentages in the high speed ranges, 50 mph or greater, than passive crossings as a whole.

Figure 5-4 shows the percent of urban crossings with train speeds greater than 35 mph. The high and low accident rate categories have substantially the same percentage, about 15 percent which is somewhat less than the percent of passive crossings as a whole, 22 percent. A large difference between the categories can be seen in Figure 5-5. The percent of rural low accident rate observations with train speeds greater than 50 mph is substantially more than either the percent of passive crossings as a whole or those with high rates. The high rate

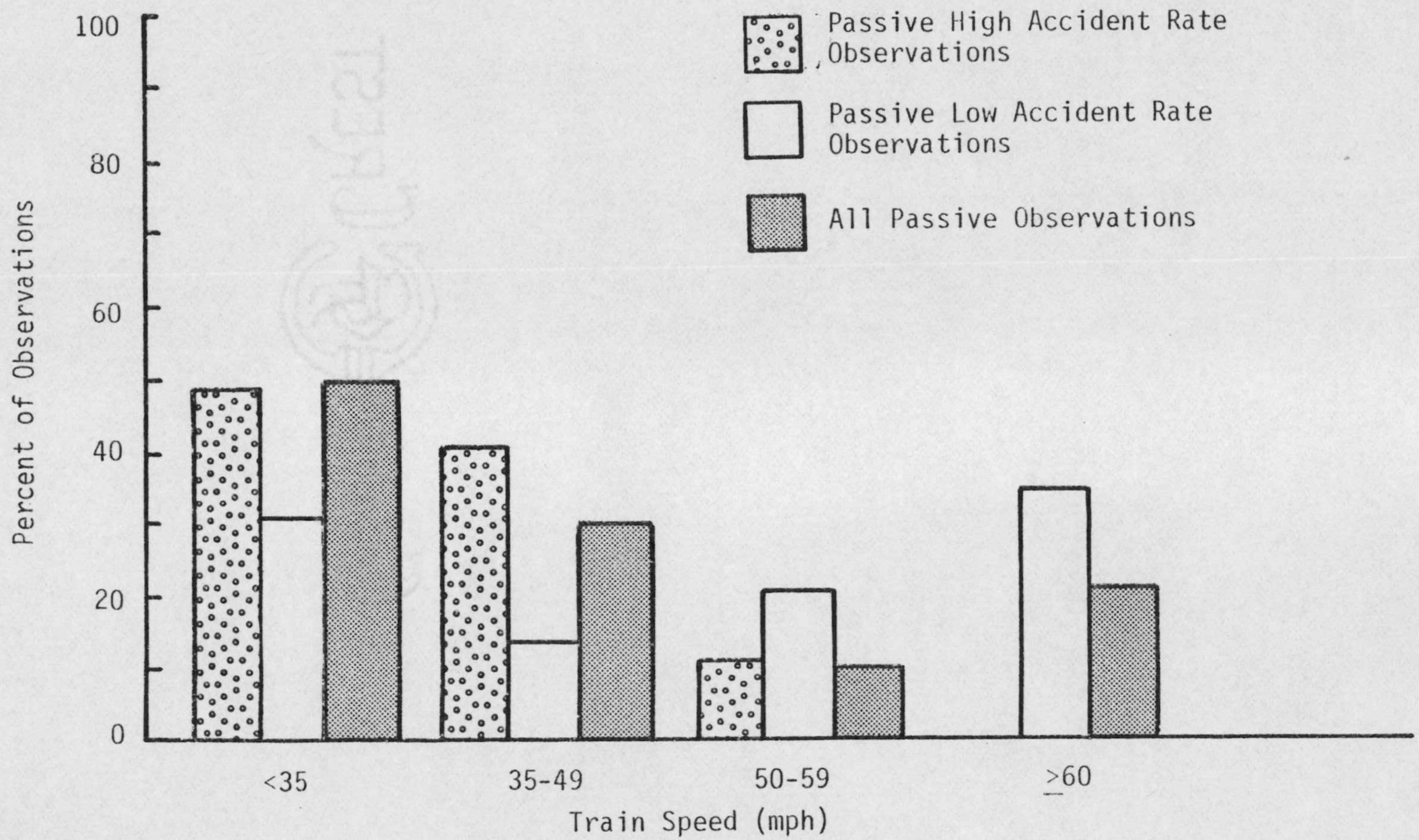

FIGURE 5-3

TRAIN SPEED DISTRIBUTIONS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

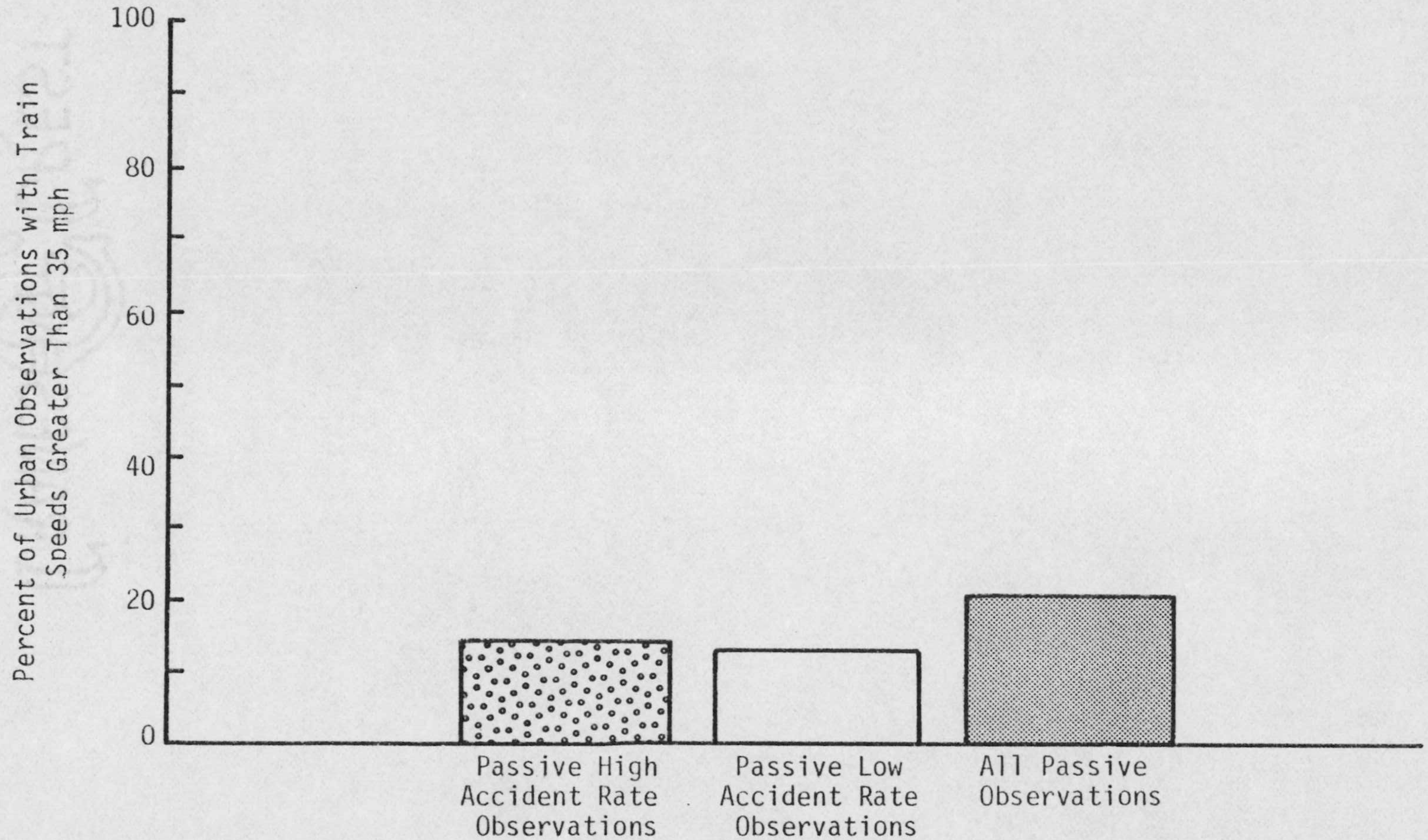

FIGURE 5-4

COMPARISON OF TRAIN SPEED AT URBAN LOCATIONS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

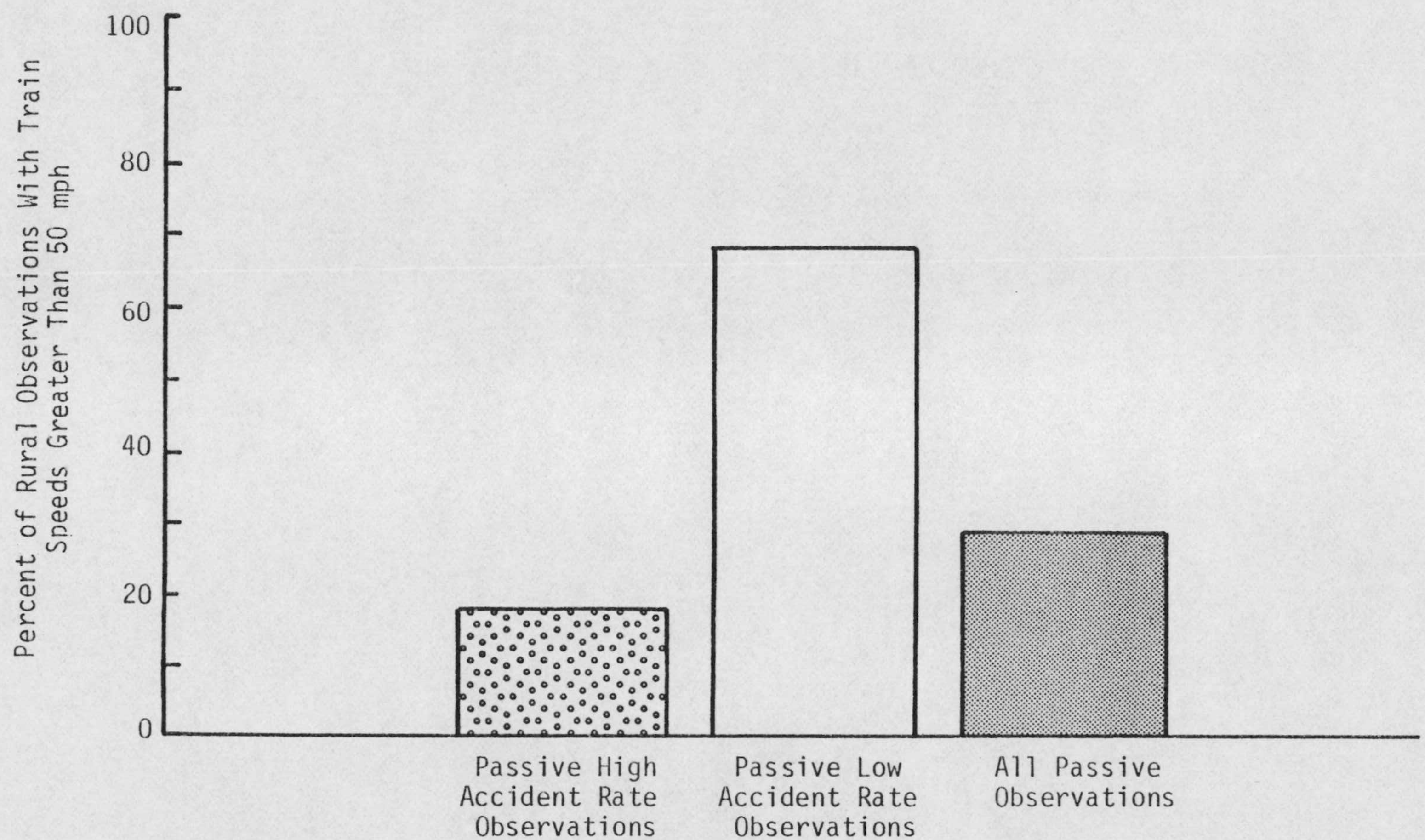

FIGURE 5-5

COMPARISON OF TRAIN SPEED AT RURAL LOCATIONS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

observations had a lower percentage than passive crossings overall, 27 percent compared to 18 percent.

Crossing location. The percent of urban and rural crossings in each category is shown in Figure 5-6. The percent of urban and rural crossings for the low accident rate crossings and the passive crossings overall are very similar. About 35 percent of the high rate observations were located in urban areas, which is somewhat more than the percent of passive crossings overall.

Highway type. The percent of crossings in each category which were located on local roads are shown in Figure 5-7. The percent of crossings with low rates is nearly the same as the percent of all passive crossings. The percent of crossings with high rates on local roads was somewhat less, about 15 percent, than the percent of the crossings with low rates.

Train volume. The train volume distribution for each category is shown in Figure 5-8. The difference between high and low accident rate observation is substantial. Almost 90 percent of high rate observations have train volumes of six or less per day. In contrast, only 7 percent of observations with low rates had train volumes of six or less per day. Almost 85 percent of all passive crossings had train volumes of 10 or less per day. Sixty-two percent of the low accident rate crossings had volumes of 11 or more per day. In general, the high rate observations had lower volumes than passive crossings as a whole, and the low accident rate crossings had higher train volumes than passive observations overall.

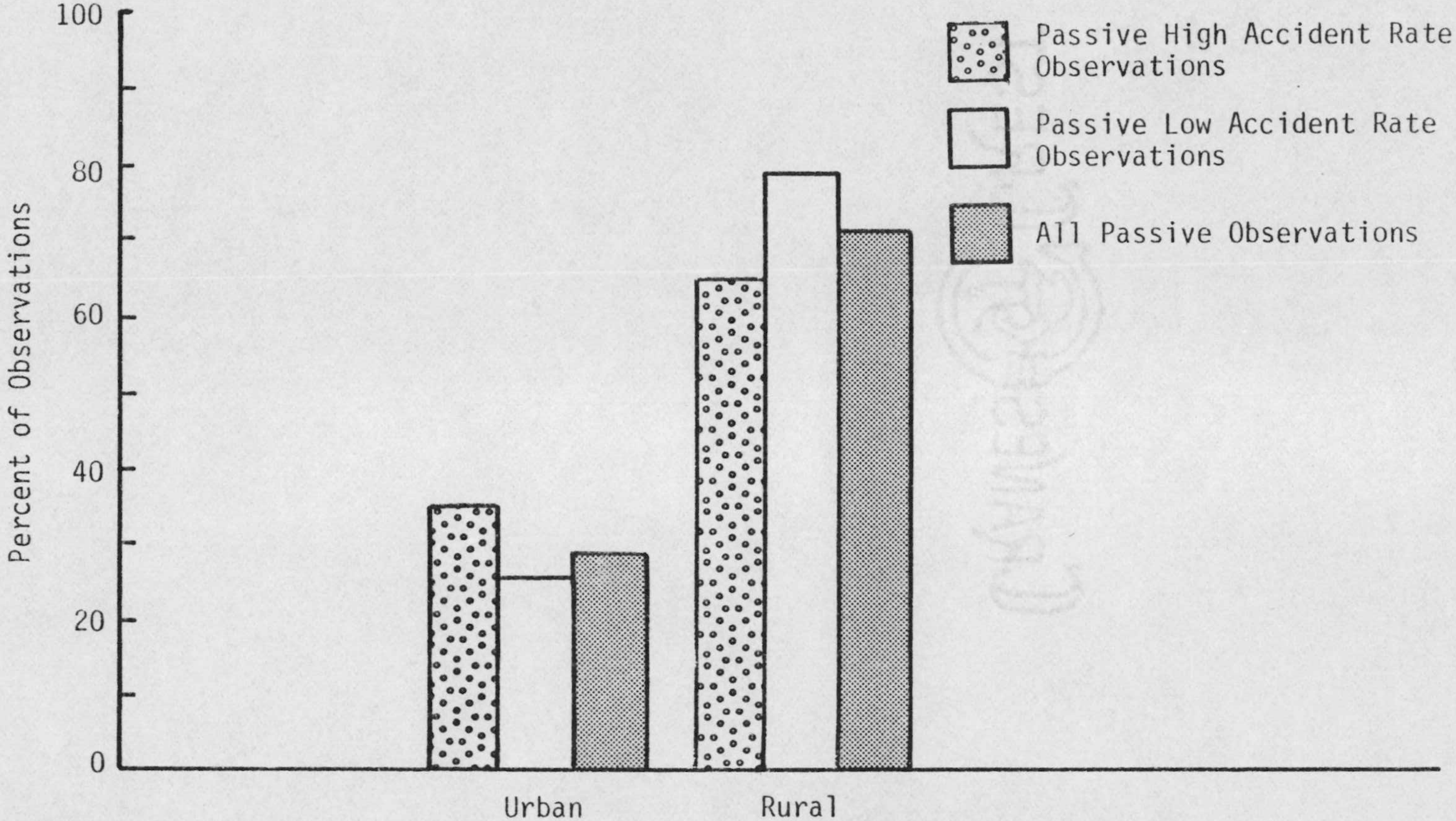

FIGURE 5-6

COMPARISON OF CROSSING LOCATION OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

