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16. Abstract

This research identified and analyzed contributing factors to train-involved crashes in Texas. A detailed literature review was performed to investigate driver expectancy and experience, driver knowledge of highway-railroad grade crossings, human factors issues, driver attitudes, and crash investigations of train involved crashes. Warning activation technologies were investigated to determine their effect on crashes at the crossings. The contributing factors for three years of crash data were classified as railroad factors, environmental factors, roadway factors, and driver/passenger factors. The frequency distributions for these crashes were compared to corresponding national and statewide crash frequency distributions. Hypotheses were formulated and tested to relate potentially contributing human, geometric, and other factors to crashes at highway-railroad grade crossings.

The five most frequently identified primary contributing factors were; tried to beat train; impaired driver; stuck, stalled, or stopped on tracks; driving around gates; and driver inattention. The findings of the crash analysis revealed that a greater proportion of male drivers are involved in "tried to beat the train" crashes, semi-tractor trailers and trucks with trailers are more frequently involved in crashes where intersection proximity is the primary contributing factor, and the average severity of crashes occurring at passive crossings is greater than the average severity of crashes occurring at active crossings.

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ENHANCED TRAFFIC CONTROL DEVICES AND RAILROAD OPERATIONS FOR HIGHWAY-RAILROAD GRADE CROSSINGS: FIRST YEAR ACTIVITIES

by

Daniel B. Fambro, P.E.
Associate Research Engineer, Texas Transportation Institute
Associate Professor, Civil Engineering Department
Texas A&M University

Scott A. Cooner
Assistant Research Scientist
Texas Transportation Institute

Jennifer Messick
Graduate Research Assistant
Texas Transportation Institute

and

Richard T. Bartoskewitz
Engineering Research Associate
Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

This report describes activities completed during the first year of a two-year study focusing on improving safety at highway-railroad grade crossings. The activities completed during the first year included a review of published literature on driver behavior at highway-railroad grade crossings; an assessment of railroad operating practices at highway-railroad grade crossings, including audible warning devices and locomotive conspicuity measures, and requirements for their use; an assessment of basic train detection technologies used at active highway-railroad grade crossings; and a statewide crash study.

In the second year of the study, the results of these and other ongoing study activities will be used in the development and evaluation of enhanced traffic control devices. At the end of the study's second year, implementation of the study's recommendations may be accomplished through revision of the *Texas Manual on Uniform Traffic Control Devices*, Texas Department of Transportation (TxDOT) policies, or focused public education campaigns and materials.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Daniel B. Fambro, P.E. No. 47535 (Texas).

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The authors wish to acknowledge the contributions of the Technical Advisory Committee which includes Herbert Bickley (Lufkin), David Greear (Traffic Operations Division), Gerald Jackson (Waco), and Mark Thorp (Traffic Operations Division) of the Texas Department of Transportation, and Ken Rouse of the Union Pacific Railroad. The committee provided technical input and suggestions for the research plan, which was greatly appreciated.

The authors would also like to acknowledge Hoy Richards and Neil Rowan for providing related information and technical assistance, and help in reviewing the report.

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SUMMARY

A highway-railroad grade crossing is a unique intersection where two different transportation modes (trains and vehicles) share the same physical space. Many factors contribute to collisions between trains and vehicles at highway-railroad grade crossings. Crashes involving trains and vehicles are a significant safety problem in Texas each year. This research attempts to identify and analyze contributing factors to train-involved crashes in Texas.

A detailed literature review was performed investigating driver expectancy and experience, driver knowledge of grade crossings, human factors issues, driver attitudes, and crash investigations of train involved crashes. In addition, warning activation technologies commonly employed at grade crossings were investigated to determine their effect on crash history at the crossings.

Three years of crash data (1328 total crashes) were analyzed for the contributing factors. The contributing factors were classified into four categories: railroad factors, environmental factors, roadway factors, and driver/passenger factors. The crash data were analyzed using one and two-way classification tables. The frequency distributions for the crashes included in this study were compared to the corresponding frequency distributions for national or statewide crashes using a Chi-Square statistical test. Finally, research hypotheses were formulated based on a literature review of driver behavior and previous crash studies and then tested using population proportion tests.

The five most frequently identified primary contributing factors were: tried to beat train; impaired driver; stuck, stalled, or stopped on tracks; driving around gates; and driver inattention. The Chi-Square comparison showed that the protection type, activation technology, time of day, light conditions, driver age, ethnicity and gender, total occupants in vehicle, crash severity, location type, and roadway class were statistically different compared to the corresponding national and statewide frequency distributions.

The crash analysis indicated a greater proportion of male drivers were involved in crashes where tried to beat the train was the primary contributing factor. Semi-tractor trailers and trucks with trailers are more frequently involved in crashes where intersection proximity is the primary contributing factor. The average severity of crashes occurring at passive crossings is greater than the average severity of crashes occurring at active crossings.

1.0 INTRODUCTION

The Federal Highway Administration (FHWA) reports that there are 13,235 public highway-railroad grade crossings in Texas as of 1993 (1). This number is greater than in any other state; Illinois ranks second with 10,364 crossings. Approximately 4,500 (34 percent) of Texas' public grade crossings are classified as "active" crossings. Active crossings provide warning of the approach or presence of a train. A detection circuit located in the railroad track senses the presence of the train and activates the warning devices at the crossing. Examples of active warning devices include mast- and cantilever-mounted flashing light signals, automatic gates, wigwag signals, and bells. Crossings that lack train-activated warning devices are classified as "passive" crossings. Passive crossings employ signs and markings to identify the location of the crossing and direct the attention of the motorist, bicyclist, or pedestrian toward it. Passive devices provide static messages; the message conveyed by the signs or markings remain constant regardless of the presence or absence of a train. Both types of crossings use the same advance warning signs and pavement markings to alert roadway users that a highway-railroad grade crossing is nearby.

In its simplest form, a highway-railroad grade crossing is nothing more than an intersection which handles two conflicting streams of traffic; however, the grade crossing is unique in that two different modes of transportation compete for the same physical space. This attribute and the different operating characteristics of highway vehicles and trains constitute a safety problem at highway-railroad grade crossings (2). The operating characteristics of trains inhibit their ability to stop quickly. Unlike cars, trains move upon a fixed path or guideway, and cannot swerve to avoid an impending crash. Therefore, cars must yield right-of-way to trains at highway-railroad grade crossings, or conflicts will occur. Texas law clearly states that the motorist should always "slow, look, and listen, and be prepared to yield the right-of-way to an approaching train" at a highway-railroad grade crossing (3).

1.1 PROBLEM STATEMENT

Driver error is frequently cited as a contributing factor in highway-railroad grade crossing crashes. Driver error may result from failure to perceive that a train is in hazardous proximity to the grade crossing. Alternatively, the driver may detect the train but decide erroneously that adequate time is available to clear the crossing. Explanations for the driver's failure to detect the train or the faulty decision-making process are numerous. It is suggested that a leading cause of bad decisions is violation of driver expectancy. If a driver is only familiar with active highway-railroad grade crossings, he or she may not understand his or her responsibilities at a passive crossing. Further, the driver who has had experience at a crossing with infrequent trains may not pay adequate attention at unfamiliar locations with higher train volumes.

Another possible source of confusion at highway-railroad grade crossings is the current system of visual communication. The advance warning sign and railroad crossbuck sign do not differentiate between active and passive crossings, thereby complicating the driver's decision-making task. National statistics show that more than 50 percent of all collisions between motor vehicles and trains occur at active crossings, which in theory should have substantially fewer crashes or no crashes at all. One potential explanation is that the types of warning device technologies used and the warning time they provide may contribute to the frequency of crashes at these crossings. The point should be made that many more collisions, injuries, and fatalities would have occurred if active warning devices had not been installed at the crossings.

1.2 RESEARCH OBJECTIVE

The objective of this study is to develop, test, evaluate, and recommend improved methods for communicating with drivers at both active and passive highway-railroad grade crossings. Proposed new devices should demonstrate compliance with the *Manual on Uniform Traffic Control Devices* (MUTCD), high conspicuity and target value, adequate comprehension by the Texas driver population, and relatively low implementation cost versus alternative measures. To accomplish the research objective, the research team formulated a work plan consisting of nine tasks:

1. Assess driver behavior and causes of driver error;
2. Assess warning device activation technologies;
3. Assess railroad operating rules and practices;
4. Conduct a statewide grade crossing crash study;
5. Monitor experimental passive sign systems at test crossings;
6. Develop and evaluate enhanced traffic control devices;
7. Create and convene a public education advisory committee;
8. Develop a comprehensive plan for highway-railroad safety awareness; and
9. Prepare and submit a final report documenting the research findings and recommendations.

This report documents the results from the study's first year activities—Tasks 1 through 4.

1.3 ORGANIZATION

This report contains six sections, including this introductory section. Sections 2 through 5 discuss the following research activities completed during the first year of this two-year study:

- Review of literature on driver behavior at highway-railroad grade crossings;
- Study of train detection technologies for highway-railroad applications;
- Study of railroad operating rules and practices at grade crossings; and
- Analysis of contributing factors in grade crossing crashes in Texas.

Section 2.0 summarizes the findings of previously-conducted research; specifically, information relating to driver behavior at highway-railroad grade crossings and train-involved crash studies. Section 3.0 describes train detection technology for activating highway-railroad warning devices. Section 3.0 also discusses railroad operating rules and practices which impact highway-railroad safety. Section 4.0 describes the study design for the crash analysis study. Section 5.0 describes the results of the crash analysis study. Section 6.0 describes the conclusions and recommendations from the first year activities.

2.0 DRIVER BEHAVIOR

Driver behavior at highway-railroad grade crossings has been the subject of numerous research studies in the past three decades. These studies have resulted in effective countermeasures that have enhanced driver behavior and highway-railroad grade crossing safety. These countermeasures, along with the conversion of many passive crossings to active crossings, have contributed to improvements in safety as crashes resulting in fatalities have decreased from 998 in 1976 to 489 in 1992 (4). However, significant safety problems at grade crossings can be improved with a better understanding of the overall issue.

This section provides a comprehensive overview of driver behavior at highway-railroad grade crossings, which contributes to collisions between trains and motor vehicles. Specifically, driver expectancy and experience, driver knowledge of grade crossing information, human factors considerations, enforcement, and driver compliance are discussed.

2.1 DRIVER EXPECTANCY AND EXPERIENCE

There are a number of theoretical models formulated to explain driver behavior at highway-railroad grade crossings. Nearly all of these comprehensive models share the important feature of incorporating the concept of driver expectancy. This inclusion recognizes the driver responds to not only what is physically present in the driving environment, but also to what is anticipated based on past experience. In essence, expectancy is a condition in which a driver is prepared to perceive or respond to a set of circumstances and is unprepared for others. An expectancy may be based on an integration of long-term (*a priori*) driving experience or may be based on recent, short-term (*ad hoc*) driving experience (5).

Expectancies may be factors in driver behavior at highway-railroad grade crossings. These expectancies could relate to the likelihood of encountering a crossing, the types of traffic control devices present at the crossing, the likelihood of a train in the vicinity of the crossing, the warning time provided by the flashing signals, the amount of delay caused by waiting for the train, etc. A driver's expectancies at grade crossing sites can influence what he or she sees, hears, and does in certain situations.

A driver's expectations of the likelihood of encountering a train and the physical context of the crossing influence the detection and recognition of objects at a highway-railroad grade crossing. There is some evidence that a low expectancy of the presence of trains at a crossing increases the time required to detect and recognize a train. Studies have shown that it takes longer to detect an object when it occurs in an improbable context than when it occurs in a probable context (6). The judgment of whether a particular context is probable depends to a large extent on past experience and knowledge of the observer.

Previous Research Findings

In 1975, Sanders surveyed 1,200 drivers and found that approximately 80 percent relied on past experience and memory to detect a grade crossing. Drivers familiar with particular crossings were more likely to rely on past experience and their perception of train volume than observation (7). Another study established the significance of driving experience to comprehension of grade crossing traffic control devices. Specifically, the more miles traveled per year, the higher the comprehension level (8).

In 1979, Tidwell and Humphreys tested 879 drivers and found that 35 percent thought all grade crossings have active protection. Nineteen percent believed that all grade crossings, except those grade crossings with low train volumes, have active protection (9). The authors asserted that these expectancies may affect the driving behavior of those drivers as they approach passive crossings. Drivers who believe that signals are placed at all crossings regularly used by trains would be expected to drive as if they had the right-of-way unless they saw a flashing signal or lowered gate. A study by Richards and Heathington produced similar results concluding that 62.5 percent of participants age 18 and below believed all crossings had flashing lights (compared with 21.6 percent of all drivers surveyed) (8). Finally, an analogous driver survey administered by Fambro and Heathington found that 12 percent of the subjects believed that flashing light signals existed at every crossing (10).