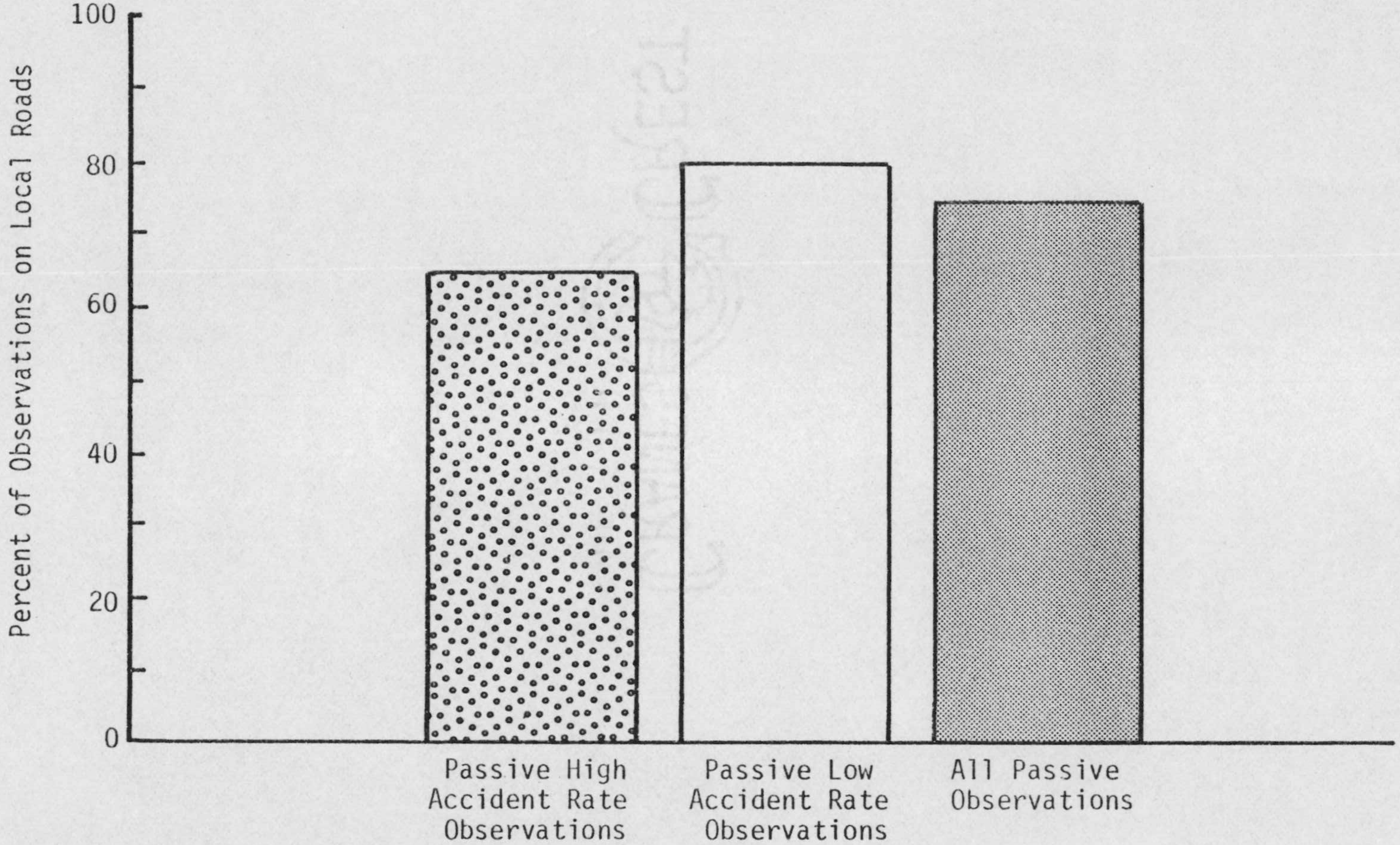

FIGURE 5-7

COMPARISON OF THE PERCENT OF OBSERVATIONS ON LOCAL ROADS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

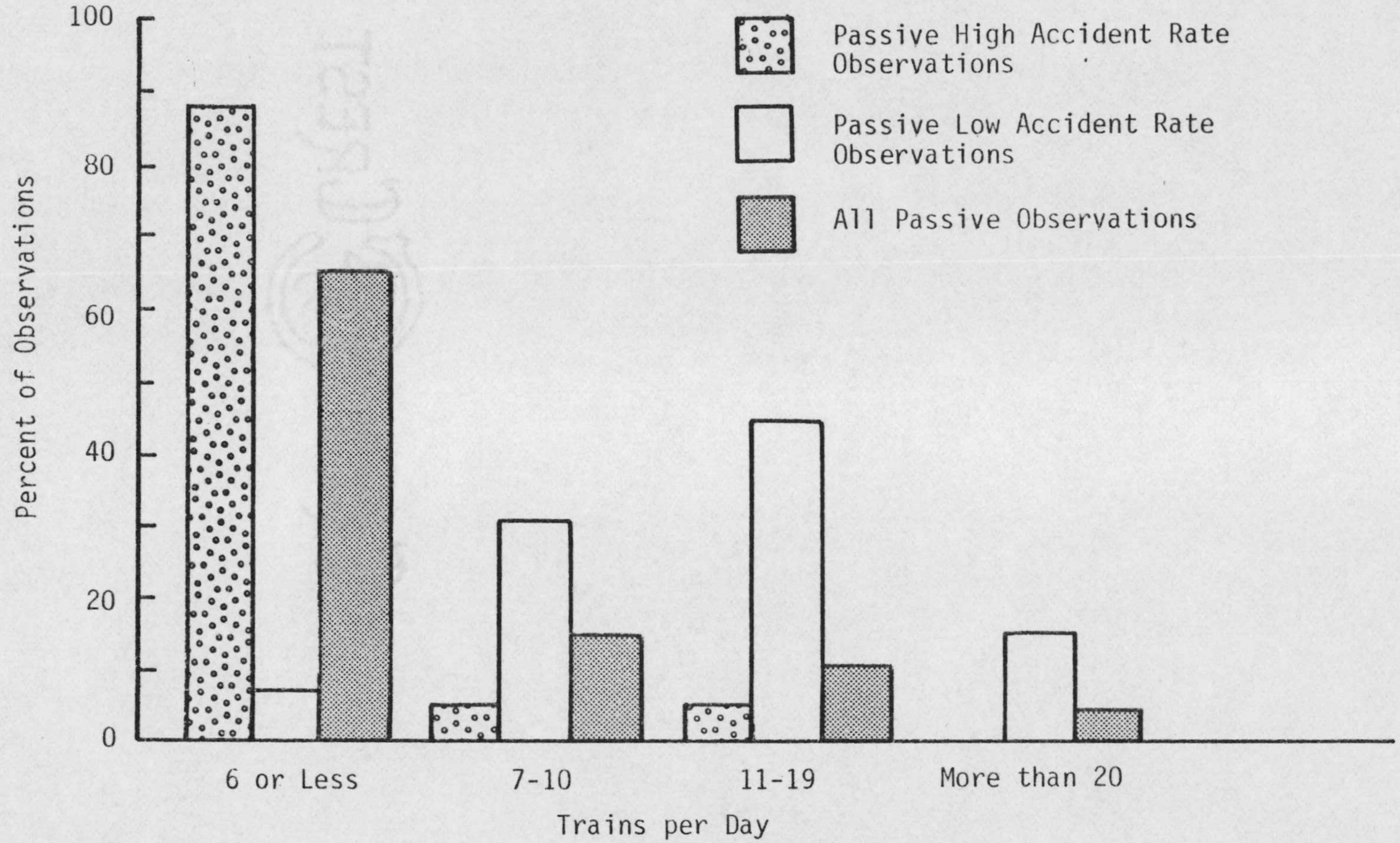

FIGURE 5-8

TRAIN VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

Highway traffic volume. As can be seen by examination of Figure 5-9, the majority of passive crossings, regardless of category, had low traffic volumes. The high accident rate observations do have higher percentages, compared to either low rate observations or all passive crossings, in the 1,000 to 2,999 ADT and 5,000 to 10,000 ADT ranges.

Observations with Flashing Light Signals

In the flashing light signal category, ten observations were identified as having high accident rates and nine were identified as having low rates. The total number of observations classified as having flashing light signals was 64.

Device suitability. A comparison of the degree of device suitability of flashing light signals is shown in Figure 5-10. The percent of observations with suitable devices is nearly the same for high rates and flashing light signals overall. Ninety percent of the locations with high rates and about 88 percent of all flashing light signals met FHWA criteria.

Conformance to MUTCD standards. Figure 5-11 reflects the percentages of crossings that met MUTCD requirements. None of the warning systems at the low accident rate locations conformed to the standards. Thirty percent of the systems at high rate locations were in conformance which was more than twice that of flashing light signals overall, 12.5 percent.

Train speeds. Examination of Figure 5-12 reveals that 90 percent of the train speeds at high accident rate locations with flashing light

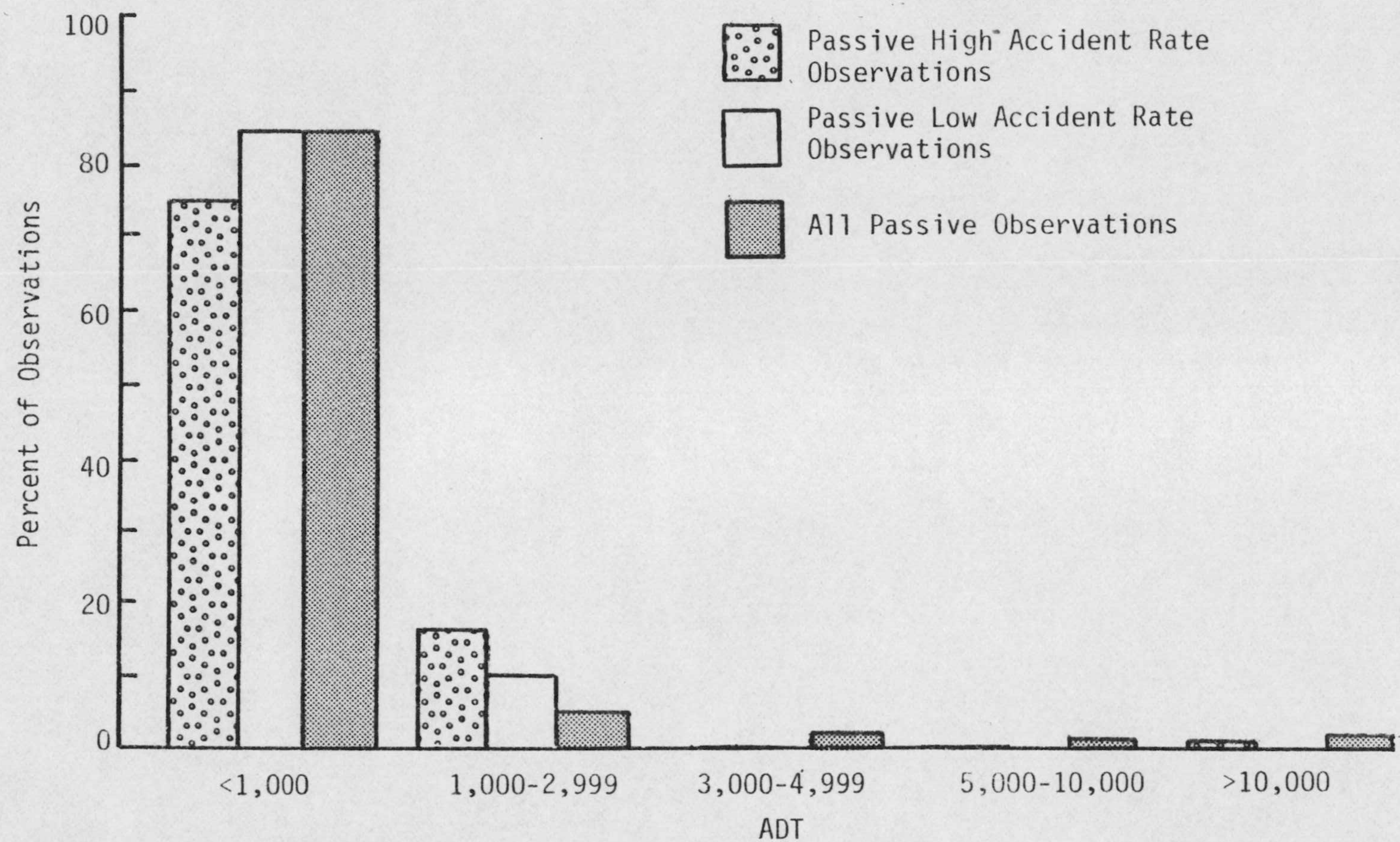

FIGURE 5-9

HIGHWAY VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES OF PASSIVE OBSERVATIONS

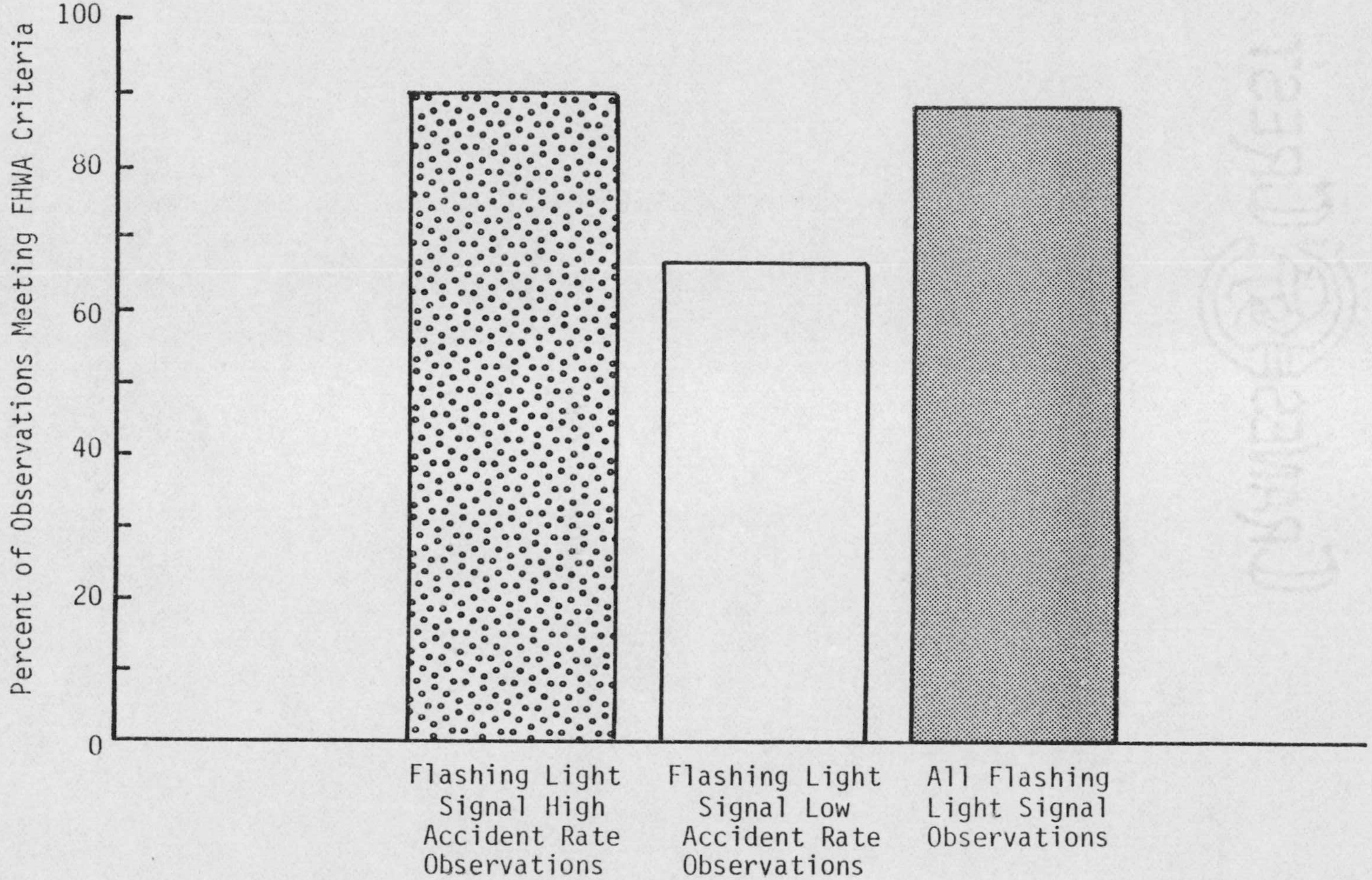

FIGURE 5-10

COMPARISON OF THE PERCENT OF OBSERVATIONS MEETING FHWA CRITERIA OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

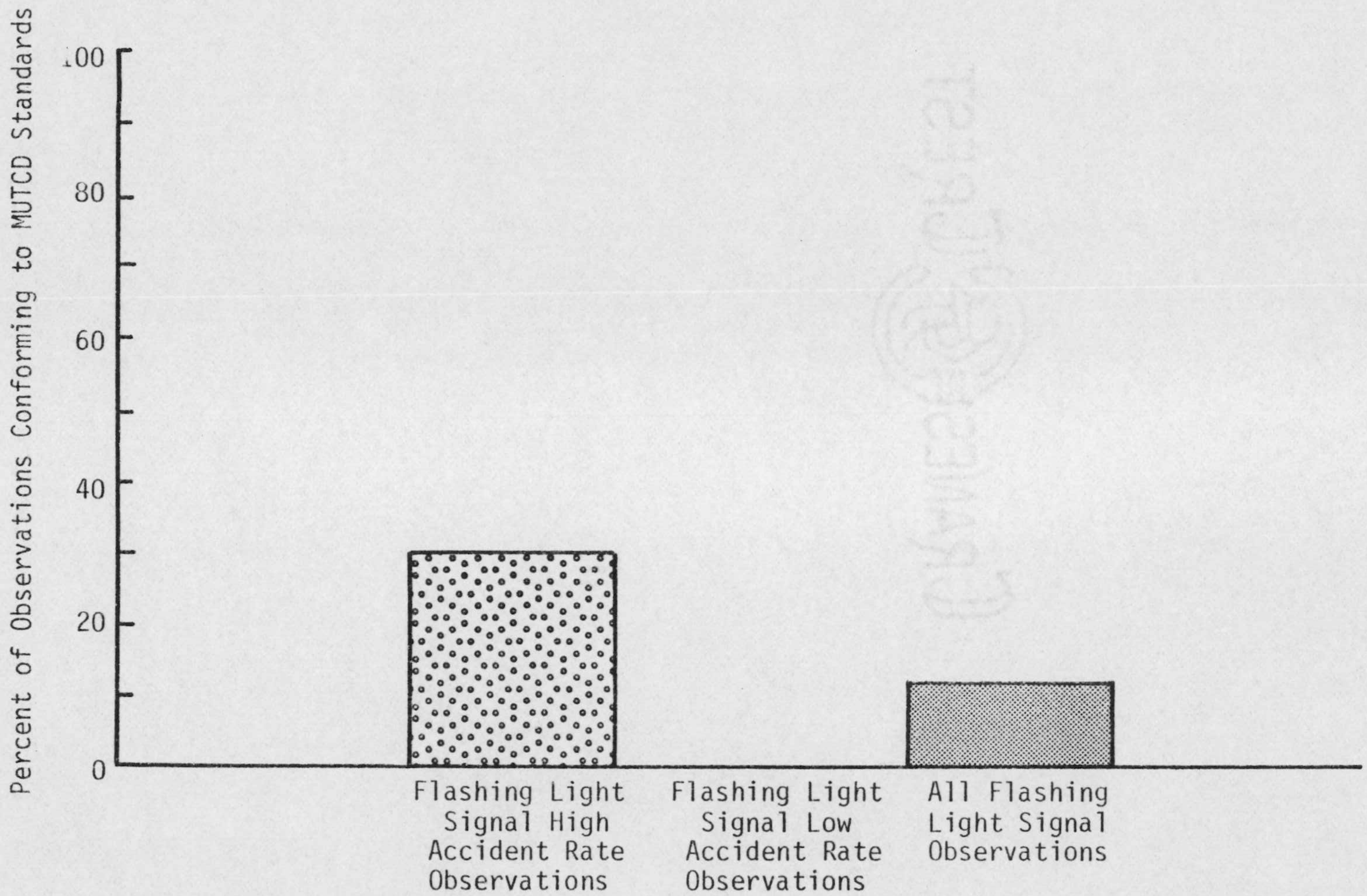

FIGURE 5-11

COMPARISON OF THE PERCENT OF OBSERVATIONS CONFORMING TO MUTCD STANDARDS OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

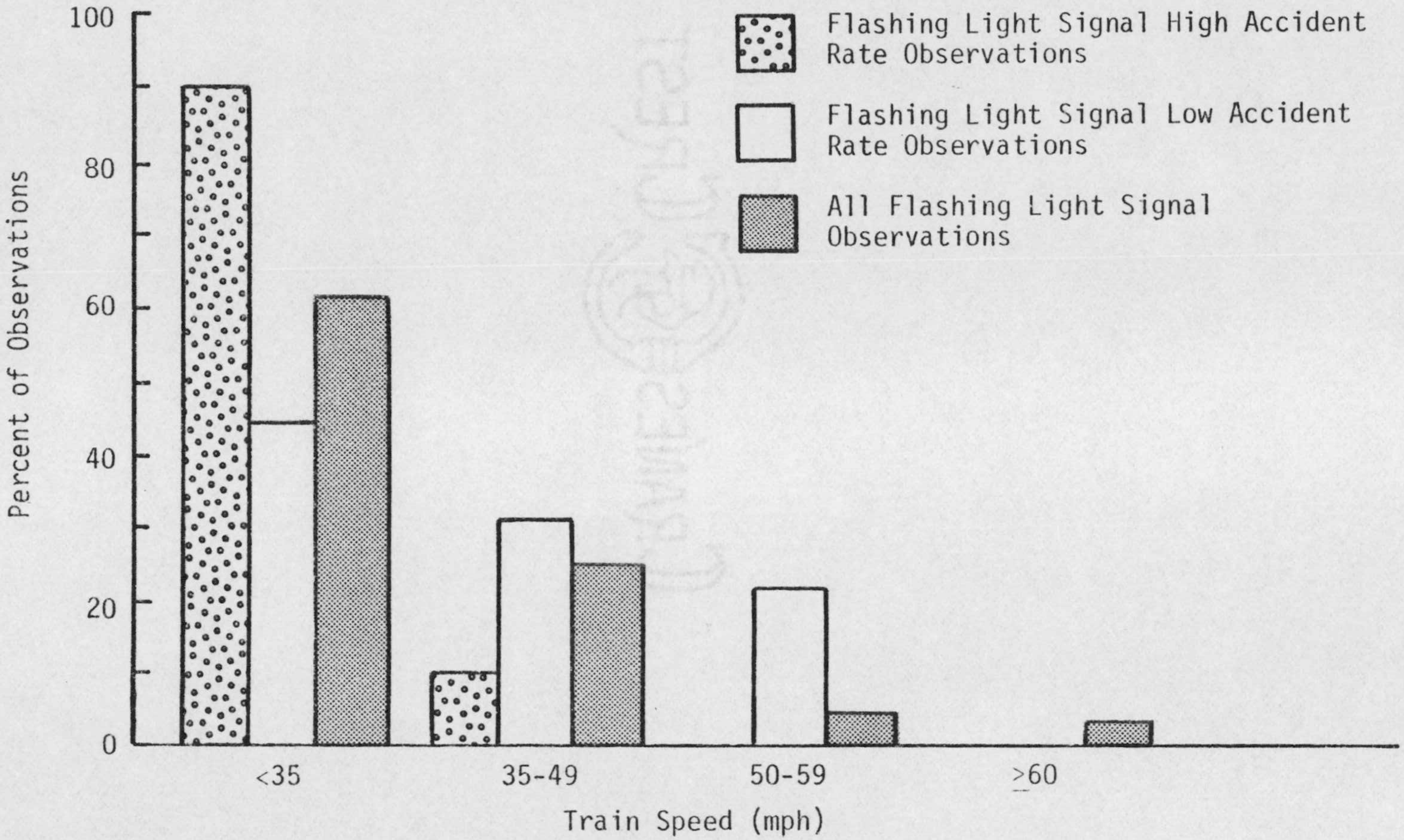

FIGURE 5-12

TRAIN SPEED DISTRIBUTIONS OF SELECTED CATEGORIES
OF FLASHING LIGHT SIGNAL OBSERVATIONS

signals were less than 35 mph, and all the high rate observations had train speeds less than 50 mph. On the other hand, the majority, 55 percent of locations with low rates had train speeds from 35 mph to 59 mph. Neither the high nor the low categories had any observations with train speeds in excess of 60 mph, although almost 5 percent of all observations with flashing light signals did. In general, most high accident rate crossings had low train speeds, less than 35 mph, whereas the low accident rate crossings tended to have higher train speeds. Both differed from the distribution of speeds for observations with flashing light signals as a whole.