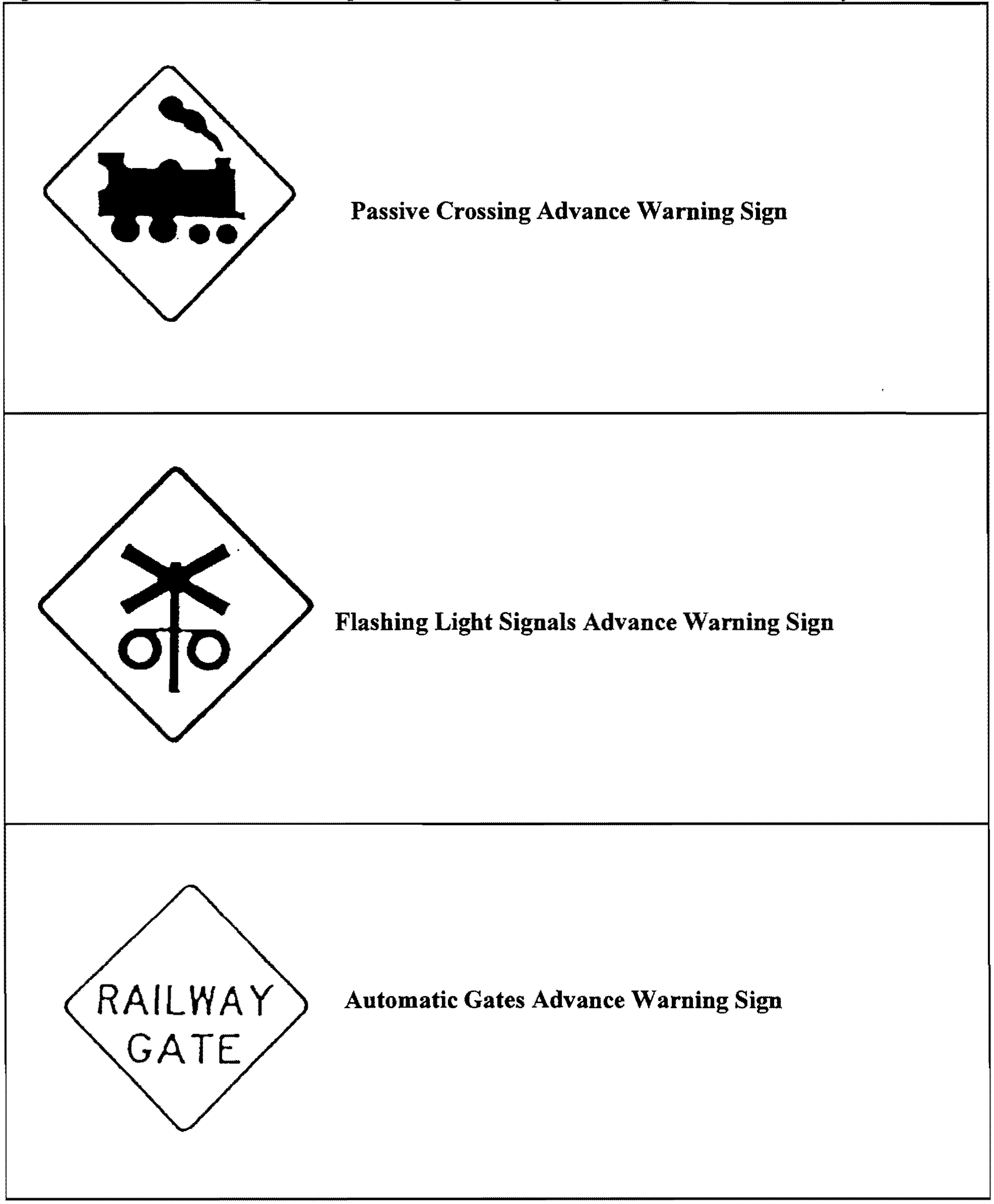
Distinctive Advance Warning Signs

The advance information required by the driver depends on the type and characteristics of the grade crossing. Currently, advance signing and pavement markings are the same for both active and passive crossings, even though the two types of crossings require vastly different driving behavior. Therefore, it is the driver's responsibility to identify the type of crossing and respond accordingly.

Several studies contend that consideration be given to developing unique advance signing to inform drivers of their responsibility as they approach highway-railroad grade crossings (11,12). Having the same sign and marking system at both crossing types is a major deficiency of advance signing and, further, that it violates the driver's expectancy and may be confusing to the average motorist (13). As a result, the motorist must detect the presence or absence of active warning devices at the grade crossing. This recognition occurs later than if the driver were informed by the advance warning sign (5).

The lack of information about whether a grade crossing is actively protected is particularly critical at night. Berg pointed out that a driver may be unable to discern the type of crossing until he or she is already in the nonrecovery zone (14). Although crossbuck signs and gate arms at crossings are normally reflectorized, the problem is compounded because active warning lights at the crossing are usually not reflectorized. Therefore, if the grade crossing is neither illuminated nor gate-protected, no obvious cues are present to distinguish between an inactivated signal and the absence of an automatic signal until the driver is close to the grade crossing.

Australia, Great Britain, and Israel use distinctive advance warning signs, depending on the type of protection system at the grade crossing (i.e., if the crossing is actively protected, the signs inform the driver of whether there are flashing lights or gates). The Australian advance warning sign system (Figure 1) uses an icon of a steam locomotive to indicate a crossing with passive protection, a flashing light icon to indicate a crossing with flashing light signals, and a word message to indicate a crossing with automatic gates. The Israeli standard advance warning sign is a triangular sign with three black diagonal stripes on a light rectangular background. A train symbol without



Passive Crossing Advance Warning Sign

Flashing Light Signals Advance Warning Sign

Automatic Gates Advance Warning Sign

Figure 1. Australia: Advanced Warning Signs

a circle indicates a passive crossing; a train symbol with a filled circle above it indicates a grade crossing protected by flashing lights; and a gate symbol with a filled circle above it indicates a grade crossing with flashing light signals and gates (5). At many highway-railroad grade crossings (intersections) in the United States, advance warning signing provides the motorist with more explicit information of what action is required, i.e., STOP AHEAD, YIELD AHEAD, or SIGNAL AHEAD text or icon messages. This type of warning information could also be useful to motorists approaching highway-railroad grade crossings.

2.2 DRIVER KNOWLEDGE OF GRADE CROSSING INFORMATION

The success of any traffic control system depends on its ability to convey clear, and understandable information about what is required of the motorist. The ability of traffic control devices and warning signs to communicate a clear and understandable message is important at highway-railroad grade crossings because of the specialized requirements placed on motorists. Motorists must understand the requirements and traffic control devices at highway-railroad grade crossings in order to safely negotiate them.

Driver Requirements at Highway-Railroad Grade Crossings

The Uniform Vehicle Code (UVC) is a comprehensive guide for state motor vehicle laws. Each state typically uses the UVC in one form or another. Section 11-701 describes stopping requirements at grade crossings (15):

> (a) Whenever any person driving a vehicle approaches a railroad grade crossing under any of the circumstances stated in this section, the driver of such a vehicle shall stop within 15.25 meters but not less than 4.57 meters from the nearest rail of such railroads, and shall not proceed until he can do so safely. The foregoing requirements shall apply when:
>
> 1. A clearly visible electric or mechanical signal device gives warning of the immediate approach of a train;
> 2. A crossing gate is lowered or when a human flagman gives or continues to give a signal of the approach or passage of a railroad train;
> 3. A railroad train approaching within approximately 457.50 meters of the highway crossing emits a signal audible from such distance and such railroad train, by reason of its speed or nearness to such crossing, is an immediate hazard;
> 4. An approaching railroad train is plainly visible and is in hazardous proximity to such crossing.
>
> (b) No person shall drive any vehicle through, around or under any crossing gate or barrier that is closed or is being opened or closed.

Section 11-801 of the UVC covers driver action and approach speed:

> No person shall drive a vehicle at a speed greater than is reasonable and prudent under the conditions and having regard to the actual and potential hazards then existing. Consistent with the foregoing, every person shall

> drive at a safe and appropriate speed when approaching and crossing an intersection or railroad grade crossing. . . . (15)

Traffic Control Devices at Highway-Railroad Grade Crossings

Five traffic control devices (TCD's) are commonly used at highway-railroad grade crossings, as specified in the *Manual on Uniform Traffic Control Devices* (MUTCD) (16):

1. Railroad Crossing (Crossbuck) Sign (R15-1), with an associated auxiliary sign (R15-2) which indicates the number of tracks if there is more than one;
2. Railroad Advance Warning Sign (W10-1), with other versions (W10-2,3,4) for use where roads are parallel to the tracks;
3. Pavement markings, consisting of an X, the letter RR, traverse lines, and a no passing marking (for two lane roads);
4. Flashing light signals (post or cantilever mounted); and
5. Automatic gates (used in conjunction with flashing light signals).

Comprehension of Traffic Control Devices

Numerous studies have addressed motorist understanding of grade crossing traffic control devices and their associated traffic laws. Most of the studies show there is a good understanding of the primary message that there is a grade crossing nearby, and that the active devices (flashing lights and gates) indicate there is a train approaching or occupying the grade crossing. However, the studies have often concluded that there is a poor discrimination of the precise meaning, location, and required actions of the grade crossing traffic control devices listed above.

Sanders et al. examined drivers' knowledge and attitude concerning highway-railroad grade crossing traffic control devices and their corresponding observed behavior (7). The study determined that motorists' ability to make correct decisions at grade crossings is related to their knowledge and attitudes toward the crossing traffic control devices.