Figure 5-13 shows the percentage of urban crossings with flashing light signals that had train speeds greater than 35 mph. None of the high rate observations in urban locations had speeds in excess of 35 mph. However, 20 percent of the low accident rate observations and 13 percent of all urban locations with flashing light signals did.

The same trend is evident in Figure 5-14. Similarly, none of the rural high accident locations had speeds in excess of 50 mph, whereas half of the low accident rate locations did. About 23 percent of all rural locations had train speeds greater than 50 mph.

In both cases, rural and urban, the low accident rate locations tended to have higher train speeds than the higher accident rate locations. Flashing light signal locations as a whole had higher train speeds than the high rate locations but lower speeds than the low rate locations.

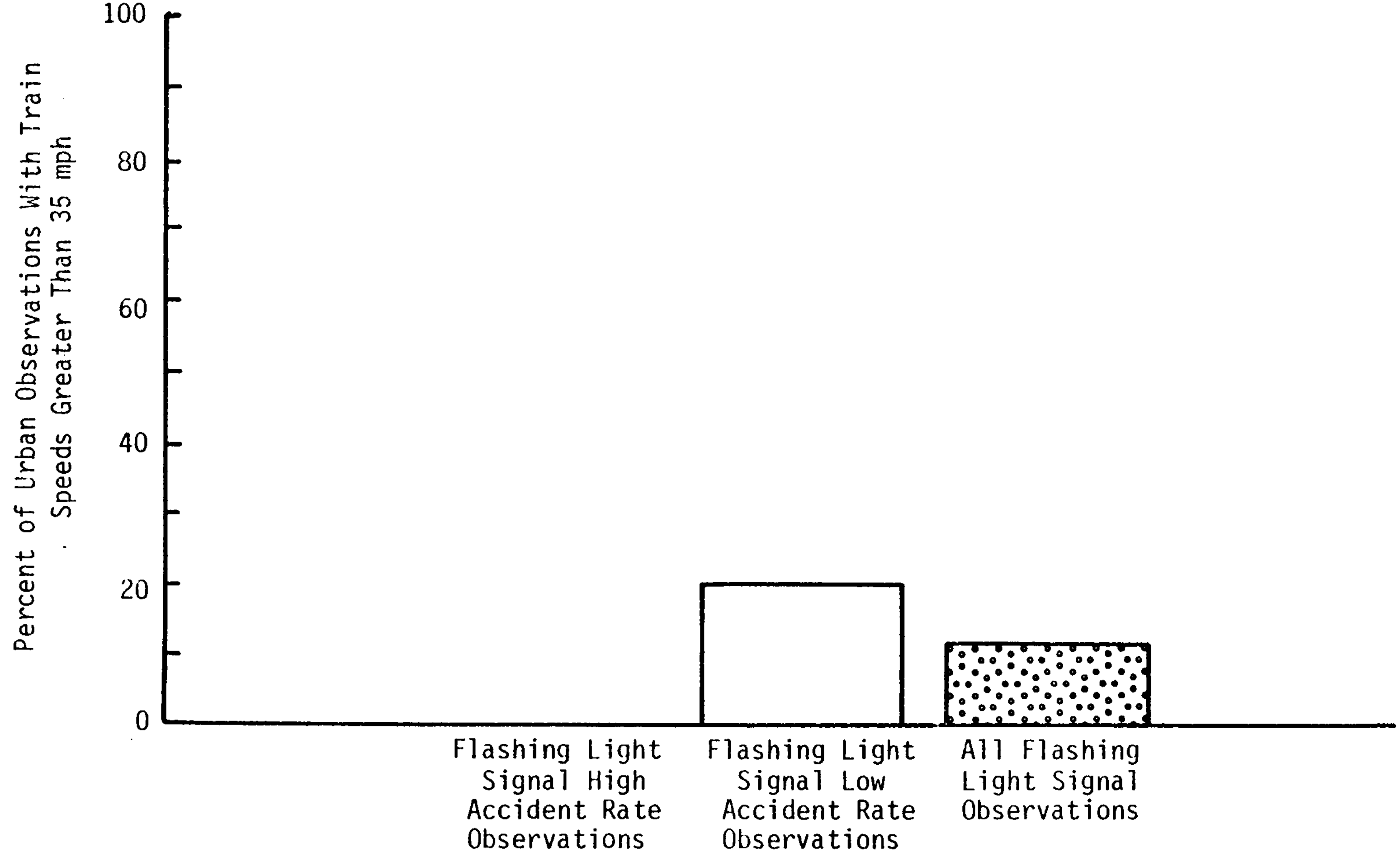

FIGURE 5-13

COMPARISON OF TRAIN SPEED AT URBAN LOCATIONS OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

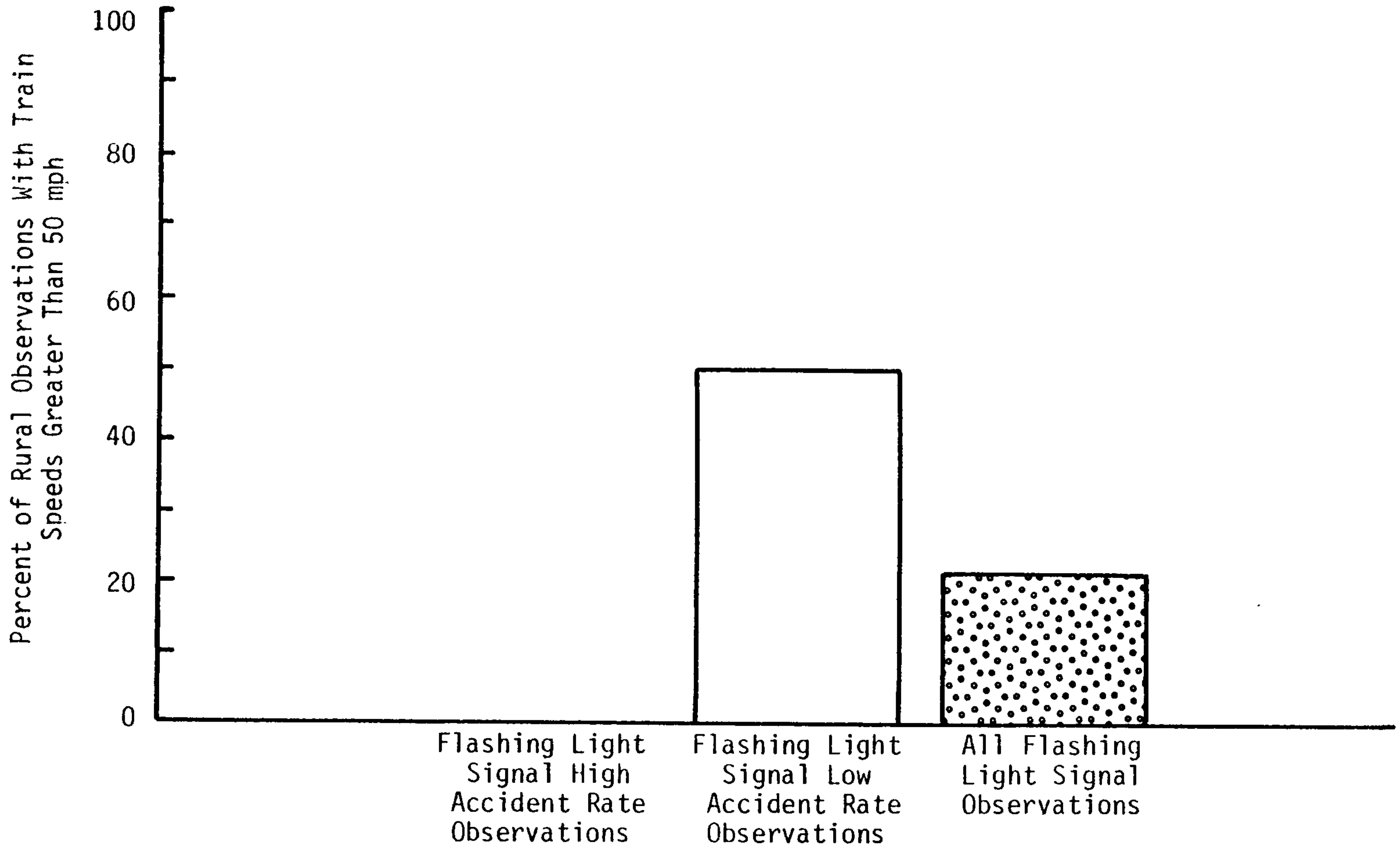

FIGURE 5-14

COMPARISON OF TRAIN SPEED AT RURAL LOCATIONS OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

Crossing location. The percent of observations with flashing light signals in urban or rural areas is shown in Figure 5-15. The high accident rate locations had somewhat more urban crossings than either the low rate observations or flashing light signal crossings as a whole. Seventy percent of the high rate locations were in urban areas; about 60 percent of all flashing light signal crossings and about 56 percent of the low accident rate observations were in urban areas.

Highway type. Figure 5-16 shows the percentage of crossings located on local roads for each category. The percent of high accident crossings on local roads, 10 percent, is considerably less than flashing light signal crossings overall. The percent of low rate crossings on local roads, 44 percent, was slightly higher than the overall percent of about 37 percent.

Train volume. The difference in train volumes between high and low accident rate crossings is shown in Figure 5-17. All of the observations with high rates had train volumes of less than six per day. In contrast, 44 percent of the low accident observations had train volumes of 20 or greater and all of the observations in that category had volumes greater than 10 per day. Both these distributions were different than the distribution for flashing light signals as a whole. Fifty-six percent had train volumes of less than six per day. The remaining 44 percent were nearly evenly distributed over the other three ranges of 7 to 10, 11 to 19, and more than 30 trains per day.

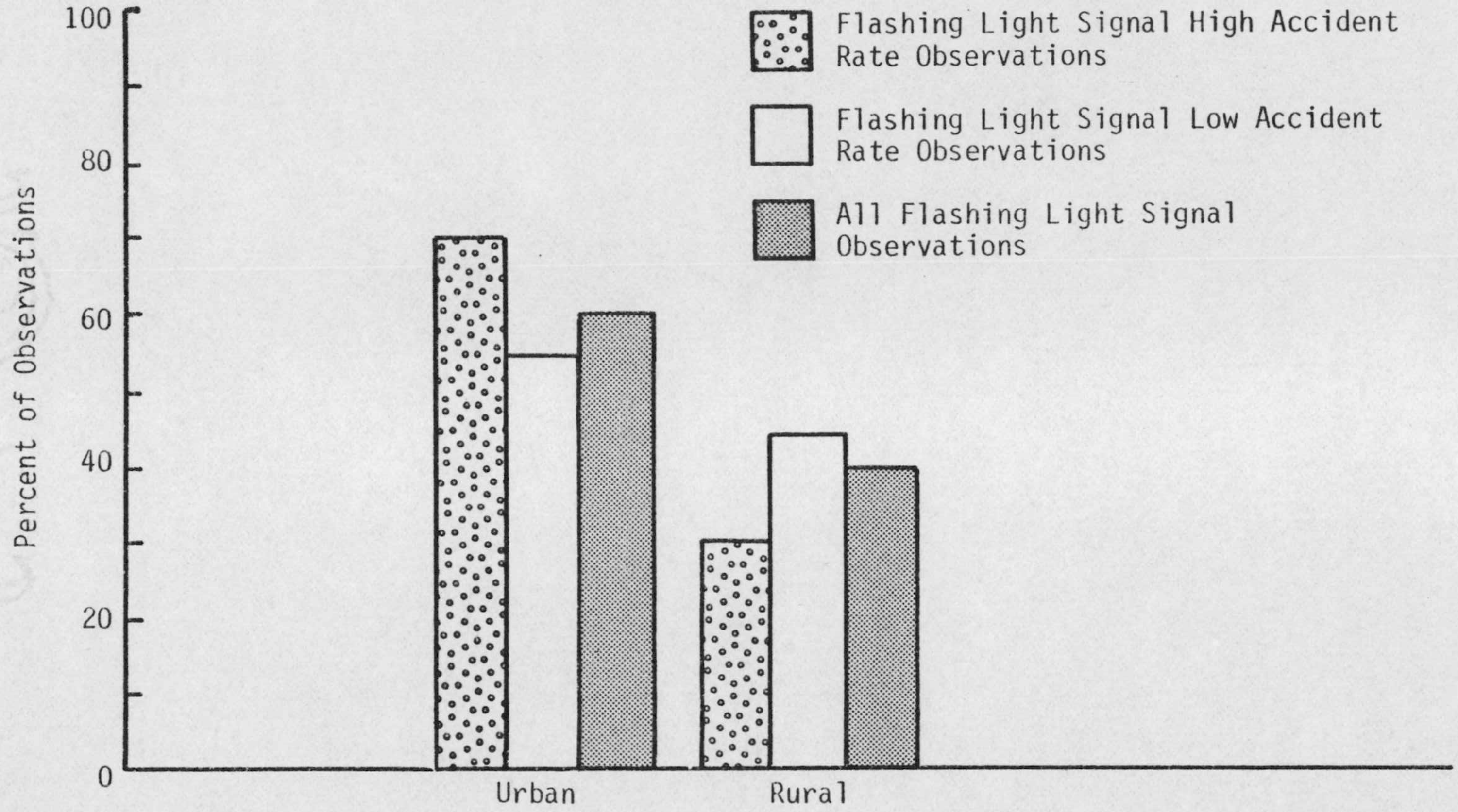

FIGURE 5-15

COMPARISON OF CROSSING LOCATION OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

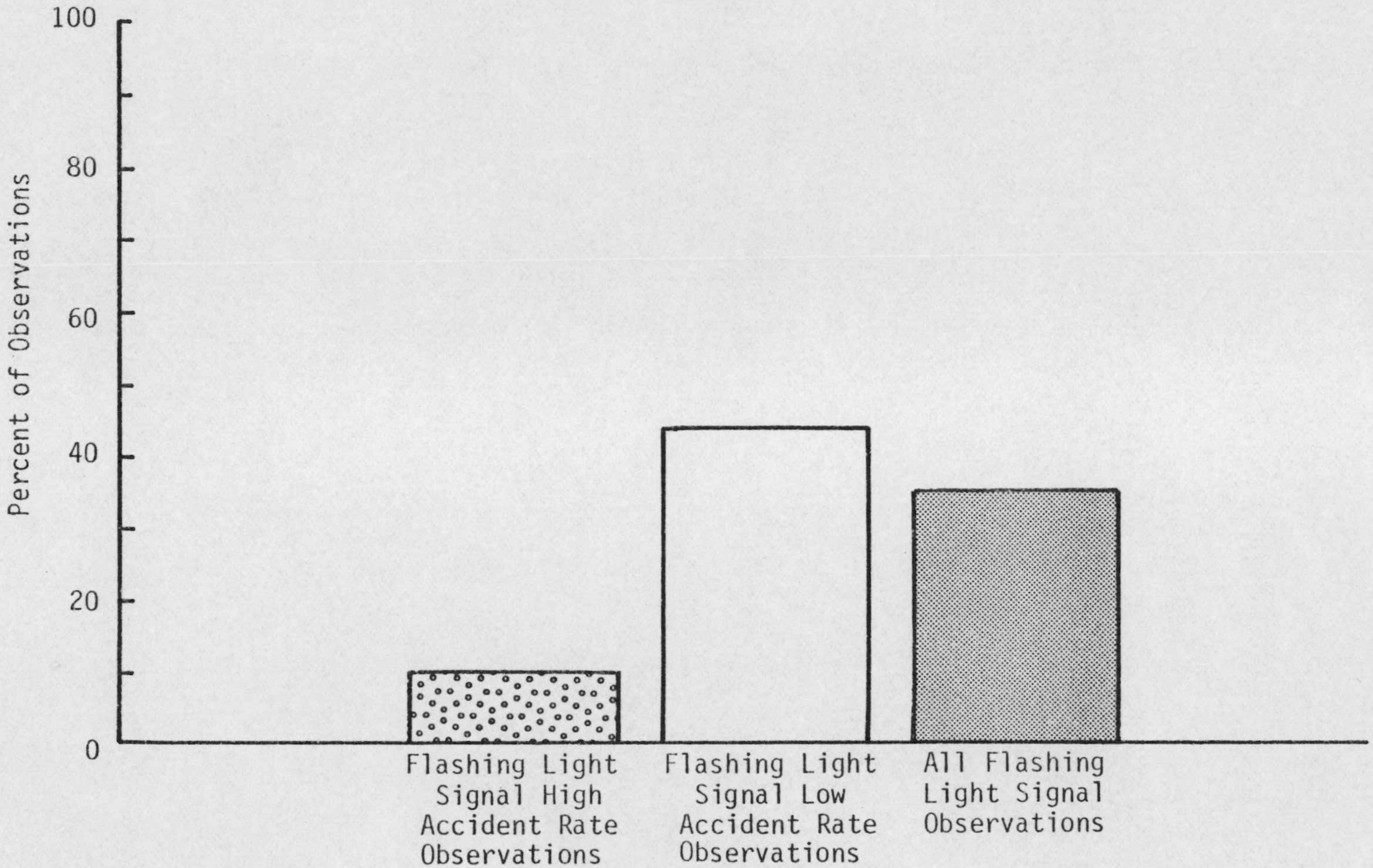

FIGURE 5-16

COMPARISON OF THE PERCENT OF OBSERVATIONS ON LOCAL ROADS OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

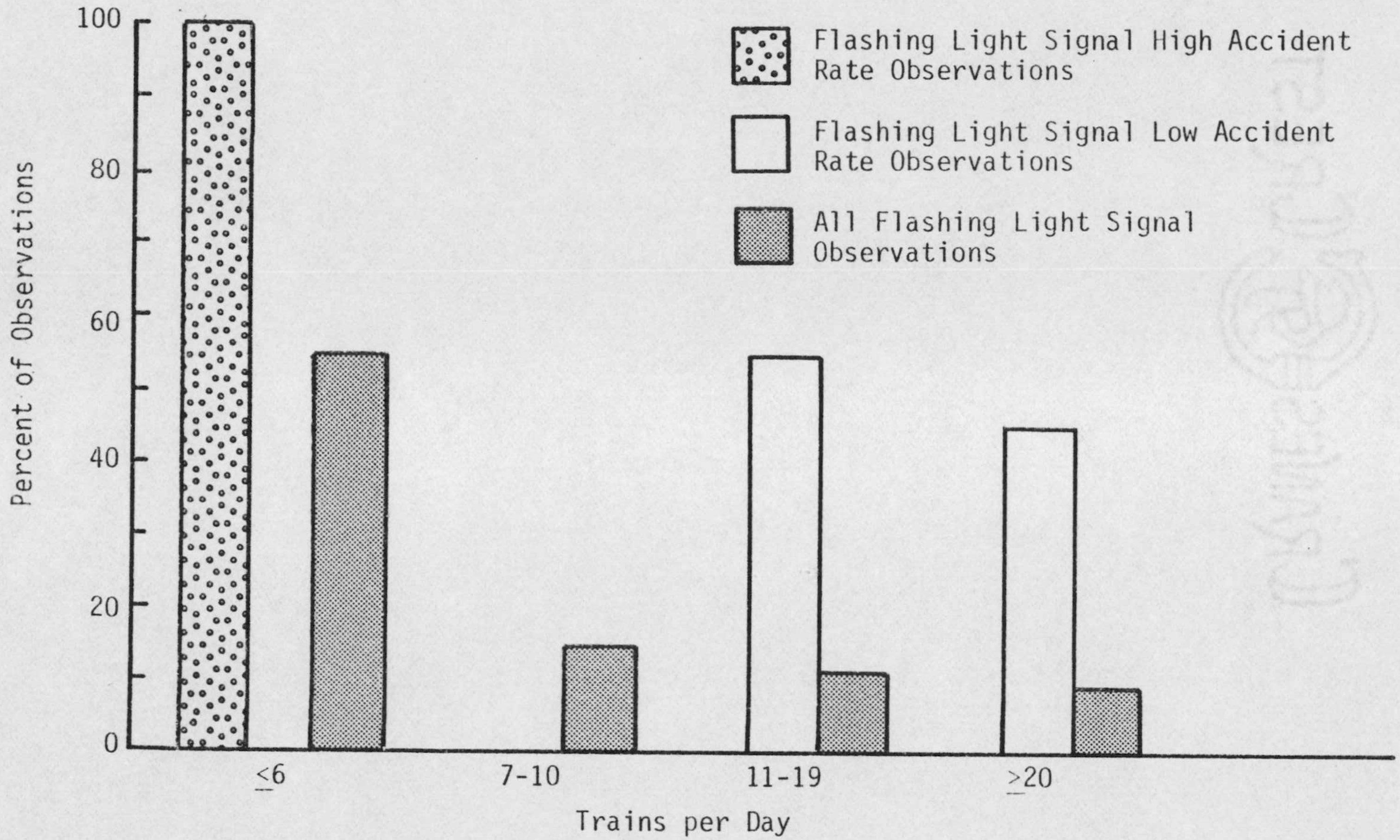

FIGURE 5-17

TRAIN VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES OF FLASHING LIGHT SIGNAL OBSERVATIONS

Highway traffic volume. The distribution of ADT's for each category of flashing light signal crossings is shown in Figure 5-18. The high rate locations tended to have higher traffic volumes than either the flashing light signals as a whole or the observations with low rates. The low accident rate crossings had somewhat more crossings with ADT's or less than 5,000 than the flashing light signals did overall, 89 percent compared to 72 percent. All the categories have similar values for the ADT range of 5,000 to 9,999. Forty percent of the higher accident rate observations had ADT's of 10,000 or greater; however, none of the low accident rate locations had crossings in this range and only 14 percent of all observations with flashing light signals had ADT's in that range.