Womack et al. conducted a study investigating driver understanding of the railroad advance warning sign (W-10) (12). The study found that 42 percent of the subjects surveyed did not know the advance warning sign was circular, 60 percent did not know it was yellow, and 64 percent believed it was placed at the grade crossing. The study also revealed that 70 percent of the sampled drivers did not expect to see the crossbuck after the advance warning sign, and 17 percent said they would "stop and look for trains" upon seeing the advance warning sign. Because of the large difference between intent and response, this study requires additional verification.

2.3 HUMAN FACTORS CONSIDERATIONS

The decision and reaction time of drivers determines how quickly they can recognize a hazard, make decisions on how to avoid the hazard, and take the appropriate action. In the case of a highway-railroad grade crossing, the driver must be able to detect the presence or arrival of a train, decide whether to continue across or stop prior to the grade crossing, and control the vehicle according to the decision that was made. If a driver makes a bad decision or control error, the likelihood of being involved in a crash would increase. The following sections provide an overview of some of the human factors considerations that may contribute to collisions between trains and vehicles.

Illumination

Due to the limitations of the human eye, drivers have difficulty seeing at night. Night-vision relies on contrast sensitivity to detect objects. In order for an object to be seen at night, it must be significantly either brighter or darker than its background.

In order for information to be perceived by a driver, it must be physically visible to the driver. Visibility depends on the illumination in the immediate forward roadway field and the reflected visual energy (luminance) reaching the driver's eyes from objects, the roadway, the peripheral area (the roadside), and roadside lighting. The degree of luminance relates to the candlepower of the headlight of the vehicle and the location of the object relative to the headlight beam. The highest intensity from properly aligned headlights is to the right and down. In most rural areas, the majority of the illumination for a highway-railroad grade crossing is provided by the vehicle's headlights.

Russell concluded that the current placement of the crossbuck does not utilize the light generated by the vehicle's headlights (17). By lowering the crossbuck 0.61 meters, the illuminance could be increased by 69 and 50 percent from distances of 76.25 and 45.75 meters, respectively. Illuminance is at a maximum at the base of the pole and decreases rapidly with the height above the base. Certain combinations of headlight angle and crossing geometry can result in a luminance value of zero for the crossbuck. This can be very dangerous, particularly at passive crossings where there is no other indication of track location.

Detection and Recognition of Trains at the Crossing

When a motor vehicle strikes a train, particularly when it hits part of the train other than the lead unit (engine), poor visibility of the train at the crossing is more likely to be a contributing factor than when a train strikes a vehicle. Several studies have investigated the difficulties drivers have in detecting trains at crossings without illumination at night (13,18). Studies have shown a higher incidence of vehicles running into trains in darkness than in daylight conditions (18).

Schoppert and Hoyt Study

Schoppert and Hoyt estimated that in approximately 13 percent of all grade crossing crashes occurring between 1960 and 1964, the train was already occupying the crossing when the driver was at the decision point (11). The researchers derived this statistic by analyzing such variables as the part of the train involved in the crash (e.g., the lead unit vs. the second quarter), the number of cars in the train, and the speeds of the train and the vehicle. Their research also allowed them to infer that lower-speed trains are more difficult to detect at night than higher-speed trains. One rationale given to explain this inference is the phenomenon that headlights aimed at a higher speed train produces a strobe effect as the railcars travel by the crossing.

McGinnis Study

The McGinnis study analyzed 1975 highway-railroad grade crossing crash data to determine whether the train was in the crossing when the driver needed to make a decision to stop (18). The part of the train involved in the accident, the speeds of the vehicle and the train, and the condition of the pavement were considered in the analysis. The study found that in 8.5 percent of all grade crossing crashes analyzed, the train was at the crossing when the driver was at the decision point.

These two studies show that in approximately ten percent of all grade crossing crashes, limited visibility due to darkness is a primary factor. Illumination of the grade crossing and reflectorization of the train are recommended countermeasures. However, the problem is not in detecting the train, but detecting the train before it reaches the grade crossing (5).

Judgment of Train Speed and Distance

Leibowitz performed a study of human factors issues related to crashes in 1985 (19). The research concentrated on the estimation of the safe time interval and perceived risk. Leibowitz contends that judgment of train speed and distance, which is essential in determining the safe time interval, is subject to several sensory and perceptual biases. The illusion of velocity, size, and perspective, as well as the deceptive geometry of collisions are biases that can mislead drivers into concluding that the safe time interval for crossing the tracks is longer than in reality.

Illusion of Velocity and Size

The illusion of velocity and size arises from the fact that, the larger the object, the slower it appears to be moving. This phenomenon can be observed at airports by comparing the apparent landing speeds of different sized aircraft. Although the aircraft have approximately the same landing velocities, the larger aircraft appear to be traveling more slowly. This illusion is created by the required effort of the human eye to "pursue" the object. The effort required to make a pursuit eye movement is determined by the actual velocity and contour of the object being tracked. The more the contour is moving in the direction orthogonal to the eye movement, the slower the apparent velocity. The net result is that, the larger the object, the slower the perceived velocity. The illusion of velocity and size affects driver behavior at grade crossings because drivers may overestimate the safe time interval for crossing the tracks. This overestimation may give the driver the impression that they have enough time to cross ahead of the approaching locomotive.

Illusion of Perspective

The illusion of perspective involves learned responses to monocular cues to depth (two-dimensional cues that can be appreciated with one eye). The perception of size and distance is not innate, but rather is learned as a consequence of perceptual and perceptual-motor experience. The monocular cues operate unconsciously to signal depth relationships in the surrounding environment. Several of these cues are normally present when a motorist views an oncoming train, e.g., the tracks, the ties, the ballast or stone in the vicinity of the tracks, and in some cases, rows of telephone poles or trees. The effect of these cues would be to increase the perceived distance to the train and would also contribute to overestimation of the safe time interval.

Deceptive Geometry of Collisions

If two objects traveling in straight lines at constant velocities are on a collision course, their positions relative to each other in the visual field remain constant. At the distance which a motorist's decision is usually made, the expansion pattern of the train is increasing slowly giving the motorist the perception that the train is traveling at a slower speed than is actually the case. This perception can also result in the overestimation of the safe time interval by the motorist.

Auditory Factors

Auditory warning signals from train whistles/horns provide redundancy to the messages provided by visual cues. The detectability of an acoustic signal is a joint product of the intensity and frequency of the signal, and the level and frequency spectrum of the noise background against which it must be detected. There are three primary factors that limit the intensity (and subsequent detectability) of the warning signal from a train whistle (5):

1. Distance reduces sound intensity with a 6 decibel decrease for each doubling of distance (i.e., the sound level 244 meters from the source will be 24 decibel lower than it was 15.25 meters from the source);
2. Physical barriers such as rolled up car windows, buildings, foliage, etc.; and
3. Wind direction and speed.

Additional factors that limit the detectability of a train whistle for motorists approaching a grade crossing are car stereos, fan, engine and tire noise, wind noise, conversation in the car, and other outside noises such as traffic. In addition to these factors, the hearing capability of the driver may also restrict the recognition of a train whistle.

Mortimer Study

The actual location for the first sounding of the horn as a train approaches a highway-railroad grade crossing varies from state to state. The first sounding location ranges from 91.50 to 549 meters with 402.60 meters being the most typical (20). Research performed by Mortimer indicates that for noisier environments (e.g., trucks, loud radios), a train horn may be difficult to hear until it is only about 152.50 meters away (21). The primary conclusion is that train horns will not be reliably detected and recognized to give adequate warning to a significant portion of motorists. These findings support the contention that many drivers report not hearing the whistle after being involved in a train-involved crash.