Observations with Gates

Both the high accident rate and low accident rate categories had four observations. None of the observations in the high rate category were eliminated because they had no accidents. The low number of observations in the high and low rate categories was expected since there were only 23 observations with gates in the sample used for the analysis. No comparison was made on device suitability since all gate installations were considered to meet FHWA guidelines.

Conformance to MUTCD standards. As can be seen in Figure 5-19, none of the high accident rate observations conformed to MUTCD standards. Twenty-five percent of the observations with low rates did, which is nearly the same percentage that all gate crossings displayed.

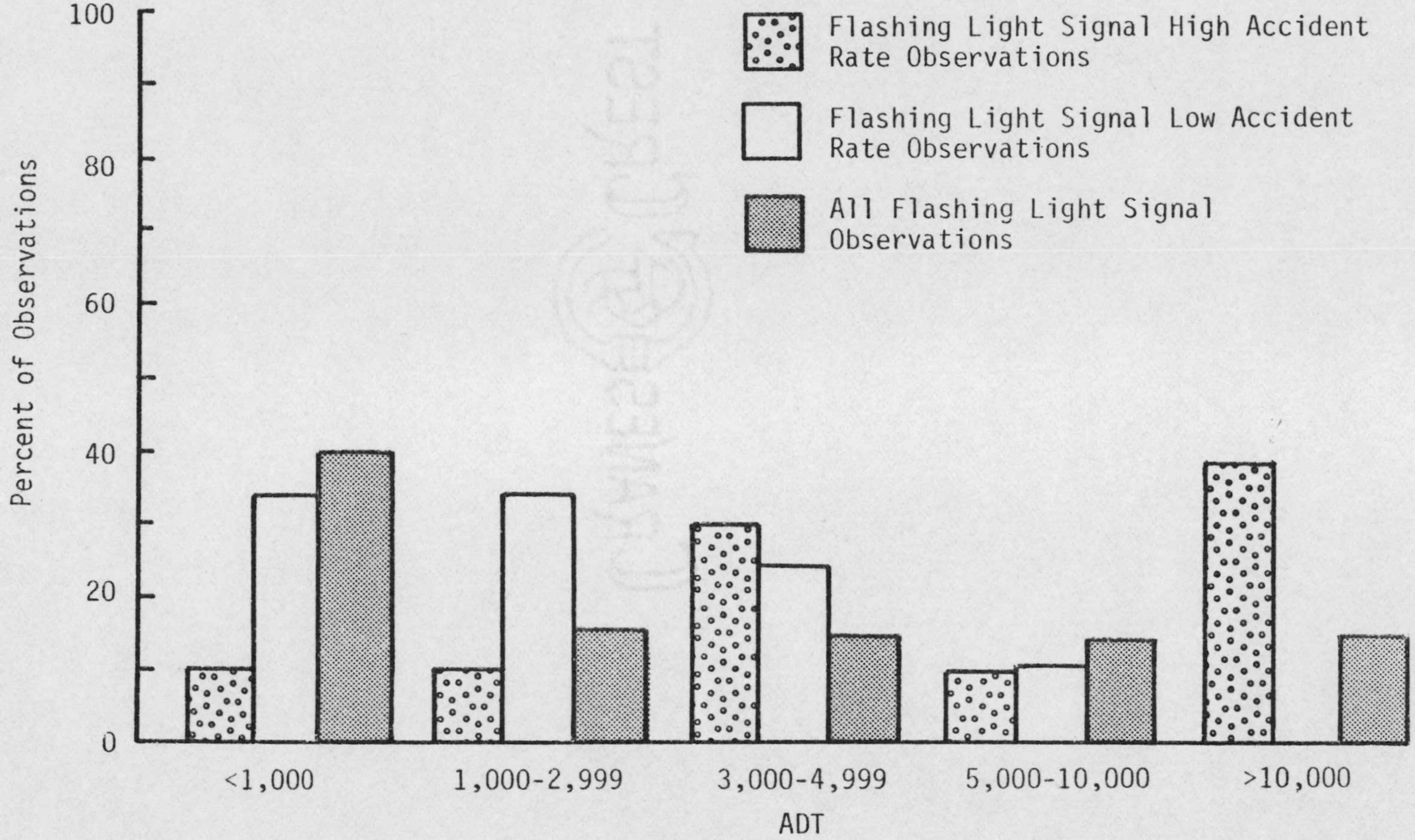

FIGURE 5-18

HIGHWAY VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES
OF FLASHING LIGHT SIGNAL OBSERVATIONS

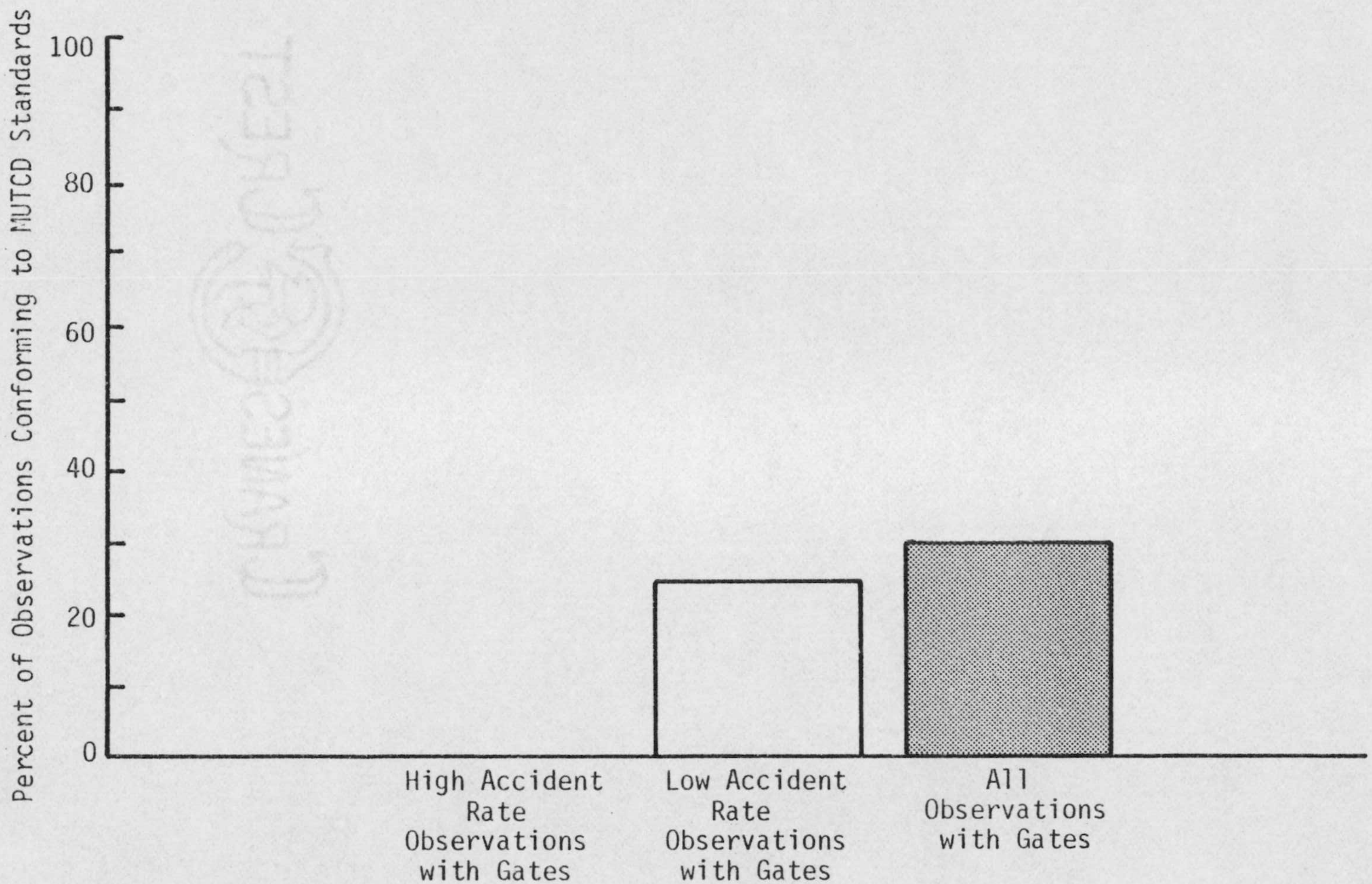

FIGURE 5-19

COMPARISON OF THE PERCENT OF OBSERVATIONS CONFORMING TO MUTCD STANDARDS OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

Train speeds. The distributions of train speeds for the different categories are shown in Figure 5-20. There is a substantial difference between the high and low rate observations. Seventy-five percent of the high rate crossings had train speeds less than 35 mph whereas an equal percentage of low accident rate crossings had train speeds of 60 mph or greater. None of the high rate crossings had train speeds in the highest range, and none of the low rate crossings had speeds lower than 35 mph. Very similar percentages for all three categories were found in the 35 to 40 mph and 50 to 59 mph ranges.

Figure 5-21 shows that 100 percent of the low accident rate crossings in urban areas had train speeds in excess of 35 mph. About 33 percent of the high accident locations and 57 percent of all crossings with gates in urban areas had trains which exceeded 35 mph.

In rural areas, Figure 5-22, all of the low rate crossings with gates had trains which exceeded 50 mph. This value is similar to that found for all rural crossings with gates, about 89 percent. No high accident rate observations had trains in that speed range.

Crossing location. Figure 5-23 reveals that most crossings with gates, regardless of the category, were in urban areas. Somewhat more of both high and low rate crossings were in urban areas compared to gate crossings overall. However, both high and low rate crossings exhibit much of the same properties as all crossings with gates with respect to location.

Highway type. The percent of crossings located on local roads in each category is shown in Figure 5-24. The low rate observations and

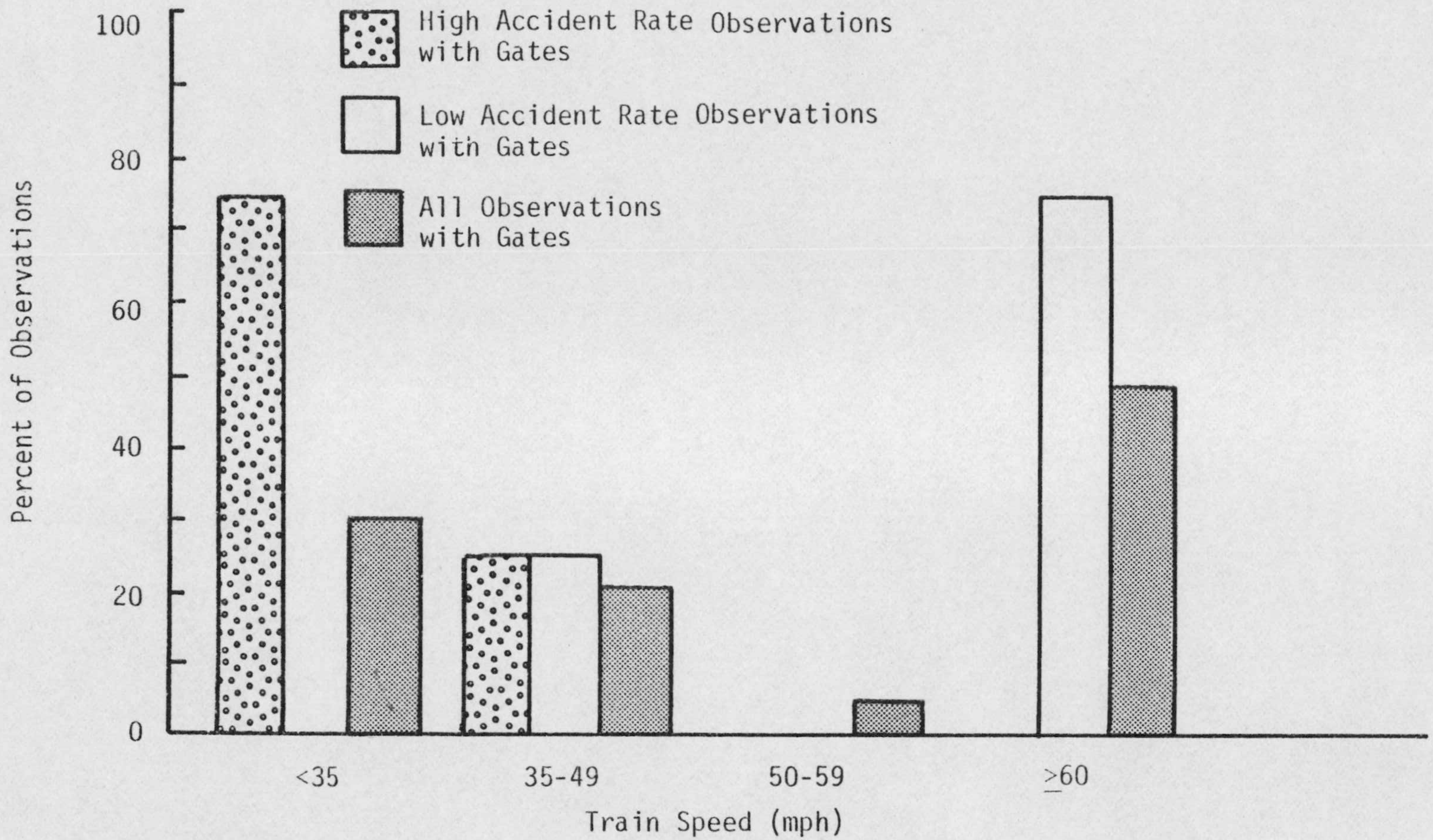

FIGURE 5-20

TRAIN SPEED DISTRIBUTIONS OF SELECTED CATEGORIES
OF OBSERVATIONS WITH GATES

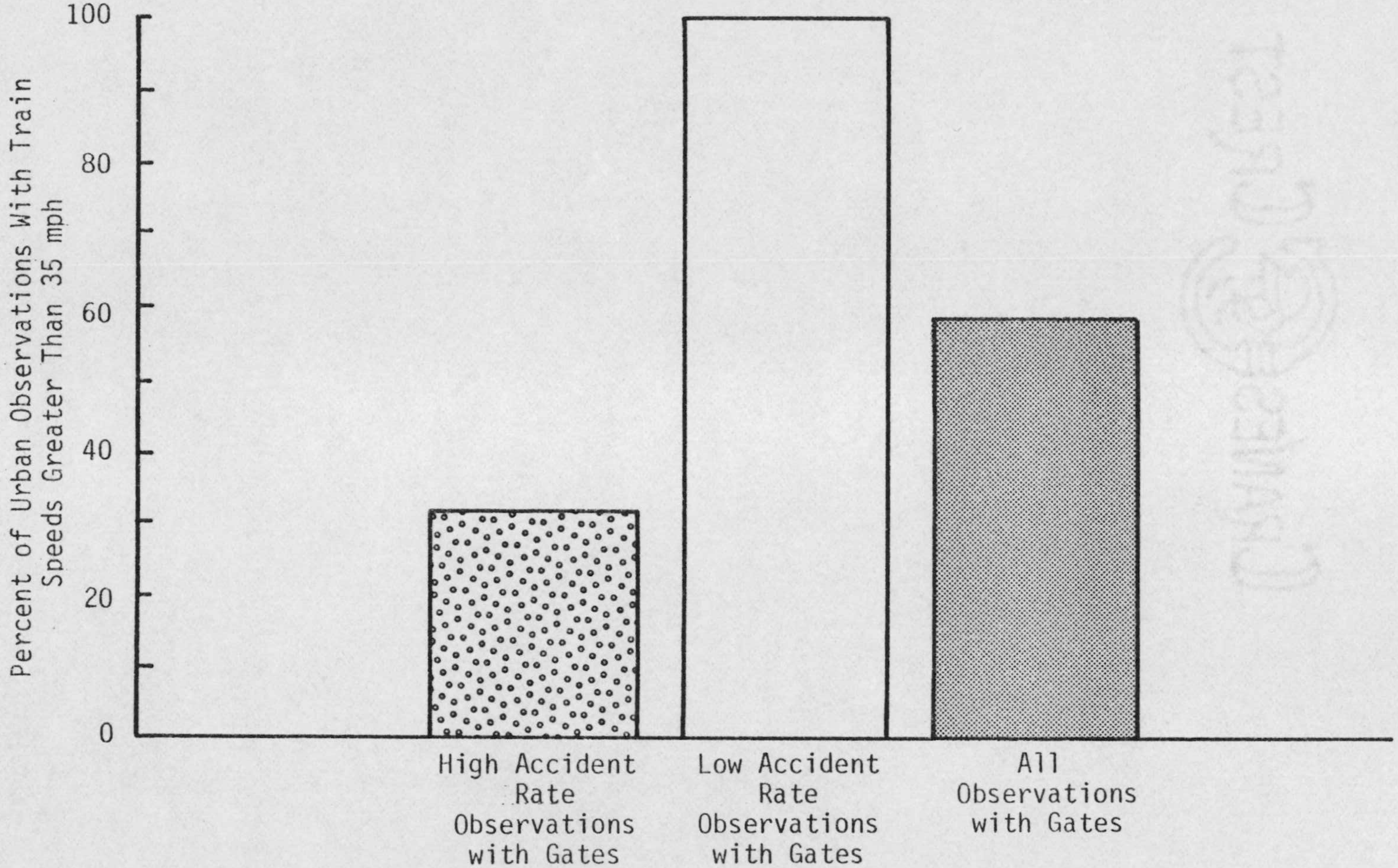

FIGURE 5-21

COMPARISON OF TRAIN SPEED AT URBAN LOCATIONS OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

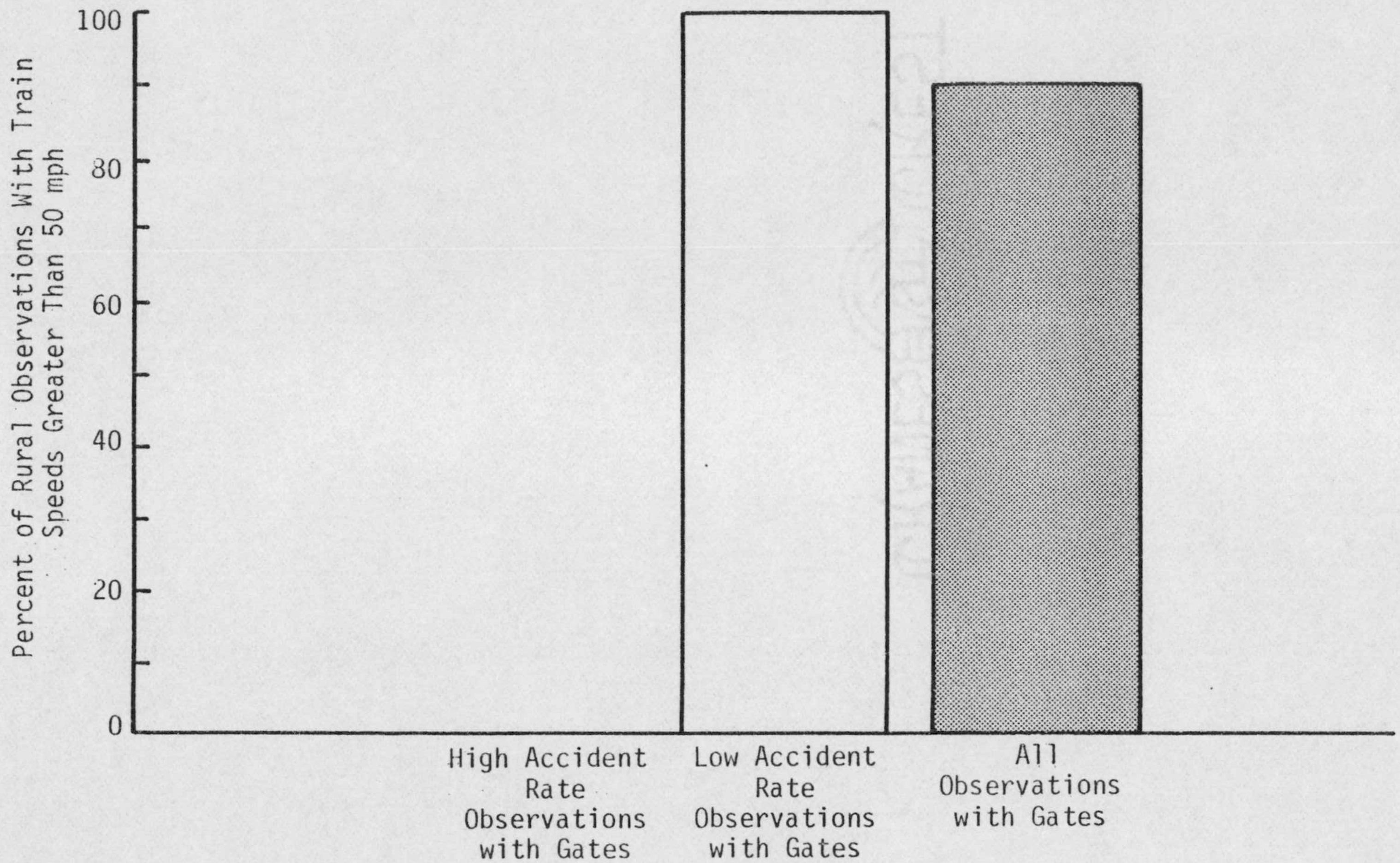

FIGURE 5-22

COMPARISON OF TRAIN SPEED AT RURAL LOCATIONS OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

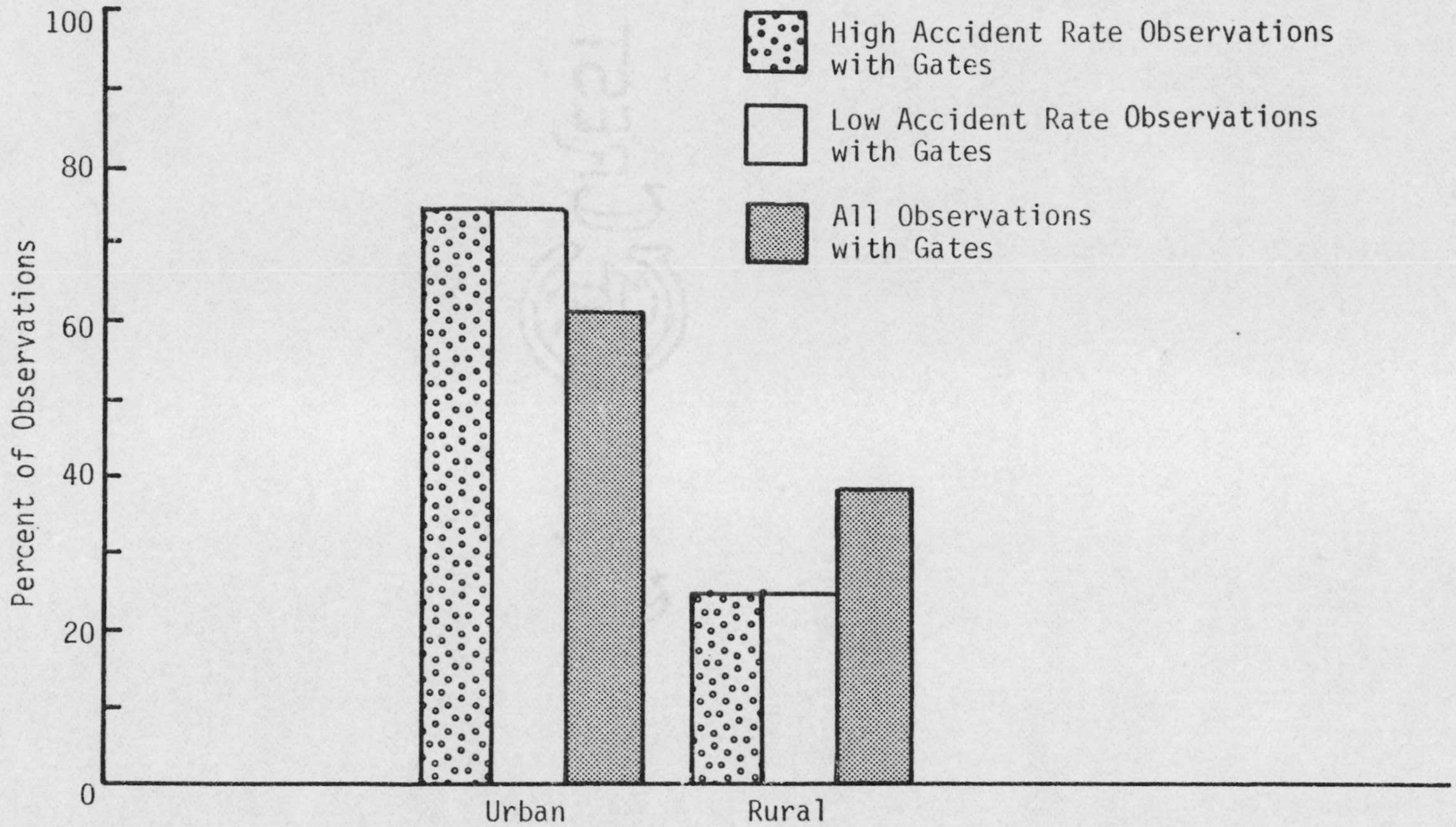

FIGURE 5-23

COMPARISON OF CROSSING LOCATION OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

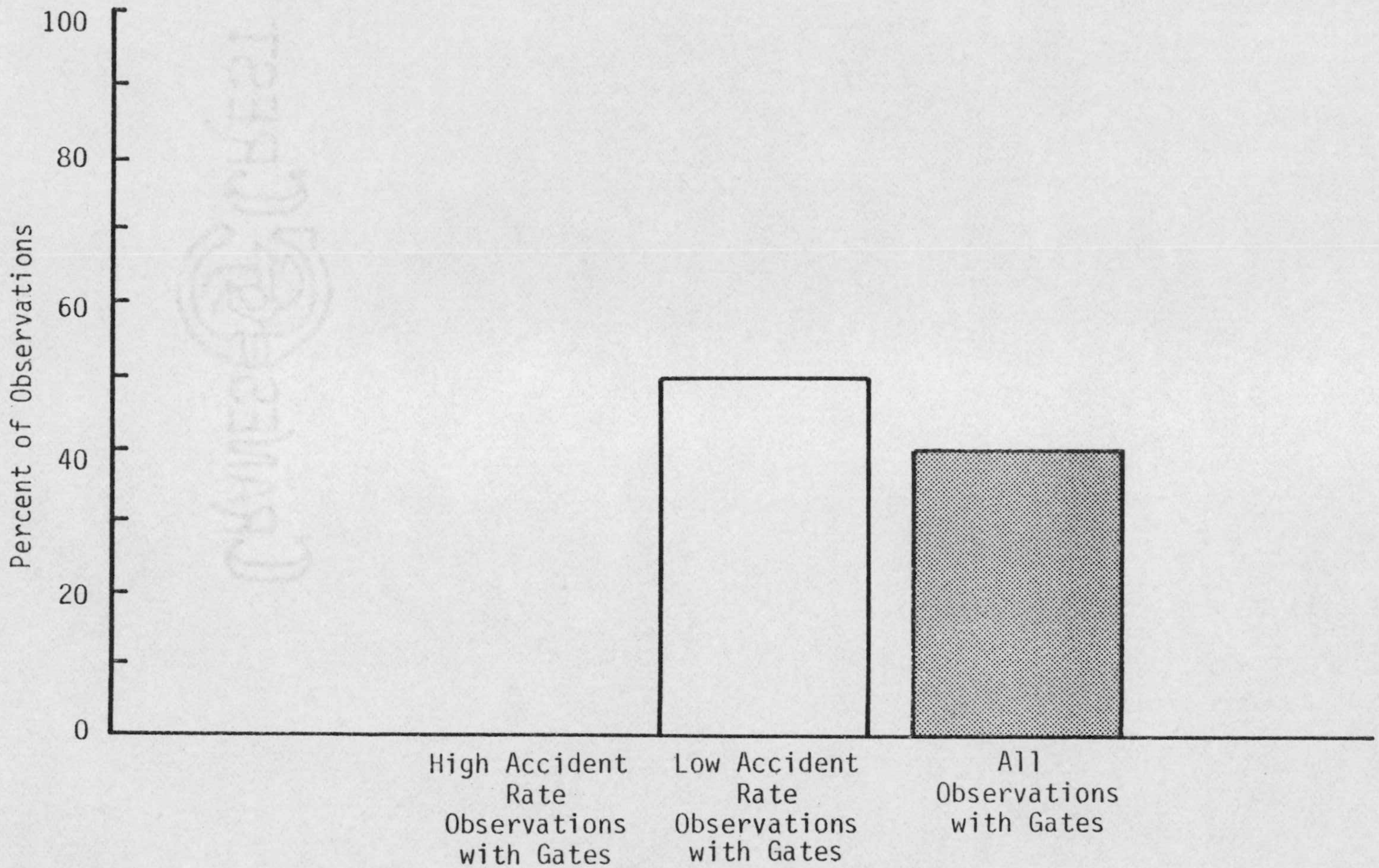

FIGURE 5-24

COMPARISON OF THE PERCENT OF OBSERVATIONS ON LOCAL ROADS
OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

all crossings with gates have fairly similar percentages of crossings on local roads, 50 percent and 39 percent, respectively. None of the high rate locations were on local roads.

Train volume. The distributions of train volume are shown in Figure 5-25. All of the low accident rate observations had train volumes of 20 or more per day. Fifty percent of the high rate locations and about 44 percent of all crossings with gates had volumes in the highest range. The high rate crossings tended to have somewhat lower train volumes than gate crossings as a whole. Neither the high rate crossings nor the low rate crossings had any observations with six or less trains per day.

Highway traffic volume. Figure 5-26 shows the ADT distributions for high and low accident observations and gate crossings as a whole. The low rate observations were very evenly distributed across the ADT range categories. The high rate observations had more crossings in the lower ranges; 75 percent had ADT values of less than 3,000. In comparison, 65 percent of all crossings with gates that had ADT's of less than 3,000.

All Observations

Crossing characteristics were also examined for the sample as a whole. Forty-five observations were categorized as having low accident rates and 24 had high accident rates. Again, the high category has less observations since observations with no accidents were not considered for the high rate category. An examination of device type was

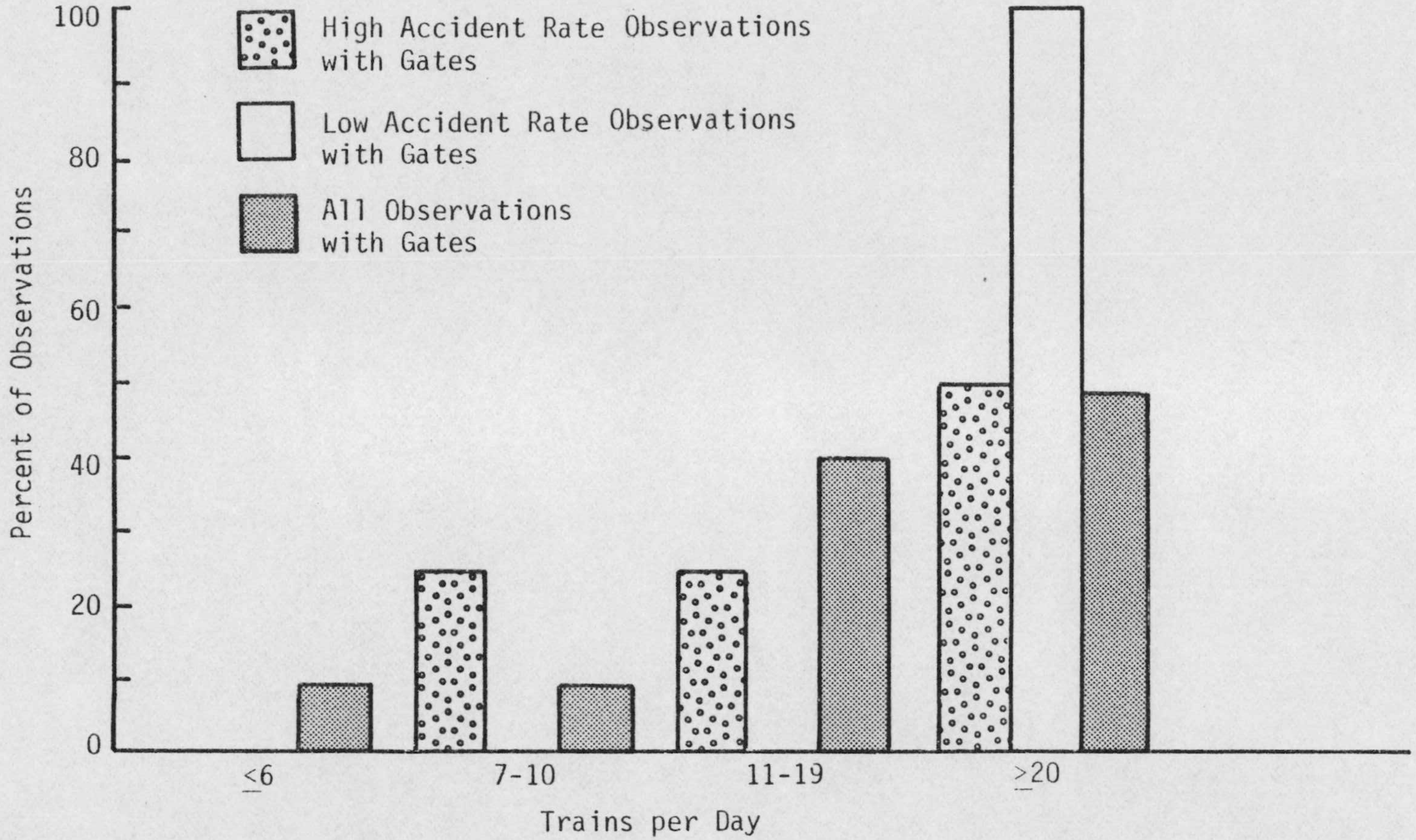

FIGURE 5-25

TRAIN VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES OF OBSERVATIONS WITH GATES

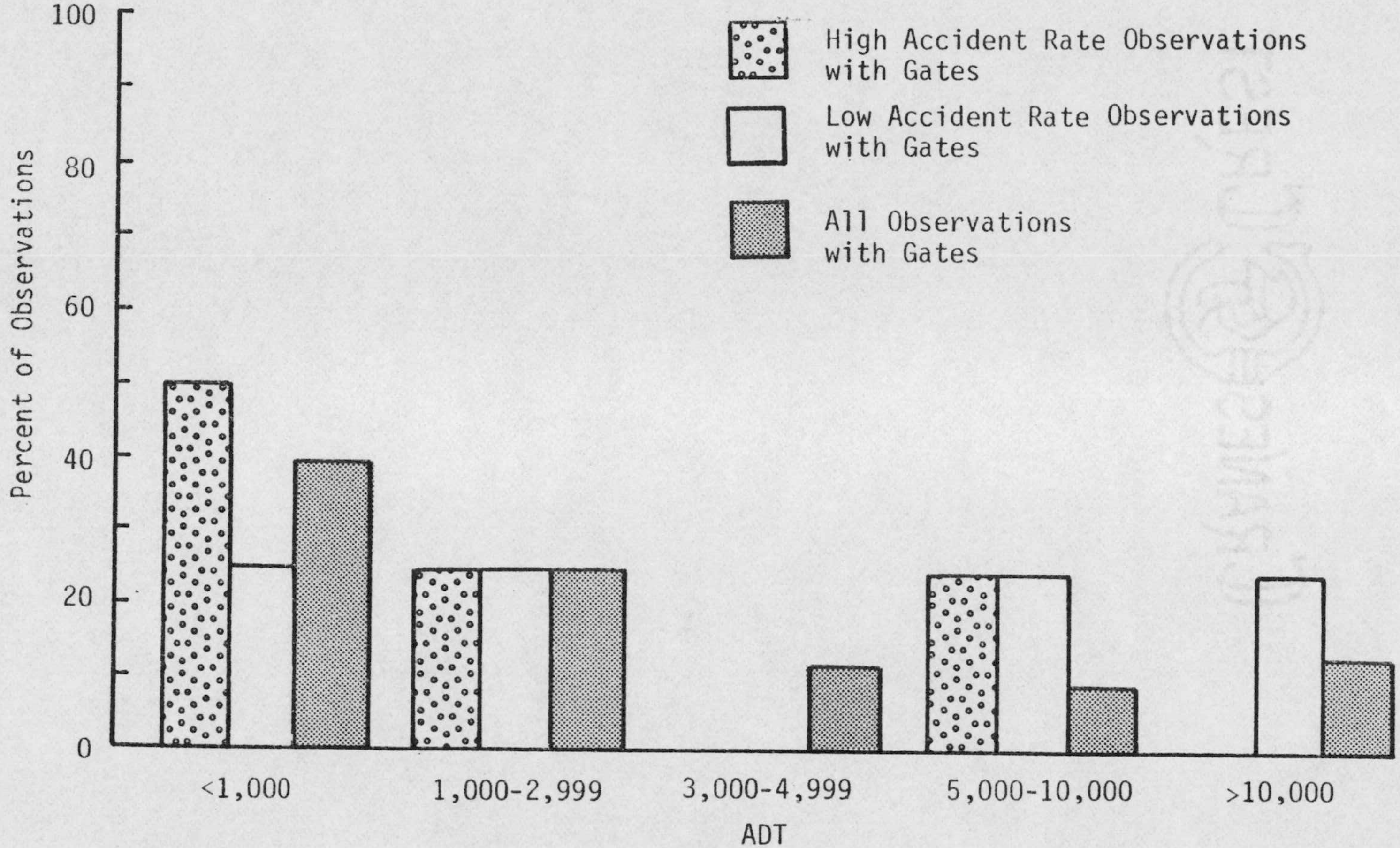

FIGURE 5-26

HIGHWAY VOLUME DISTRIBUTIONS OF SELECTED CATEGORIES
OF OBSERVATIONS WITH GATES

made in addition to the characteristics analyzed in the previous section.