Tactile

Literature on driver perception has shown that the use of redundant sensory stimulation increases the likelihood of detecting an event. This theory has been applied to highway-railroad grade crossings through the use of rumble strips. Rumble strips have typically been placed a few hundred feet before the warning signs as a means of enhancing the warning sign through redundant stimulation of both the visual, tactile, and auditory senses. The intended goal of the rumble strip is to warn motorists of a potentially hazardous situation by enhancing the existing traffic control devices.

The three main arguments supporting the use of rumble strips are as follows:

1. They provide both vibratory and auditory stimulation where other devices only utilize one of the senses.
2. They have the potential to capture the attention of the driver earlier, and more easily, than visual signals.
3. They do not rely on the driver's eye position for their effectiveness.

The use of tactile devices at highway-railroad grade crossings has been met with mixed reviews. Zaidel, Hakkert and Barkan (1986) have suggested that rumble strips are more resistant to familiarity effects than other countermeasures because vibratory stimulation at high speeds is uncomfortable for the driver regardless of how frequently the driver experiences it (22). The 1971 study performed by Skinner indicated that rumble strips located at low-volume, passive crossings produced fewer crashes and fewer reports of near misses after rumble strips were installed (23).

The counter argument for these suggestions comes from a study performed by Parsonson and Rinalducci (1982) where the authors found rumble strips promoted unsafe driver behavior. An average of 12 drivers per day was observed swerving into the opposing lane of traffic to avoid the rumble strips (24). These findings show how difficult it is to influence drivers who are familiar with a roadway. Parsonson concluded that rumble strips should be reserved for nonresidential areas where unfamiliar drivers are numerous.

Despite the mixed reviews regarding rumble strips, some of the potential benefits include:

- Decreased approach speeds;
- Increased awareness of warning signs;
- Increased awareness of a potentially hazardous intersection;
- Visual detection of painted rumble strips effective in reducing speed prior to the driver's experience of vibratory and auditory stimulation; and
- Increased compliance with stop signs.

The negative effects associated with rumble strips and the mixed results of the existing studies conflict with the fact that the benefit of redundant stimulation of the different senses has been well established in the perception literature. Therefore, the application of rumble strips at highway-railroad grade crossings needs to be investigated further.

2.4 DRIVER ATTITUDES

Perceived Risk

Many decisions are based on the concept of perceived risk. Perceived risk involves a comparison between the inconvenience of a particular action and the perceived risk of the alternative. In the context of highway-railroad grade crossings, signal systems are often designed to accommodate the so-called "worst case" scenario (i.e., they must be activated in sufficient time to accommodate the fastest train, the slowest motorist, and the worst weather). For the majority of drivers, the warning activation time will be excessive causing drivers to judge for themselves whether it is safe to proceed. This judgment is based on the perceived risk of colliding with a train balanced against the uncertainty of how long it might take the train to clear the crossing. Although traffic crashes are a major cause of death and injury, the perceived risk on the highway is apparently so low that motorists are willing to risk a crash rather than be inconvenienced by obeying grade crossing and traffic signals, fastening seat belts, complying with posted speed limits, or maintaining safe headways from the next vehicle.

The perceived risk of a crash at a highway-railroad grade crossing is probably lower than other intersection types due to the low frequency of trains at some crossings. Motorists are typically impatient and they expect the automobile to save time in their daily lives. When motorists are delayed by a red traffic light, they know approximately how much time they will be delayed (normally less than one minute); however, there is much more uncertainty at a highway-railroad grade crossing. It is not unusual for a freight train to block an intersection for as long as 10 minutes (5 minutes is normal). Leibowitz argues that an imbalance between the perceived risk of an accident versus the inconvenience of the time it will take the train to clear the crossing causes many motorists to ignore the signal warnings and attempt to beat the train (19).

Social/Emotional Influences

Driving, like many other human activities, is influenced by the presence and actions of others. Research has shown that drivers tend to make more conservative judgments when there are other passengers in the car with them (25). Studies have also revealed that a driver's decision can be influenced by social facilitation. Seeing another motorist violate a rule without negative consequence provides a model and may weaken the barrier for others to also break the rule. For example, when one driver goes around a lowered gate barrier at a railroad crossing, others will be more likely to copy that behavior.

A driver's decision-making process at a crossing may also be influenced by his or her emotional state. The frustrations of driving in traffic can lead to impatience and aggressive driving. This frustration has been illustrated by a study of gap acceptance in highway traffic (25). The study found that drivers were more likely to accept short gaps after they have been forced to wait. It is reasonable to assume that the same frustrations and emotional consequences can be experienced by a driver at a highway-railroad grade crossing. Train crews and law enforcement officers on Operation Lifesaver tours report frequently encountering drivers who try to beat the train (26).

Enforcement and Driver Compliance

In general, enforcement can influence driver attitudes of driving situations. Drivers become familiar with their typical route and learn exactly "how much they can get away with." By law, drivers are required to stop 4.57 meters from the nearest rail and are not permitted to drive around lowered gates at any time. However, due to the fact that these laws are not rigorously enforced, drivers are accustomed to violating these laws without consequence.

Typically, police enforcement activities at highway-railroad grade crossings have been very low. Motorists' surveys have revealed that most (95 percent plus) drivers have not and do not know of an acquaintance who has received a traffic citation for a traffic violation at a highway-railroad grade crossing (8,9). There are certain problems that limit enforcement at highway-railroad grade crossings: the difficulty in defining a violation for many situations, the low frequency of trains actually utilizing the given crossing, and the lack of funding for enforcement at these locations.

A lack of enforcement activity at highway-railroad grade crossings could contribute to poor compliance at active crossings. It is generally recognized that motorists have more respect for traffic signals at conventional intersections than for the active warning devices (flashing light signals and automatic gates) at highway-railroad grade crossings. Locomotive engineers report motorists routinely drive around lowered gate arms and through crossings with signals flashing. Without a real threat of enforcement, motorists are probably more likely to disobey the warnings given by active devices. Ultimately, the lack of enforcement by police and the lack of compliance by drivers at highway-railroad grade crossings (particularly at crossings with active protection) may contribute to increased crash experience.

2.5 ACCIDENT INVESTIGATIONS OF TRAIN-INVOLVED CRASHES

How drivers behave as they encounter highway-railroad intersections is an important factor in determining safety problems at these intersections. Several significant studies have identified and described contributing factors for crashes between trains and motor vehicles. The following section will give an overview of significant findings of several of the more prominent accident investigations.

Berg et al. Causal Factor Study

Driver decision errors play an important role in safety at highway-railroad grade crossings. A major study contributing to understanding the role of decision-making errors in train-involved crashes was done by Berg et al. (27). These authors analyzed crashes from accident records and site investigations and then classified drivers' errors as recognition errors, decision errors, or action errors. A recognition error is defined as a breakdown in the detection and/or perception of the necessary information to safely negotiate the crossing. A decision error is defined as either a breakdown in the analysis of that information, or an incorrect choice of action. Finally, an action error is the failure to execute the chosen action.

The study found decision errors were predominant at sites with flashing lights (estimated between 53 and 71 percent) and less frequent (between 17 and 19 percent) at crossbuck-only sites. Recognition errors were the most prominent error type (estimated between 77 and 85 percent) at crossbuck-only crossings. The authors further classified decision-making errors into several subcategories, and identified common contributing factors to each case. The primary kinds of decision errors (and their approximate occurrence frequencies) were as follows:

Flashing Light Sites

1. Driver recognizes signal from approach zone, does not stop, does not detect train (18 percent);
2. Driver recognizes signal from the approach zone, does not stop, recognizes train from the non-recovery zone, attempts to stop (17 percent);
3. Driver recognizes signal from the approach zone, does not stop, recognizes train from the non-recovery zone, does not stop (22 percent); and

4. Driver recognizes signal from the approach zone, brakes to stop, recognizes train, attempts to cross (5 percent).

Crossbuck-Only Sites

1. Driver recognizes train from approach zone, does not stop (7 percent);
2. Driver recognizes train from approach zone, enters non-recovery zone, attempts to stop (8 percent); and
3. Driver recognizes train from approach zone, brakes to stop, attempts to cross (3 percent).