Device suitability. The percentage of observations that met FHWA guidelines is shown in Figure 5-27. The percent of high rate observations meeting the criteria was nearly the same as that of crossings overall, both about 88 percent. The low accident rate observations had a somewhat lower percent of crossings with suitable devices, about 76 percent.

Conformance to MUTCD standards. The degree of conformance for low and high rate observations is very similar, 27 percent and 29 percent respectively. This is shown in Figure 5-28. The percent of all observations was about 16 percent, which is less than either the high or low accident rate conformance.

Train speed. The distribution of train speeds is shown in Figure 5-29. The distribution of train speeds for the high rate observations and all observations are similar in nature; however, the observations with high rates had a greater percentage of train speeds less than 35 mph and a lower percentage of speeds 60 mph or greater than the sample as a whole. In fact, no observations with high rates had train speeds in the highest range. In contrast, about 35 percent of the low accident rate observations had train speeds of 60 mph or greater. Only about 13 percent of all observations fell into that range. The low accident rate observations also had a lower percentage of train speeds less than 35 mph than either of the two other categories. About 29

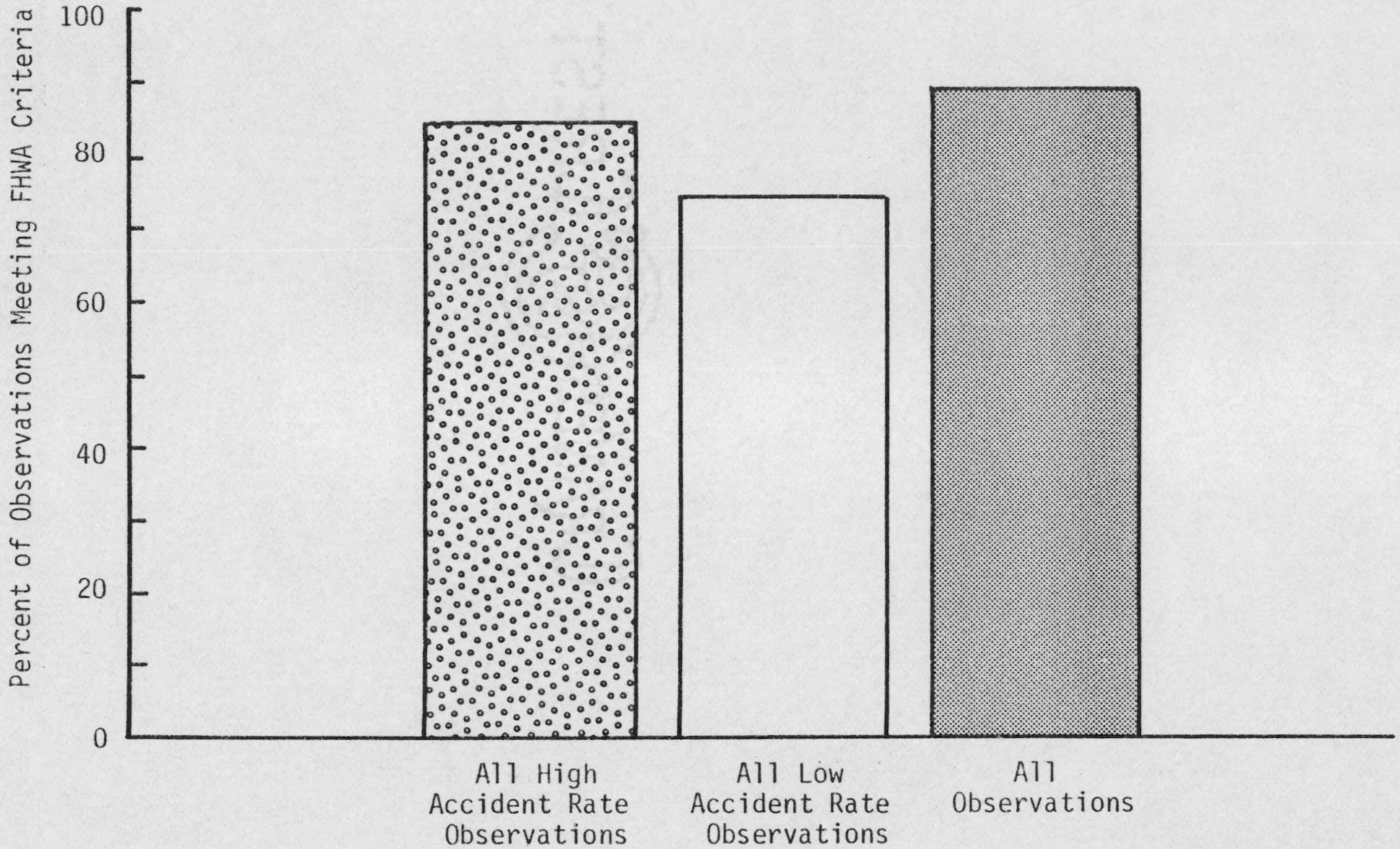

FIGURE 5-27

COMPARISON OF THE PERCENT OF OBSERVATIONS MEETING FHWA CRITERIA OF SELECTED CATEGORIES OF ALL OBSERVATIONS IN THE SAMPLE

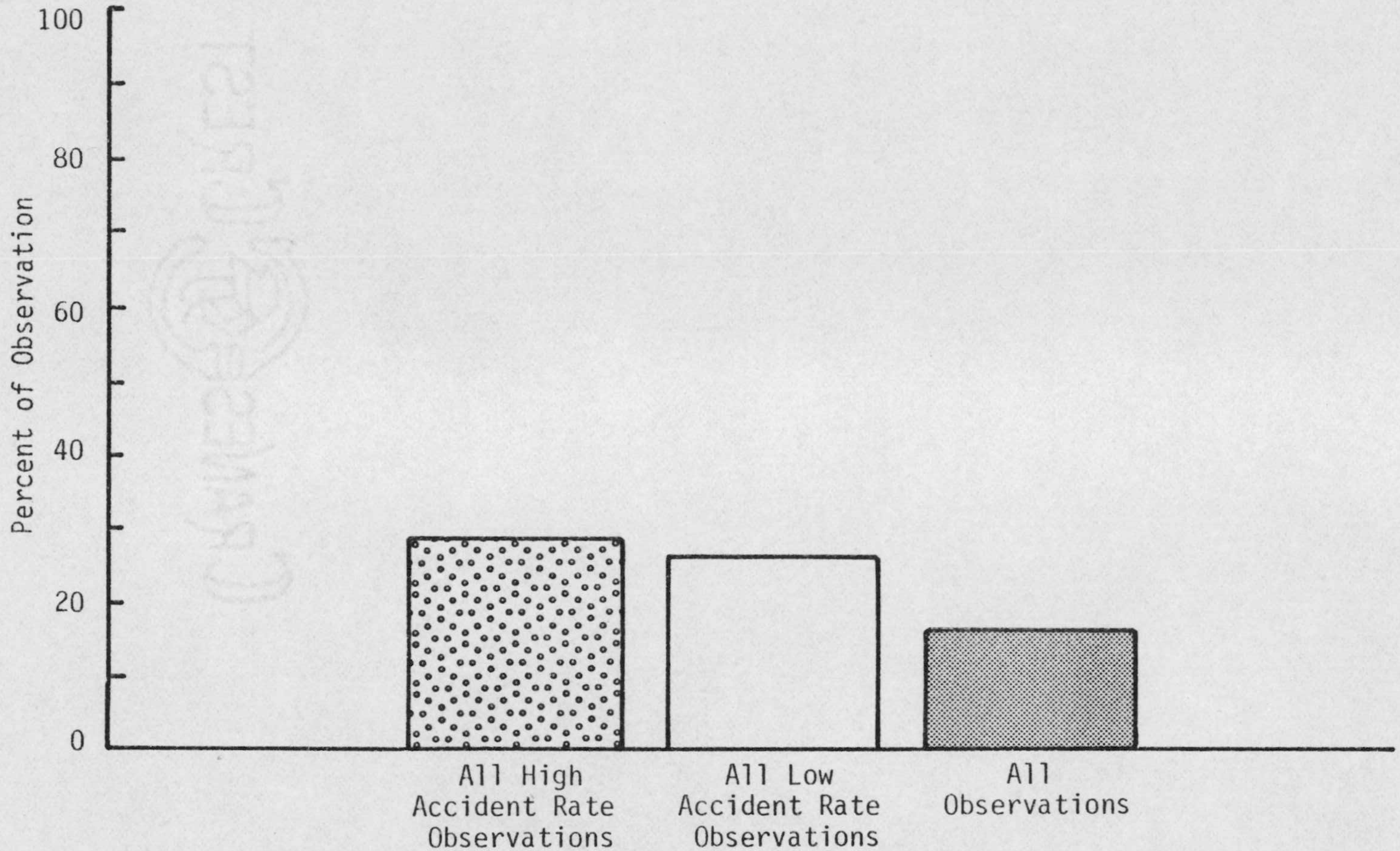

FIGURE 5-28

COMPARISON OF THE PERCENT OF OBSERVATIONS CONFORMING TO MUTCD STANDARDS
OF SELECTED CATEGORIES OF ALL OBSERVATIONS IN THE SAMPLE

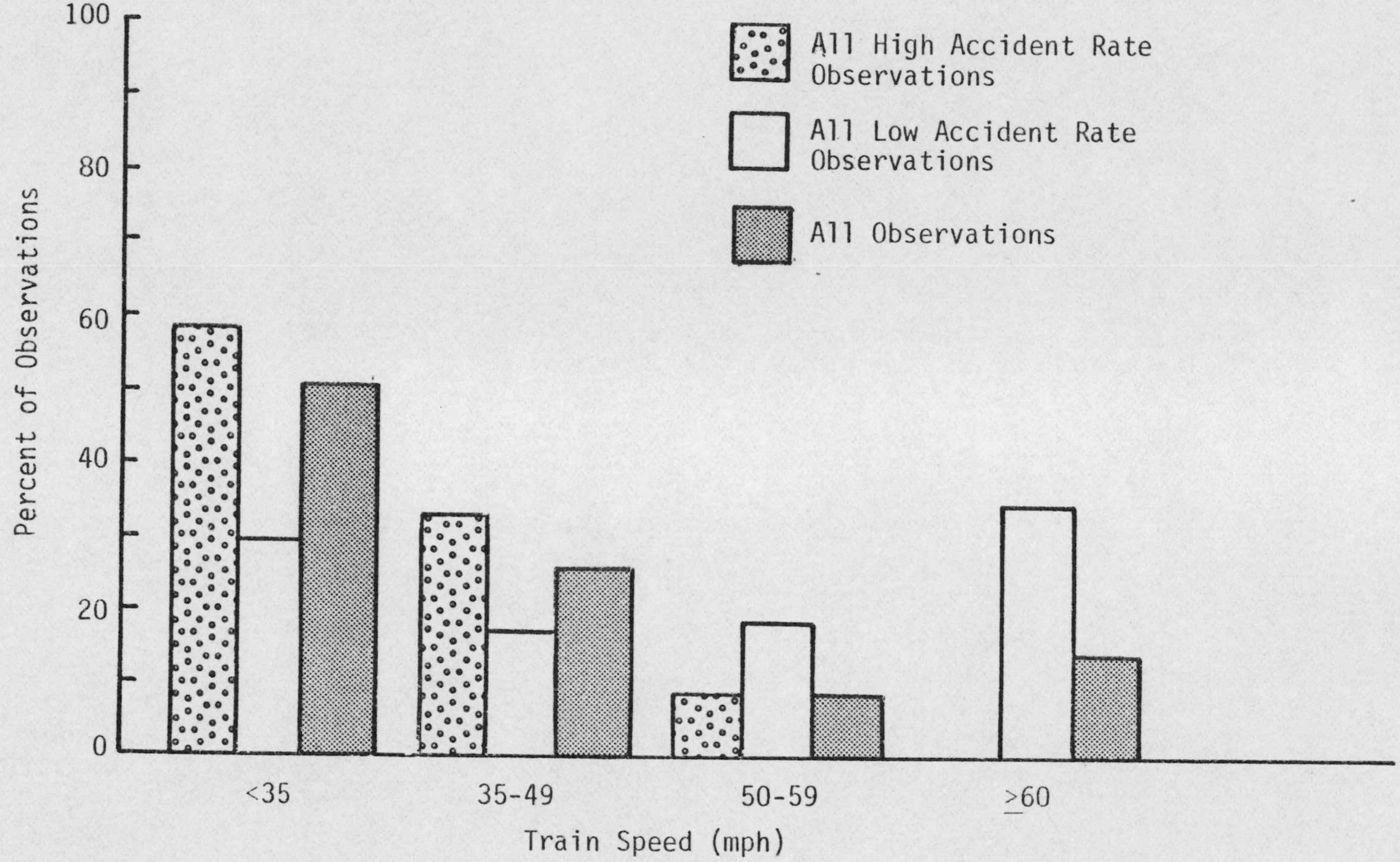

FIGURE 5-29

TRAIN SPEED DISTRIBUTIONS OF SELECTED CATEGORIES
OF ALL OBSERVATIONS IN THE SAMPLE

percent of the observations with low rates had speeds in the lowest range, whereas the high rate had approximately 58 percent, and the percent of all crossings was about 51 percent in the less than 35 mph range.

The percent of urban crossings in each category with train speeds greater than 35 mph is shown in Figure 5-30. Forty percent of the urban low accident rate observations had train speeds greater than 35 mph. This is substantially more than the 15 percent of urban high rate crossings that had speeds in that range. The percentage of all urban crossings with train speeds greater than 35 mph was about 23 percent.

Even greater differences were found for rural crossings, Figure 5-31. Eighty percent of the rural low accident rate crossings had train speeds greater than 50 mph compared to only 18 percent of the rural high rate locations. Thirty percent of all rural crossings had train speeds greater than 50 mph.

Crossing location. The percentage of urban and rural crossings in each category is shown in Figure 5-32. Over half of the high rate observations were in urban areas in contrast to 37 percent of all crossings. The low accident rate crossings also had a greater percentage, 44 percent of urban crossings than all crossings, but a lower percentage than the high rate locations. It follows, then, that the low and high rate categories had lower percentages of crossings in rural areas than overall, and that the high rate crossings had the lowest percentage of rural crossings.