A large percentage of crashes occurred when flashing light warning devices, age (elderly and inexperienced), truck drivers, extended warning time, and multiple tracks were contributing factors. In the sample of crashes at passive crossings, the most prominent contributing factor was visibility (i.e., sight distance). Additional significant factors were the ability to judge the rate of closure of the train, inexperienced drivers, darkness, number of passengers, and approach speed (28).

Study Limitations

This research contains several limitations that must be considered when analyzing its findings. The following list provides a summary of five of the restrictions that have been cited (5):

1. Considered sites with flashing light signals or crossbucks; therefore, gates, stop signs, or other protection treatments were not considered;
2. Excluded crashes involving alcohol as a contributing factor;
3. Relatively small sample size (43 flashing light crashes at 41 sites, 36 crossbuck-only crashes at 34 sites);
4. Limited geographic area (all North Carolina crashes and southeastern Wisconsin); and
5. Constraints of error categorization due to specific definitions of error types.

National Transportation Safety Board Study

A 1985 National Transportation Safety Board (NTSB) study investigated 75 passenger/commuter train and motor vehicle crashes (28). The analysis revealed that driver behavior was by far the most prominent cause of grade crossing crashes. More than 65 percent of the crashes involved drivers who disregarded active warning devices, were inattentive or distracted, or took improper actions that led to driving in front of a train. In cases where the crash involved a vehicle striking the side of a train, 85 percent of the drivers were familiar with the crossing. More than 10 percent of the crashes investigated indicated that crossing angle intersection (i.e., the skew of the tracks) was a factor in the collision. The study also revealed that most motorists cannot accurately assess the closing speed of a train.

NHTSA Fatal Crash Study

A recent study, *Rail-Highway Crossing Safety: Fatal Crash and Demographic Descriptors*, investigated the circumstances under which fatal rail crossing crashes occur and characteristics of the drivers involved in such crashes (29). The study also compared fatal highway-railroad grade crossing crashes to all fatal highway crashes, and all fatal intersection crashes. The study utilized data from the National Highway Traffic Safety Administration's (NHTSA) Fatal Accident Reporting System (FARS) to formulate descriptive statistics. The study included analysis of FARS database for the calendar years 1975-1992. The list below gives several of the significant findings:

1. With the exception of the 3 a.m. to 6 a.m. time frame (in which there are very few such crashes), fatal rail crossing crashes occur fairly regularly throughout the day. This is in contrast to all fatal crashes which occur more frequently between the hours of 3 p.m. to 3 a.m.

2. Almost 60 percent of fatal rail crossing crashes occur during daylight conditions, compared with less than 45 percent of all fatal crashes.

3. More than 60 percent of fatal rail crossing crashes occurred in rural areas, a greater percentage than either all fatal crashes or other fatal intersection crashes.

4. Drivers ranging from 25 to 34 years old comprised the greatest percentage (24 percent) of fatal involvements, followed by drivers 16-20 years old (17 percent).

5. Male drivers comprised approximately the same percentage involvement in fatal rail crossing crashes (77 percent) as in all fatal crashes and fatal intersection crashes.

6. Drivers in fatal rail crossing crashes exhibited rates of alcohol involvement (a BAC of 0.10 or greater) approximately twice as great as drivers in other fatal intersection crashes, but about the same rate as drivers in all fatal crashes.

Appendix C of the NHTSA fatal crash study presents findings for train-involved crashes in the state of Texas for the years 1989-1992. The crash data revealed that the number of rail crossing crashes and fatal rail crossing crashes has significantly declined during the four-year study period. This pattern is supported by the pattern established in the FARS database for the entire country over the same time frame. In 95 percent of these highway-railroad grade crossing crashes, the train was moving forward; in 3 percent, the train was moving backward; and in less than 2 percent of the crashes the train was standing still. The pattern of daily highway-railroad grade crossing crashes in Texas resembles the national pattern. That is, rail crossing crashes are lowest on Sundays, and increase fairly steadily during the week, reaching a peak on Friday and Saturday (although there appear to be fewer such crashes on Saturdays in Texas than the national experience indicates). Crash severity for the 2,048 highway-railroad grade crossing crashes showed that 43 percent involved no injury, 18 percent involved a non-incapacitating injury, 15 percent involved possible injury, 14 percent involved incapacitating injury, and 10 percent involved fatal injury. Also, almost 60 percent of the crashes occurred at crossings equipped with railroad gates or flashing light signals (active signals).

3.0 WARNING ACTIVATION TECHNOLOGIES

Warning activation time is the time between the actuation of an active warning device and the time a train arrives at the crossing. The amount of warning activation time provided at crossings is primarily a function of the track circuit system used to detect a train. The following sections provide results of previous studies on the effect of warning activation time on driver behavior. The sections also describe the different types of track circuit systems commonly employed at crossings.

In addition to driver behavior considerations, the research team also addresses the control equipment which governs the operation of active warning devices. Specifically, the different types of track circuitry that provide the control logic in train detection systems will be discussed. The type of circuitry giving warning to motorists as they approach a crossing may affect their behavior and influence the history of crashes at the crossing. This topic is discussed in the last portion of this section.

3.1 WARNING ACTIVATION TIME

Warning times at highway-railroad grade crossings are often cited as a critical safety factor. Warning time may vary depending on the crossing geometry, crossing surface, traffic volumes, vehicle operator and the design vehicle. This variation can lead to problems. Long warning times will encourage undesirable driver actions; however, if the clearance time is too short, the slightest misjudgment on the driver's part can result in disastrous consequences.

Many research studies have addressed the topic of warning activation time for flashing light signals. One study found that 67 percent of the drivers surveyed expected it to take 30 seconds or more for the train to reach a crossing after the railroad signal begins to flash (8). Research conducted by Heathington, Fambro, and Richards concluded that train predictors (and the constant warning time they provide) can have positive effects on safety at active crossings (30). Their findings also showed that when average warning times were reduced to lower levels, both violations and "risky" or "aggressive" behaviors of drivers were significantly diminished. Basically, motorists were less likely to try to proceed through the crossing after activation of the flashing lights or gate arms. When they did proceed after the activation of the warning devices, a safer time interval was selected. If driver behavior is significantly influenced by the different train detection systems and warning times they provide, the crash potential at these crossings may also be impacted.

3.2 TYPES OF TRACK CIRCUITRY

There are several different types of train detection systems that can be deployed to operate active warning devices at highway-railroad grade crossings. Most of these systems depend on track circuitry to provide the control logic with information regarding approaching trains. The current track circuit system that is used has evolved over more than 100 years. According to both USDOT reports and the railroad supply industry, presently, no reliable or economical replacement exists that allows for the physical separation of the train detection system from the rails. Standard warning activation technologies that are currently being used in grade crossing traffic control devices include Direct Current, Alternating Current-Direct Current, Audio Frequency Overlay, Motion Sensing, and

Constant Warning Time activation circuitry. The following sections describe how each type of track circuit detects trains as they approach highway-railroad grade crossings.