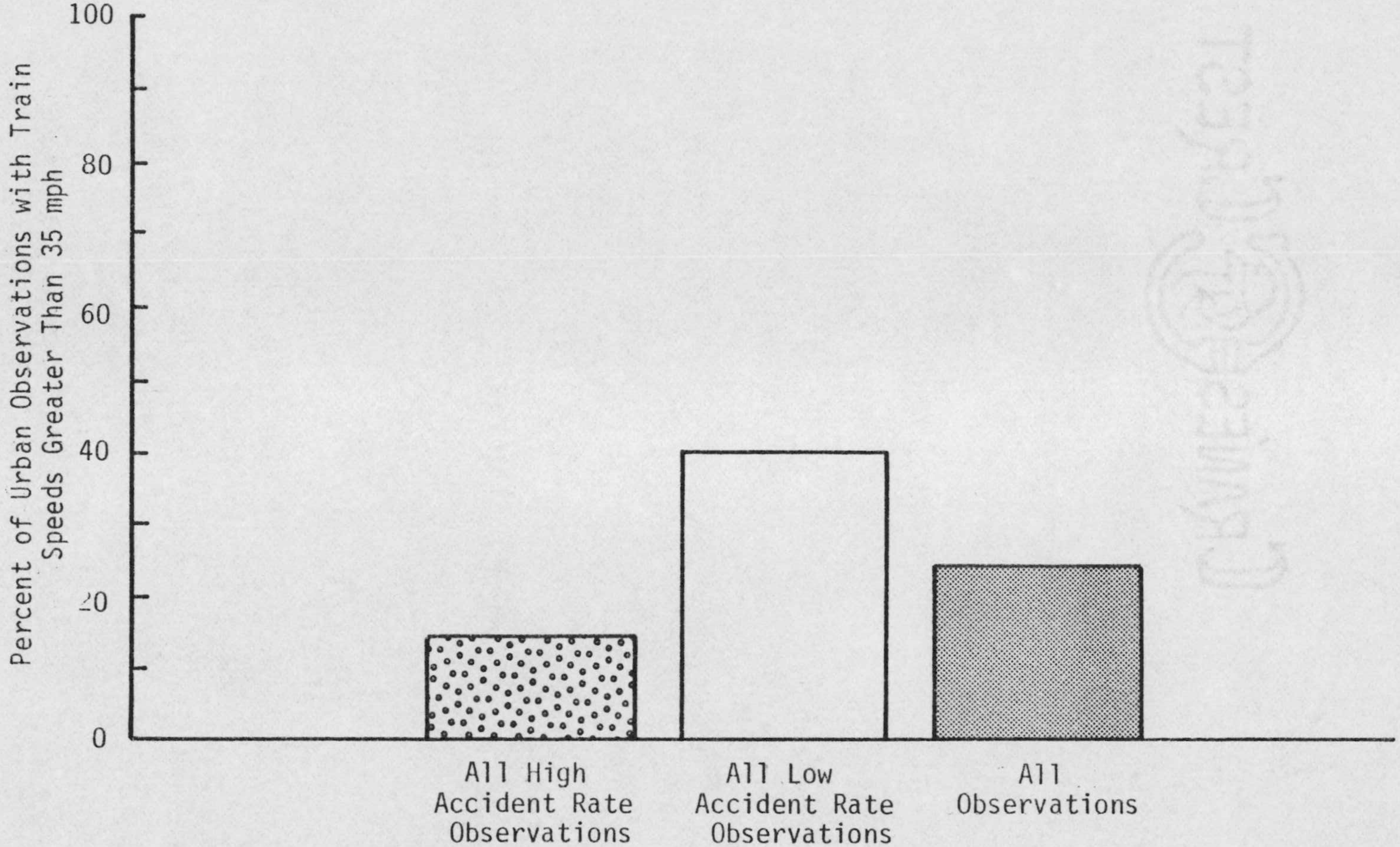

FIGURE 5-30

COMPARISON OF TRAIN SPEED AT URBAN LOCATIONS OF SELECTED CATEGORIES OF ALL OBSERVATIONS IN THE SAMPLE

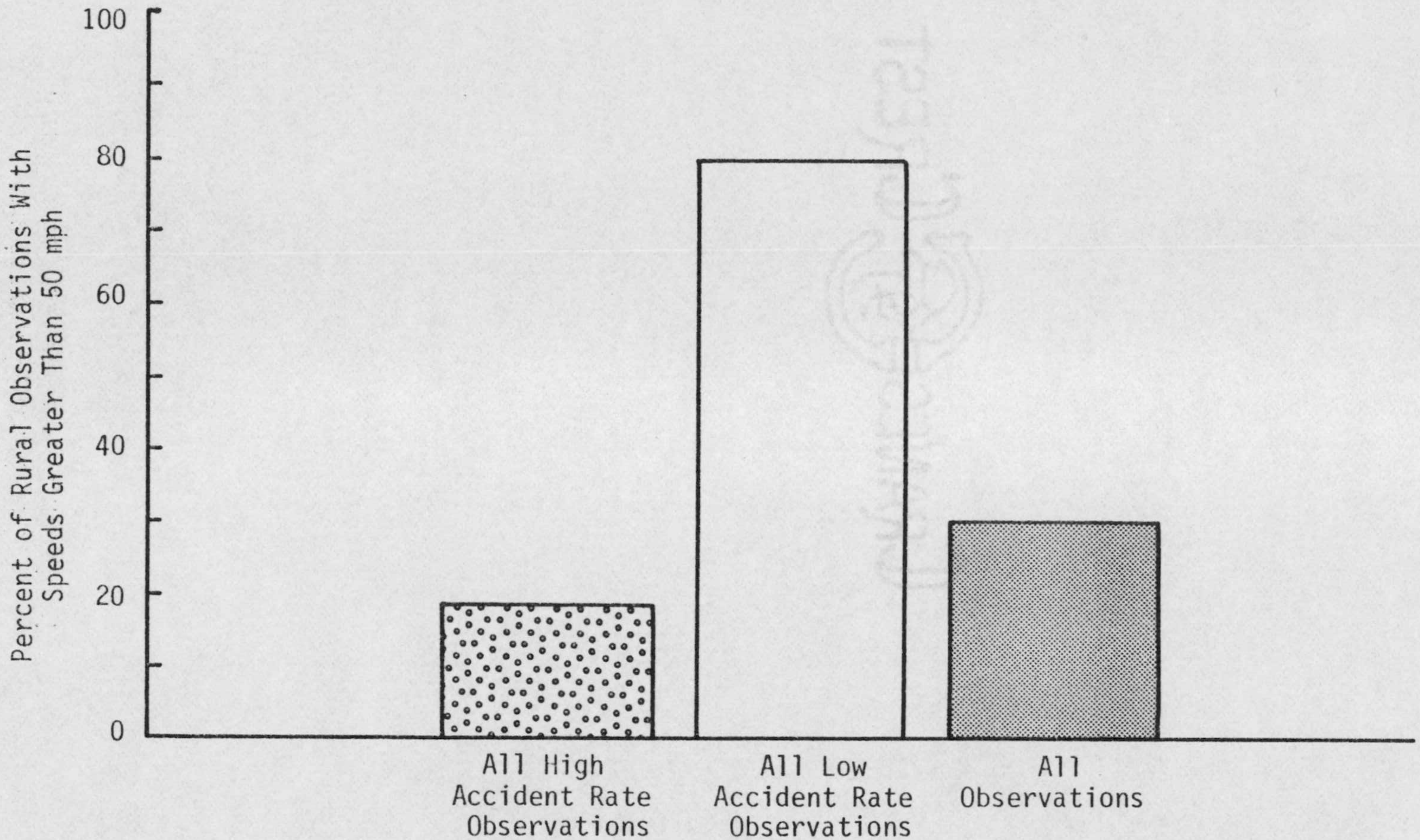

FIGURE 5-31

COMPARISON OF TRAIN SPEED AT RURAL LOCATIONS OF SELECTED CATEGORIES OF ALL OBSERVATIONS IN THE SAMPLE

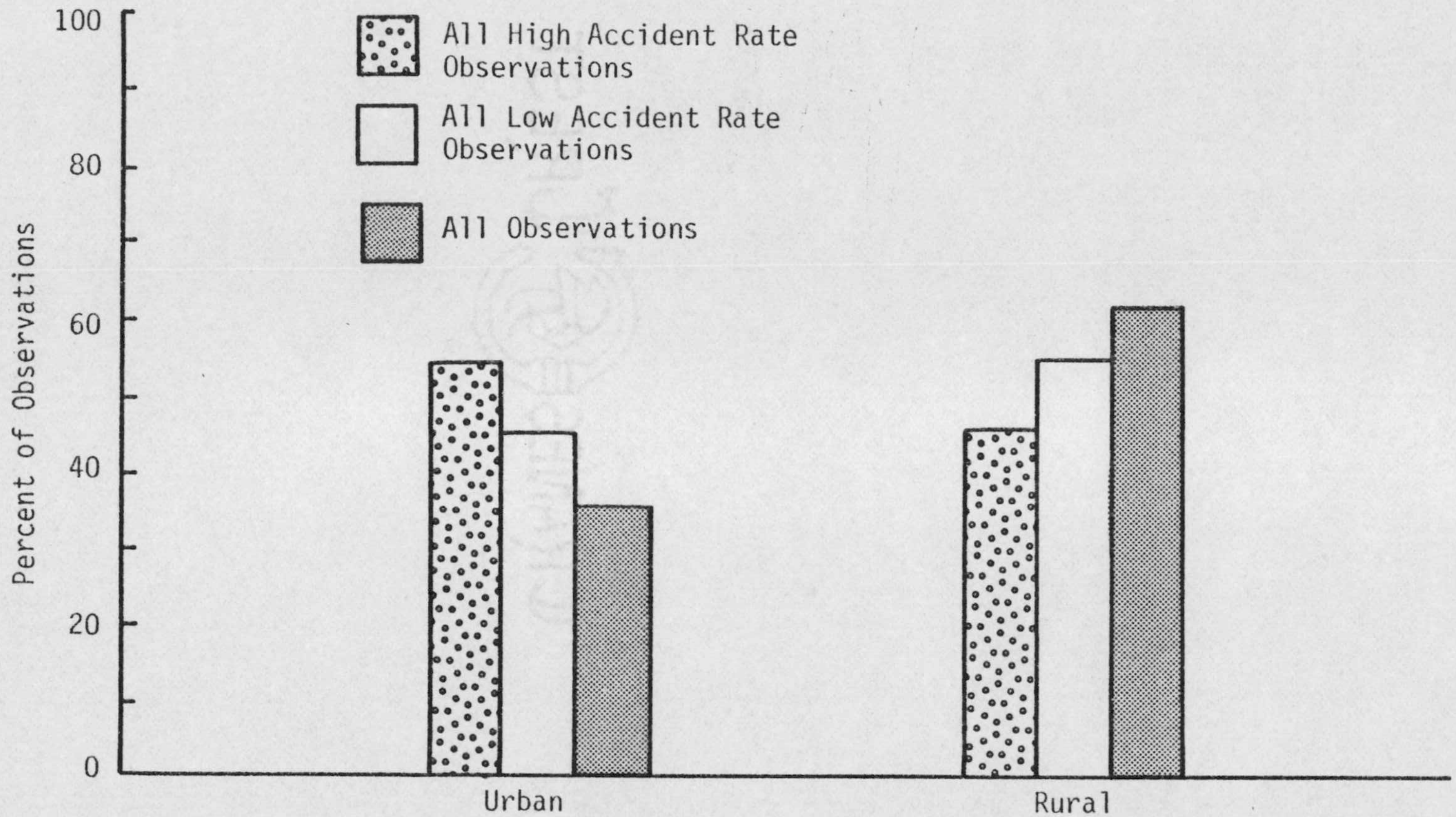

FIGURE 5-32

COMPARISON OF CROSSING LOCATION OF SELECTED CATEGORIES
OF ALL OBSERVATIONS IN THE SAMPLE

Highway type. The percent of crossings on local roads for each category is shown in Figure 5-33. The percentages of crossings on local roads for low rates and all observations is almost the same, 60 percent and 65 percent respectively. The high rate observations have a slightly lower percentage of crossings on local roads, 50 percent.

Train volume. The differences in the train volume distributions for the different categories is evident from Figure 5-34. The vast majority, more than 90 percent, of the high accident rate locations had train volumes of less than six per day. In contrast, over 30 percent of low rate crossings had train volumes of 20 or more per day and more than 85 percent had volumes of more than 10 per day. The distributions for crossings considered as a whole shows that about 60 percent had train volumes less than six and the remaining 40 percent was spread fairly evenly over the three remaining volume ranges. The high rate crossings followed a distribution similar to that found for all crossings; however, a greater percentage of high rate locations had volumes in the lowest range. The distribution for low rate crossings differs appreciably from the other two.

Highway traffic volume. The distributions of ADT for each category is shown in Figure 5-35. The distributions are fairly similar. The high and low rate categories had lower percentages of observations in the lowest volume range, less than 1,000. The percent of observations that had high rates and highway volumes greater than 10,000 is higher than either of the percentages of the highest ADT range for the other two categories.

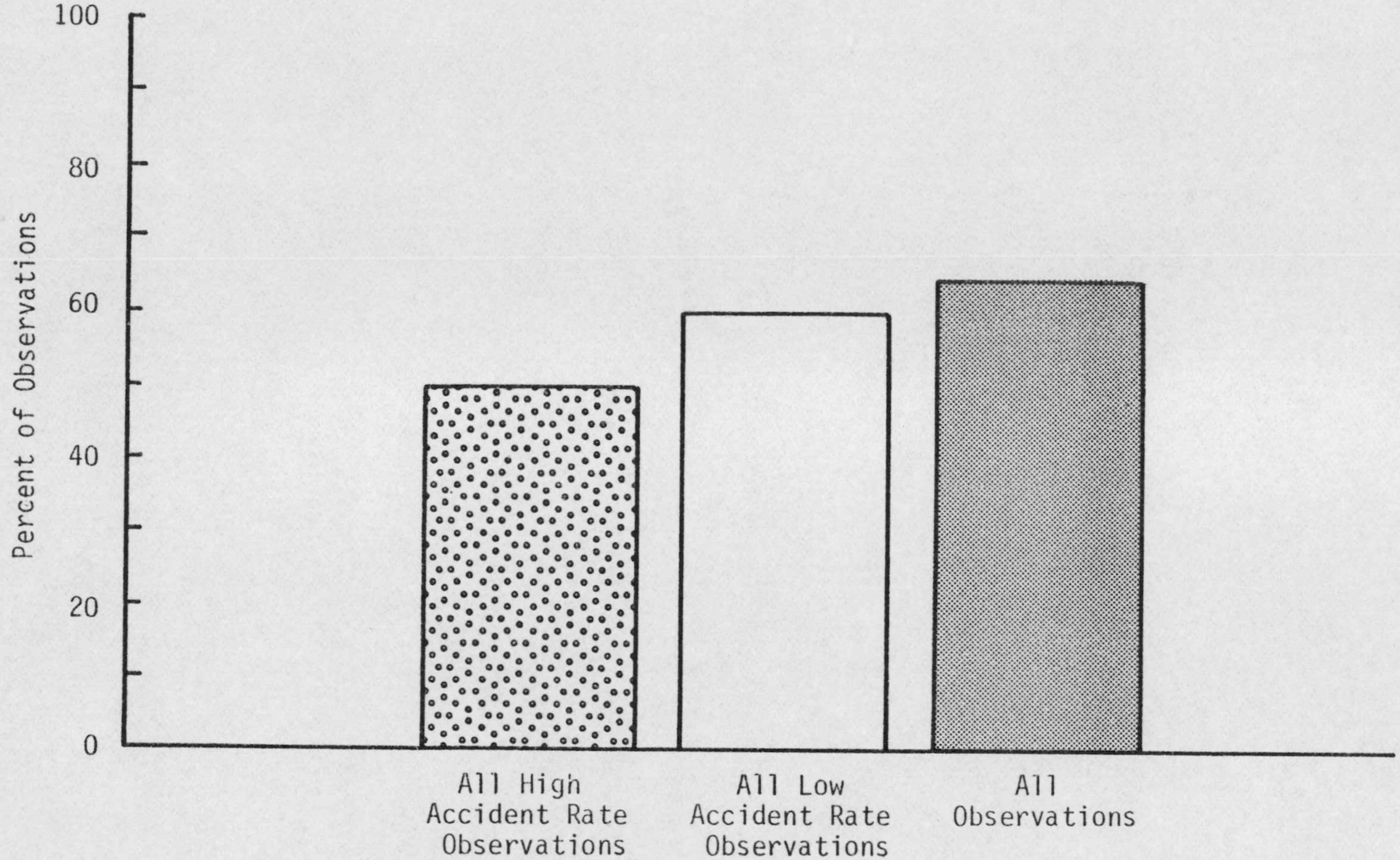

FIGURE 5-33

COMPARISON OF THE PERCENT OF OBSERVATIONS ON LOCAL ROADS OF SELECTED CATEGORIES OF ALL OBSERVATIONS IN THE SAMPLE

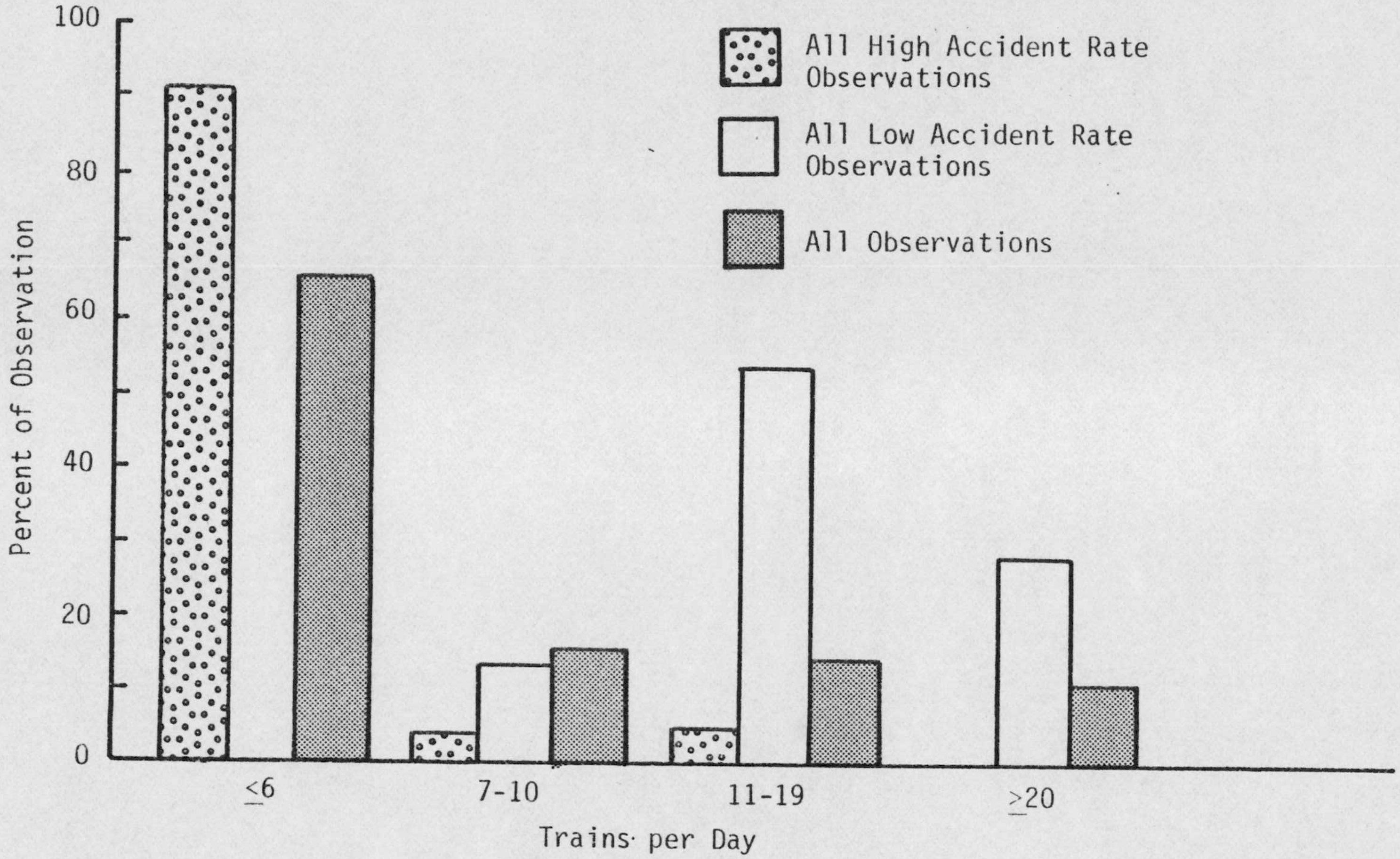

FIGURE 5-34

TRAIN VOLUME DISTRIBUTION OF SELECTED CATEGORIES
OF ALL OBSERVATIONS IN THE SAMPLE

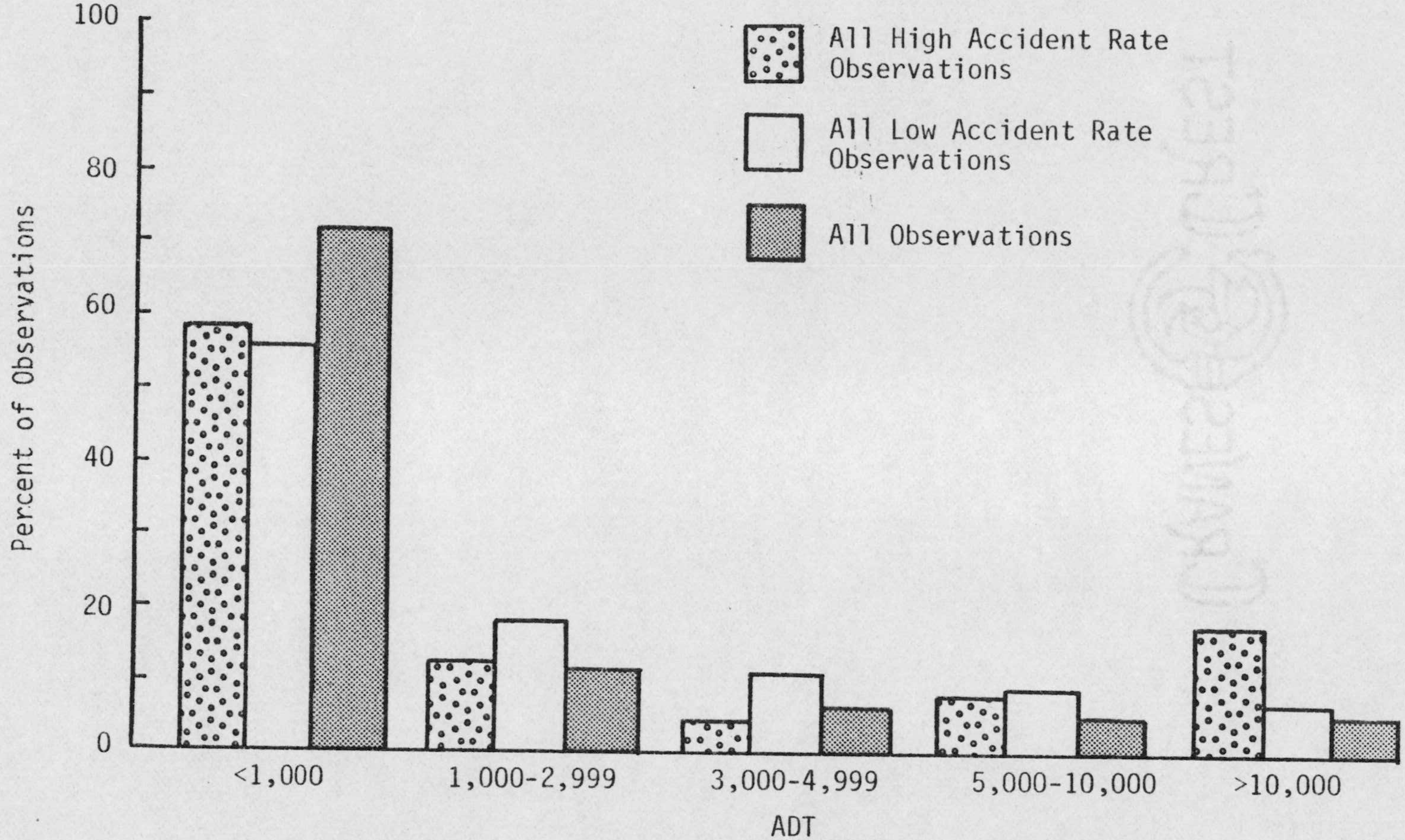

FIGURE 5-35

HIGHWAY VOLUME DISTRIBUTION OF SELECTED CATEGORIES
OF ALL OBSERVATIONS IN THE SAMPLE

Device type. A breakdown of the type of warning devices found at the crossings in each category is shown in Figure 5-36. The high rate observations and the sample as a whole had very similar percentages of passive devices. The low rate observation had considerably less than either. The percent of observations with flashing light signals is very similar for all three categories, although both the high and low rate categories had more than the overall sample.

No crossings with gates were identified as having a high accident rate. About 27 percent of the low accident rate crossings had gates. However, only 8 percent of all observations had gates.

Discussion of the Results of the Analysis of Crossing Characteristics

The analysis of crossing characteristics was performed to identify characteristics associated with high and low accident rates. A low accident rate suggested warning devices that effectively met the needs of motorists. The low rates observations had high demand, or stress, levels as measured by the number of highway vehicles and trains and a good performance record in terms of accidents. In contrast, the high accident rate category identified crossings whose warning devices apparently did not meet the needs of motorists since, in comparison with other observations, they had noticeably higher rates. In each category, the characteristics of all the observations in that category were used as a reference.

Device suitability. The degree of device suitability for passive devices, flashing light signals, and the entire sample was similar. Observations with gates were not analyzed since all gates met FHWA

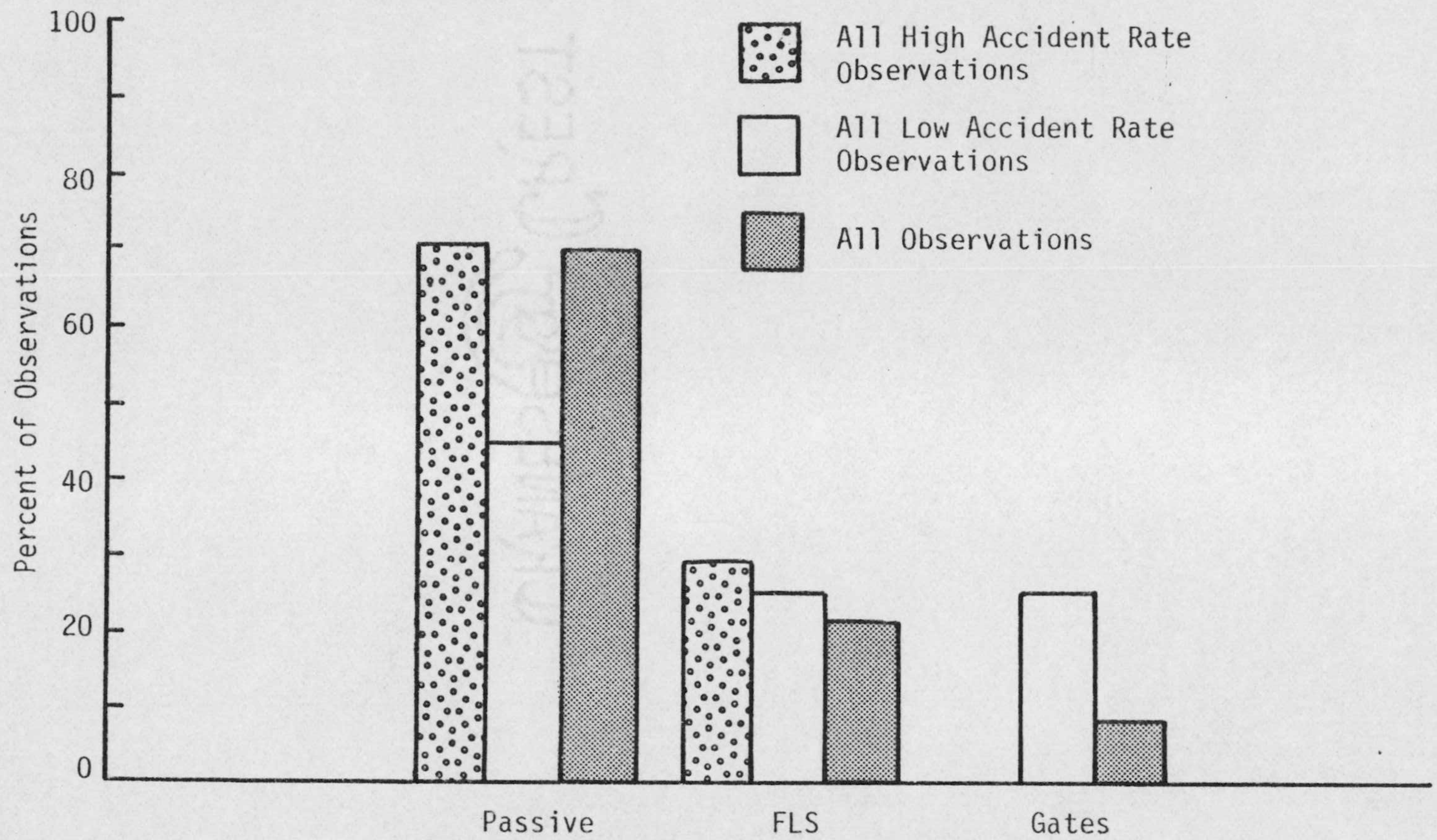

FIGURE 5-36

WARNING DEVICE TYPE DISTRIBUTION OF SELECTED CATEGORIES
OF ALL OBSERVATIONS IN THE SAMPLE

guidelines. In each category, the observations with high rates displayed about the same percentage of conformance as all crossings within that category. In each case, the low accident rate observations exhibited a lower rate of suitability than either the high rate observations or all observations within a category. A high percentage of observations met the FHWA criteria in all categories, however.

The indication was that observations with low rates, regardless of warning device type, were somewhat less likely to have suitable devices, as determined by application of FHWA guidelines, than other observations. This result is consistent with the analysis of variance results which indicated that crossings which met the FHWA guidelines usually had lower accident rates than crossings which did not meet the guidelines.

Conformance to MUTCD standards. The results differed considerably for the different device categories. Observations with high or low accident rates in the passive category each had greater percentages of crossings which conformed to standards than passive crossings did as a whole. This was also the case when this comparison was made for the entire sample. In the flashing light signal category, none of the low accident rate observations conformed, and the high rate observations had a greater percentage that conformed than all flashing light signal observations did. A very different result was found for observations with gates. No high rate crossings conformed to standards; however, the low accident rate crossings and all gate observations had similar percentages of observations that conformed to standards.

No clear trend relating MUTCD conformance to accident rates was exhibited by passive observations or the sample as a whole. The flashing light signal and gate categories displayed distinct, but opposite, results. Apparently, flashing light signals which had low accident rates were less likely to conform to MUTCD standards than other flashing light signal observations, and the high accident rate locations were more likely to conform than other flashing light signal observations. This result seems to be consistent with the analysis of variance results which indicated that crossings with flashing light signals that conformed to standards had higher accident rates than those which did not. This may mean that even when flashing light signals conform to accepted standards, they do not really meet the needs of the motorists.

In the case of observations with gates, the opposite was true, both in the analysis of variance and the high and low rate comparison. Perhaps conformance to MUTCD standards is more critical for gates than flashing lights, and gate crossings which do conform to standards better meet the needs of motorists than gate systems that do not. The indication is also that some flashing light signals, in spite of meeting MUTCD requirements, are not able to fully meet the needs of motorists.

Train speed. The passive, flashing light signal, and gate observations, as well as the sample as a whole, displayed a similar trend. Crossings with low accident rates tended to have high train speeds and observations with high rates tended to have low speeds. This trend was especially strong in the cases of flashing light signals and gates.

The results of the analysis of urban locations with speeds greater than 35 mph and rural locations with speeds greater than 50 mph also indicated this trend for the most part. Passive observations at urban locations did not exhibit much difference between high and low rates, but, in the rural case, low rates had a substantially greater percentage of observations that exceeded 50 mph than either the high rates or all rural observations with passive devices.

No observations with flashing light signals and high accident rates, in either rural or urban locations, had train speeds in excess of the limits. The low rate flashing light signal observations tended to have a greater percentage of observation in excess of the limits than flashing light signals as a whole. Similar results were found for gate observations and the entire sample.

Overall, low accident rates were likely to be associated with high train speeds and high accident rates were likely to be associated with low speeds. This was not absolute since there were low accident observations with low speeds and, similarly, high accident rates at crossings with high train speeds. However, the trend is very distinct.

It appears that train speed may influence driver behavior at crossings. Perhaps greater care is generally taken at crossings with high train speeds and less caution exercised at crossings with low train speeds. Furthermore, automatic signals do not seem to be completely capable of overcoming these perceptions. The indication was fairly strong in both cases that high accident rates were associated with low speeds. Perhaps there is more of a problem with signal credibility at low speed crossings. The perceived hazard may be low and the automatic signals may not convey a believable warning. Whatever the cause, there are definite indications that train speed is associated with warning device effectiveness and that warning devices are not equally effective under different train speed conditions.

Crossing locations. The analysis of crossing locations did not reveal any clear and consistent trends. For passive and flashing light signal observations, the low rate observations were distributed between urban and rural locations in a similar manner to all crossings in their respective warning device category. In each case, the high rates tended to have a somewhat greater percentage of urban observations than low rates or all crossings within the category.

Observations with gates and the entire sample displayed similar characteristics in terms of location. In each case, both high and low rates had greater percentages of observations in urban areas than all the crossings in their respective categories. The indication is that accident rates do not seem to be strongly associated with location, although in the passive and flashing light signal cases, high accident rate observations are somewhat more likely to be in urban areas than observations with those devices are in general.

Highway type. The analysis of highway type identified the percent of crossings for each category that were located on local roads. Local roads are usually low speed and low volume facilities. In each category, passive, flashing light signals, gates, and the sample as a whole, the percentage of low accident rate crossings on local roads was very similar to that of all crossings in the category. Apparently, low accident rate observations are as likely as any other crossing to be on a local road.

Generally, a lower percentage of high rate observations were found on local roads than were found for all the crossings in a particular category. Passive observations with high rates were only somewhat less likely than all passive observations to be on local roads. However, high accident rate observations with automatic signals, flashing lights, or gates, had substantially lower percentages of observations on local roads than flashing light or gate observations in general. The low and high accident rate observations identified from the entire sample were both somewhat less likely to be on local roads than all crossings in general. The high rate crossings had the lowest percent of observations on local roads in the categories of observations of the entire sample.

Evidently, in the cases of automatic signals, the high accident rate crossings are more likely to be on non-local roads than all crossings with automatic signals. This would seem to indicate that the automatic signals are less likely to be effective under the conditions present on non-local roads.

Train volume. The results of the analysis of train volumes were consistent for each category of warning device and for the analysis of all observations. In all cases, the low accident rate observations tended to have high train volumes, and the high accident rate observations tended to have low train volumes. Both distributions differed from the distribution of train speeds for all the crossings in a category.

The implication is that the performance of a particular warning system and, indeed, of warning devices, regardless of type, does not decrease, as reflected by the number of accidents, linearly with train volume. It would be expected that if the accident rate effectively compensated for the effect of increased train volumes or accidents, the distribution of train volumes for high and low rates would match that of crossings in general. This was not the case; warning device performance and grade crossing safety apparently do not vary linearly with train volumes. This indicates that there are other significant factors which influence warning device performance. Another indication is that warning systems, especially automatic ones, may not be effective at low train volume crossings. Perhaps driver perceptions of train frequency significantly effect safety. A greater exercise of caution may compensate for the increased likelihood of an encounter with a train at high train volume crossings, and the low expectancy of an encounter may reduce signal credibility and subsequently effectiveness.

Highway volume. Different categories of device types displayed different results for ADT distributions. Observations with passive devices and low accident rates and passive observations in general had similar highway volume distributions. Passive crossings with high accident rates were distributed similarly; however, these observations had a greater percentage of observations in the highest level, greater than 10,000 ADT, than passive observations as a whole.

In contrast, flashing light signal observations with low accident rates had greater percentages between 1,000 and 5,000 vehicles per day than flashing light signal crossings as a whole. High accident rate flashing light signal observations tended to have somewhat higher volumes than the low accident rate observations or all flashing light signal crossings.

Observations with gates and high accident rates had a highway volume distribution similar to all observations with gates. The low accident rate crossings in the gate category were somewhat more likely to have higher volumes than all observations with gates.

Generally, the highway volume distribution for observations with low accident rates, observations with high accident rates, and the volume distribution of the entire sample are very similar. The percentage of crossings in the entire sample with ADT less than 1,000 was somewhat more than the percentage for either the high or low accident rate observations.

In general, the factor in the accident rate equation which accounted for highway volume seemed to appropriately adjust for differences in ADT. However, the influence of highway volumes may be different, as the highway volume distribution for flashing light signal indicates. Apparently, flashing light signals are more sensitive in terms of effectiveness to changes in volume levels than crossings are in general. Flashing light signals with high accident rates had a tendency to have higher traffic volumes than either low accident rates or flashing light signals in general. This was not the case for passive devices or gates.

Device type. A comparison of warning devices of high and low accident rate locations was conducted for the entire sample. No observations with gates were classified as having high rates. However, the percentage of low accident rate observations with gates was substantially higher than the percentage of gate crossings in the entire sample.

About the same percentage of observations with high accident rates had passive devices as was found in the entire sample. Flashing light signals were somewhat overrepresented in the high accident rate category compared to the percent of flashing light signals in the entire sample. The low accident rate observations were substantially less likely to have passive devices than the sample as a whole.

The results again point out the differences between warning devices. Certainly, these results indicate that gates are the most effective warning device now in use. The percent of high accident rate observations with passive devices is no greater than the percent of total observations which are passive, however, they are not as likely to have low accident rates as the other devices. Interestingly, flashing light signals seem to be overrepresented in the high accident rate category, and the indication is that at least some flashing light signals are not meeting the needs of the motorists.

Summary

The analysis reported on in this chapter was successful in identifying trends exhibited by high accident rate observations, low accident rate observations, and all the observations of a particular device category. Table 5-1 presents a summary of the results of the analysis of crossing characteristics. Only gross trends are shown; the strength of the trends and differences within general trends are not reflected. However, the table presents a summary of the general results and points out the differences in characteristics between low and high accident rate observations. The results are summarized in more detail by the discussion presented in this section.

In terms of device suitability, high accident rate observations displayed a level of device suitability similar to crossings in general. The low accident rate observations generally displayed a lower level of suitability than either high accident rate observations or all observations in general.

Generally, most warning devices, regardless of category, did not conform to MUTCD standards. The comparison of high and low accident rate observations in the passive category and for all observations in the sample did not reveal any trend relating MUTCD conformance to accident rate category. However, the flashing light signal and gate categories displayed distinct results. Flashing light signal observations with low accident rates were less likely to conform to the MUTCD than other flashing light signal observations, and the high accident rate observations were more likely to conform than flashing light signal observations as a whole were. The opposite was true for observations with gates.

A consistent trend was exhibited for train speeds associated with high and low accident rates. In general, observations with low accident rates tended to have high train speeds, and low train speeds

TABLE 5-1

GENERAL TRENDS OF CROSSING CHARACTERISTICS FOR SELECTED CATEGORIES OF OBSERVATIONS

		Meets FHWA Criteria		Conformance to MUTCD		Train Speed		Location		Roadway Type		Train Volume		Highway Volume	
		Yes	No	Yes	No	High	Low	Rural	Urban	Local	Non-Local	High	Low	High	Low
Passive	High Accident Rates	X			X		X	X		X			X		X
	Low Accident Rates	X			X	X		X		X		X			X
	All Observations	X			X		X	X		X			X		X
Flashing Light Signals	High Accident Rates	X			X		X		X		X		X	X	
	Low Accident Rates	X			X	X			X	X		X		●	●
	All Observations	X			X		X		X	X			X	●	●
Gates	High Accident Rates	N.A.			X		X		X		X	X			X
	Low Accident Rates				X	X			X	●	●	X		●	●
	All Observations				X	X			X		X	X			X
Entire Sample	High Accident Rates	X			X		X		X	●	●		X		X
	Low Accident Rates	X			X	X		X		X		X			X
	All Observations	X			X		X	X		X			X		X

N.A.--Not applicable; all gates meet FHWA criteria
X--Indicates that observations in a category generally exhibited a tendency for that characteristic
●--Indicates that observations in that category did not exhibit a tendency for that characteristic

seemed to be associated with high accident rates. This trend was displayed by passive, flashing light signal, and gate observations as well as all observations in the sample. Not all low and high accident rate observations followed this trend; nonetheless, a distinct tendency was evident in all the comparisons involving train speed. This discovery indicates that train speed may influence driver behavior and that warning devices, including automatic signals, were not completely capable of overcoming driver perceptions of hazard at crossings associated with train speed.

The analysis of crossing location, rural or urban, did not reveal any strong association between location and accident rates. However, passive and flashing light signal high accident rate observations were somewhat more likely to be located in urban areas than crossings in those categories in general were.

The analysis of the percent of crossings on local roads revealed that most high accident rate observations were less likely to be on rural roads than observations in general were. This trend was most distinct in the case of automatic signals (e.g., flashing lights and gates). In both cases, high accident rate observations had substantially lower percentages of observations on local roads than those device's observations in general had. Apparently, the effectiveness of automatic signals is influenced by conditions present on non-local roads.

In all cases, low accident rates were associated with high train volumes, and high accident rates tended to have low train volumes. Two indications were given by this result. First, grade crossing accidents apparently do not vary linearly with train volumes; other significant factors seem to be involved. Secondly, warning devices are not always effective at low volume crossings, and this was especially evident for observations with automatic signals. Again, driver behavior may be influenced by train frequency, and current warning devices apparently cannot compensate for this behavior in all cases.

Similar highway volume distributions were found for high accident rate observations, low accident rate observations, and all observations within a device category for each device category examined. The factor used to account for highway volume in the accident rate equation seemed to properly adjust for differences in ADT. The only exception was flashing light signals. There were indications that the accident rates of these observations were more sensitive to differences in highway volume than observations with other warning devices.

The final comparison involved the distribution of warning device types for high accident rates, low accident rates, and observations as a whole for the entire sample. The percentage of low accident rate observations with gates was substantially higher than the percentage of gates in the entire sample, and the low accident rate observations were less likely to have passive devices than the sample as a whole was. Flashing light signals were somewhat overrepresented in the high accident rate category compared to the percent of flashing light signals in the entire sample.

CHAPTER 6

MAJOR CONCLUSIONS AND RECOMMENDATIONS

This research attempted to determine the influences certain factors had on device effectiveness, as measured by an accident rate. One segment of the research analyzed the influence of warning device type, suitability, and conformance on effectiveness, and the other investigated characteristics of high and low accident rate observations.

It should be noted that some difficulty was encountered in formulating an appropriate response variable. The relative rarity of grade crossing accidents and the relatively short period for which there is consistent nationwide data created some problems in defining an accident rate. The accident rate used may indeed not truly indicate the effectiveness of a warning device at a crossing; however, the accident rate was at least an indicator of effectiveness and was used in the absence of other viable measures. The findings of this study must be viewed with this in mind.

However, the results of this research do provide insight into at least some of the factors involved in warning device effectiveness and, in some cases, identify areas which warrant further investigation. These issues are discussed in the following summary of the major findings.

Influence of Warning Device Type on Effectiveness

Differences in effectiveness, as reflected by accident rates, were identified for the warning device categories analyzed. Generally, gates were found to be the most effective, and passive devices were least effective. However, for some cases of device suitability and conformance to MUTCD standards, no differences could be detected between flashing light signals and passive signals.

Influence of MUTCD Conformance on Effectiveness

The data used in this study do not support a conclusion that the conformance or nonconformance of warning systems to MUTCD standards significantly influence device effectiveness. Differences in accident rates could not be explained by differences in conformance. However, some types of non-conformance may have a greater impact than others. Since devices were classified according to their meeting or not meeting standards, these individual effects could not be tested. There is a need to study different types of non-conformance, especially since approximately 84 percent of the warning systems evaluated did not conform to MUTCD standards in one way or another, and conformance to standards would be expected to influence device effectiveness.

Influence of Device Suitability on Effectiveness

No consistent findings linking device suitability to effectiveness were found. Although it was expected that warning systems at locations judged to be in need of higher level signals (e.g., passive devices located where flashing light signals were apparently needed) would be less effective than devices judged to be suitable for their location's conditions, this was not found to be the case. These results suggest that the analysis based on FHWA guidelines failed to accurately assess device suitability, and perhaps additional factors should be identified and incorporated into the guidelines.

Train Speed

High train speeds were associated with low accident rates, and low train speeds were associated with high accident rates. This finding was consistent for all warning device categories considered individually and for all observations considered as a whole. This result suggests that driver behavior is influenced by train speed. Perhaps greater caution is exercised at high train speed crossings, and, due to perceptions of risk, less care is taken at low train speed locations. Additionally, active traffic control devices cannot always compensate for these attitudes. More research is needed to investigate the link between device effectiveness and train speed to examine its extent, its causes, and to identify possible countermeasures.

Train Volume

Low accident rate observations tended to have high train volumes, and high accident rate observations were associated with low train volumes. These trends were not absolute, but the tendencies were distinct. Apparently, accidents do not vary linearly with train volume. The results also suggest that driver perceptions of hazard are influenced by the frequency of train arrivals and that these perceptions in turn influence safety. Since this trend was noticed for automatic signals, there are apparently certain situations where these signals are not effective in overcoming the influence of these perceptions. Research is needed to investigate this apparent phenomenon, to determine the extent to which it influences safety, and to identify ways in which warning devices might be improved to overcome its effects.

Limitations of the National Inventory

The extensive use of information from the National Grade Crossing Inventory revealed some limitations in that data base. These limitation were generally concerned with either the accuracy or the completeness of the available information. In terms of completeness, some information which would have aided the analysis, such as highway speeds and separate data for the two highway approaches was missing, and collection of this information seems feasible within the current framework.

A great deal of the accuracy concerns are related to the lack of or incorrect inventory updates. Periodic reporting would alleviate much of this concern. There is a need to report the specific dates of changes in crossing characteristics such as train volumes and warning devices. Periodic updating of all characteristics would allow more accurate analysis of the interrelationship of the various characteristics.

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