Direct Current (DC) Track Circuit

The DC track circuit, commonly referred to as a conventional track circuit, is the precursor of all automatic train detection. A DC circuit is a simple electrical circuit that is still used in many flashing signal devices. In the DC track circuit system, the rails are used as conductors of energy supplied by the battery. The electrical current flows through the rails, the coils of a relay, and the battery completing a simple series circuit. As long as the circuit is intact, electrical current will flow uninterrupted. If a train is present, the traffic control device is activated (i.e., the signals will flash) when the flow of electrical current between the battery and relay is interrupted. There are actually three separate track circuits in the system: two approach circuits, and one island circuit. The three logic circuits deactivate the signal as soon as the train clears the intersection. If a malfunction occurs in the circuitry the control logic places the active device in its most restrictive position. Hence, the term "fail-safe" is used to describe the control logic applied to the highway-railroad traffic control device.

The maximum length of train detection for a DC track circuit is 3,050 meters. In reality, the limits of train detection are established by the placement of insulated joints between connecting rails. The circuit must have adequate length to provide for a minimum of 20 seconds of signal activation time prior to the arrival of the fastest train that uses the crossing. The drawback of this type of circuit design is that slower trains result in longer warning times which may promote more aggressive and risky behavior at crossings.

Alternating Current-Direct Current (AC-DC) Track Circuits

The AC-DC track circuit, also categorized as a conventional track circuit, is used where train activation distances are less than 915 meters. The circuit is a rectified AC circuit with all operating equipment located at the highway-railroad grade crossing. A rectifier is connected across the tracks at the train activation point. Insulated joints are used to define the limits of detection for the circuit. In effect, the rectified AC electrical current acts as DC current and operates as equivalent battery power. The presence of a train in the circuit reduces the rail voltage to near zero causing the track relay to release and activate the signal system. As with DC track circuitry, the drawback of this type of circuit design is that slower trains result in longer warning times which may promote more aggressive and risky behavior at crossings.

Audio Frequency Overlay Track Circuits (AFO)

The AFO track circuit is very similar to the DC track circuit discussed previously. The primary advantage of the AFO circuit is that it can be superimposed over other track circuits. Instead of a battery and a relay, as required by DC circuits, a transmitter and receiver of the same frequency are all that is required. Another distinct advantage of an AFO circuit is that no rail insulated joints are required for the system. A device called a "shunt" is physically placed in the track roadbed to replace the insulated joints and define the limits of the track circuit. The AFO track circuit includes a transmitter that supplies energy to the rails. The signal is then transmitted over the rail to a receiver at the opposite end of the track circuit to operate a relay. Several different frequencies can be transmitted to the receivers, therefore creating any number of track circuits. Again, the electrical energy conducted through the AFO circuit is equivalent to DC battery power. AFO track circuits can also produce longer warning times if slow trains operate through the crossing.

Motion Sensing Device

The motion sensing device is a solid state electrical component located at the highway-railroad intersection and connected to the track. A signal is fed over the rail to a series of points where the train can be detected. If the movement of the train is toward the intersection, the signals will be activated at a point in time to provide the minimum 20 seconds warning time. The signals will remain activated as long as the train movement is toward the intersection. The placement of sensor devices (terminating shunts) allows for the direction and speed of the train approaching the crossing to be monitored. These devices are normally used in rail passenger terminal areas or freight switching zones because of the improved safety and efficiency of vehicular traffic flow through the grade crossing intersection. The motion sensing device provides the distinct advantage of more reliable, constant warning times for motorists utilizing the crossing.

Constant Warning Time Device

The constant warning time device is a solid state electrical device similar to the motion-sensing device described previously. This device is located at the intersection and connected to the rail. The basic purpose of the constant warning time device is to provide a fixed signal activation time regardless of the speed of the approaching train. To accomplish this, each track approach section is equipped with its own track circuitry. A signal is transmitted along the rails in each control section to sense the approaching train's speed and distance from the crossing. A small computer generates command signals that activate the railroad signals at a constant activation time (must exceed 20 seconds) before the train arrival. These devices are the most sophisticated track circuitry, and they are widely used in railroad segments with differential speeds in railroad train operations. These devices are common where freight and passenger trains use the same railroad corridor because of the ability to provide a constant warning time even where there is a large variability in the speed of trains utilizing the crossing. This type of circuitry would be expected to provide the best driver behavior because of the uniform warning times that are produced.

3.3 RAILROAD OPERATING PRACTICES

"Railroad operating practices" refers to rules and procedures governing train operations at or near highway-railroad grade crossings. Railroad operating practices include regulations governing the use and operation of audible warning devices and certain locomotive conspicuity measures. Such rules, regulations, and procedures are enumerated in various Federal Railroad Administration (FRA) safety standards (31,32) and Interim Rules (33), and in the General Code of Operating Rules (GCOR) (34) and similar railroad rulebooks. Most of the major U.S. railroads have adopted the GCOR; Texas railroads that have adopted the GCOR include the following:

1. Atchison, Topeka and Santa Fe Railway Company;
2. Burlington Northern Railway Company;
3. Southern Pacific Lines;
4. Union Pacific Railroad;
5. Border Pacific Railroad;
6. Railtex Railroad Division;
7. Southwestern Railroad Company, Inc.;
8. Texas, Gonzales and Northern Railway Company, Inc.; and
9. Texas Northwestern Railway Company, Inc.

With the exception of the Kansas City Southern Railroad, all Class I railroads operating within the State of Texas abide by the provisions of the GCOR. Thus, the GCOR governs train operations at a majority of the public crossings in Texas.

Audible Warning Devices

FRA Requirements

Train whistles, horns, and bells are warning devices that enhance railroad safety by giving motorists, pedestrians, and other roadway users an audible indication of a train's proximity. FRA safety standards included under 49 CFR 229.129 specify requirements and performance standards for audible warning devices on locomotives (31). The FRA standards require that subsequent to August 31, 1980, each lead locomotive of a train be equipped with an audible warning device capable of producing a minimum sound level of 96 decibel at 30.50 meters forward of the locomotive in its direction of travel. (A decibel, dBA, is a unit for measuring the relative loudness of sounds which for humans range from zero, the average least perceptible sound, to about 130 for the average pain threshold.) The FRA permits a +/-4 decibel measurement tolerance for a given measurement. The device must be arranged in a manner that permits convenient operation by the locomotive engineer from the engineer's normal position in the locomotive cab.

The FRA safety standards also specify the measurement of the sound level of the audible warning device (31). A sound level meter conforming, at a minimum, to the requirements of ANSI S1.4-1971, Type 2, and set to an A-weighted slow response must be used. The locomotive must be located on level, tangent track. The microphone on the sound measuring instrument must be positioned 1.22 meters above the ground at the center line of the track. The microphone must be oriented with respect to the sound source in accordance with the manufacturer's recommendations.

FRA railroad operating practice regulations under 49 CFR 218 require that safety devices, such as audible warning devices, be operational (32). The FRA rules do not specify, however, the manner in which these devices are to be used. State laws and railroad operating rules dictate how audible warning devices should be sounded.

Operating Rule

The General Code governs the actual use of the audible warning device at most highway-railroad grade crossings in Texas (34). The GCOR requires train service personnel to ring the engine bell when approaching "public crossings at grade with the engine in front" under two specific circumstances. First, if distance permits, ringing must begin at least 0.40 kilometer before the public crossing and continue until the crossing is occupied. Second, if distance does not permit, ringing must begin soon enough before the crossing to provide a warning and continue until the crossing is occupied.

The GCOR also specifies the manner in which the engine whistle is to be used (34). The GCOR defines twelve different whistle signals, each pertaining to a different situation or circumstance. One of the twelve signals applies to trains approaching public crossings. The signal is a succession of two "long" sounds, one "short" sound, and an additional single "long" sound.

Whistle Bans

Whistle bans have been the subject of contentious debate since the late 1970s (35). Special interest groups unsuccessfully pursued nighttime train whistle bans on a national scale beginning at that time. Although these efforts failed, some attempts at the State and local level achieved greater success. Most notably, state whistle ban legislation enacted in Florida allowed local jurisdictions, cities, and counties to establish whistle bans between the hours of 10:00 P.M. and 6:00 A.M. The bans could only be imposed at crossings equipped with crossing gates, flashing lights, bells, and special highway advance warning signs, and on railroads that operated entirely within the State of Florida. By the end of 1989, seven counties and twelve additional cities in Florida had established whistle bans, covering 511 of 600 active crossings on a single railroad. Despite FRA findings that indicated significant reductions in nighttime safety levels at these crossings, no county or municipality in Florida elected to modify or repeal its whistle ban ordinance. An FRA Emergency Order issued July 26, 1991, required the railroad to sound the train horn when approaching public highway-railroad grade crossings. FRA states that reported accidents in the two-year period following the Emergency Order returned to pre-whistle ban levels.

In December 1991, FRA announced its intention to issue an Advance Notice of Proposed Rulemaking regarding a nationwide rule for train whistles at highway-railroad grade crossings (35). FRA and the Association of American Railroads (AAR), an industry trade association, agreed to conduct a national survey of train whistle bans. AAR member railroads were requested to submit information about State and local whistle bans of any type. Twenty-five railroads responded, with seventeen reporting that they were affected by whistle bans at one or more locations. These twenty-five railroads operate about 61 percent of the nation's total public highway-railroad grade crossings. Overall, the survey identified 2,705 crossings nationwide subject to either 24-hour or nighttime-only whistle bans. The results of an accident study at the affected crossings constituted the basis for a recent FRA report, *Nationwide Study of Train Whistle Bans*. The remainder of this section extracts and summarizes portions of that report relating to train whistle bans in place in Texas.

According to the FRA report, Texas is one of 27 states with one or more highway-railroad grade crossings subject to whistle bans (35). At least 78 Texas crossings are subject to whistle bans. For the FRA study, 65 Texas crossings were included in the "study group" of whistle ban crossings after a screening process to eliminate private crossings, pedestrian-only crossings, grade-separated crossings, closed crossings, and various others. These 65 crossings exist in eight Texas cities. At least six of the eight Texas cities have 24-hour whistle bans. The study revealed that 30 crashes resulting in one fatality and ten injuries occurred at Texas crossings during whistle bans between January 1, 1988, and June 30, 1994.

Headlights

FRA Requirements

FRA regulations in 49 CFR 229.125 require that each lead locomotive used in road service have a headlight capable of producing at least 200,000 candela (31). Furthermore, if a locomotive or train is regularly required to run backward for any portion of its trip, other than to pick up a detached portion of its train or to make terminal movements, it must also have a rear headlight capable of producing 200,000 candela. Each headlight must be arranged to illuminate a person at least 244 meters ahead of and in front of the headlight. The FRA regulations also require that each locomotive or train used in yard service have two headlights, one fore and one aft. Each headlight must be capable of producing a minimum of 60,000 candela and be arranged to illuminate a person at least 9.150 meters ahead of and in front of the headlight. All headlights must be wired with a dimming device.

Operating Rules

The FRA regulations in 49 CFR 229 only specify the provision and performance requirements for locomotive headlights. Various State laws and railroad operating rules mandate operational requirements. The GCOR specifies the manner in which headlights must be used under different types of circumstances (34). In summary, the headlight must be turned on in the "bright" mode to the front of every train at all times, with certain exceptions pertaining to train meets and passes which permit dimming or extinguishing the headlight. The headlight must be on "bright" when "approaching and passing over a public crossing at grade." The GCOR does not permit dimming the headlight when approaching or passing over a highway-railroad grade crossing.

If the train headlight fails, ditch lights must be used if the train is so equipped (34). In the event the headlight fails, ditch lights are not provided or are inoperable, and no other locomotive with operable equipment can serve as the lead unit, movement can continue, contingent on the requirement that a white light be displayed on the lead locomotive. Under these circumstances, the train must be stopped "before each public crossing, so a crew member on the ground can provide warning until the crossing is occupied." The GCOR states two specific exceptions to this requirement:

1. Crossing gates are in the fully lowered position; and
2. No traffic is approaching or stopped at the crossing.

Some locomotives are equipped with oscillating white headlights. These devices must be turned on when the engine is moving (34). Oscillating white headlights may be turned off under certain conditions stated in the General Code unless the movement involves public crossings.

Auxiliary External Lights

Definition

"Locomotive conspicuity" means "the enhancement of day and night visibility of the front-end unit of a train, by means of lighting, reflective materials, or other means, with particular consideration to the visibility and perspective of drivers of motor vehicles at grade crossings" (33). Auxiliary external lights are locomotive conspicuity measures in addition to the locomotive headlight. These devices include ditch lights, strobe lights, crossing lights, and oscillating lights.

Background

Section 14 of the Amtrak Authorization and Development Act (Pub. L. 102-533) added a new subsection (u) to section 202 of the Federal Railroad Safety Act of 1970 (45 U.S.C. 431). In summary, this legislation mandated the following actions (33):

1. Review of rules of the United States Department of Transportation (USDOT) with respect to locomotive conspicuity, including collection of relevant data from operational experience of railroads having enhanced conspicuity measures in service, and completion of current USDOT locomotive conspicuity research no later than December 31, 1993;

2. Issuance no later than December 31, 1992, of interim regulations identifying ditch lights, crossing lights, strobe lights, and oscillating lights as interim locomotive conspicuity measures, and authorizing and encouraging installation and use of such measures;

3. Initiation of a rulemaking proceeding no later than June 30, 1994, to issue final regulations requiring substantially enhanced locomotive conspicuity measures; and

4. Issuance no later than June 30, 1995, of final regulations requiring enhanced locomotive conspicuity measures.

Furthermore, the Act established December 31, 1997, as the deadline for equipping locomotives not otherwise specifically excluded from the regulations with (1) interim conspicuity measures (ditch lights, crossing lights, strobe lights, or oscillating lights) or (2) the conspicuity measures mandated by the final regulations.

On February 3, 1993, the Federal Railroad Administration (FRA) published interim rule IR-1 (58 FR 6899, codified as 49 CFR 229.133) concerning locomotive conspicuity enhancement measures (33). IR-1 authorized the equipping of locomotives at the head of a train or other movement with "auxiliary external lights" additional to the headlight for the purpose of improved conspicuity. The first interim rule also provided specifications or performance standards to be met by each qualifying arrangement of auxiliary external lights. The FRA solicited comments from railroads, lighting manufacturers, railroad employees, and other parties regarding (1) the concept of "locomotive conspicuity" and (2) the specific performance standards for the four auxiliary lighting arrangements.

The comments received by the FRA in response to interim rule IR-1 addressed several areas of concern (33):

1. The length of the "grandfather" period for compliance with any final rule;
2. The manner in which the auxiliary lighting systems should be activated;
3. The vertical and horizontal dimensional requirements for lighting placement;
4. The use of one versus two forward-facing, strobe lights;

5. The limitations imposed by IR-1 on the flash rates of strobes; and
6. Variations on the types of oscillating lights included in the interim rule.

FRA considered these comments sufficient to warrant revision of the interim rule. On May 13, 1994, the FRA issued a second interim rule, designated IR-2, on the matter of locomotive conspicuity and minimum standards for auxiliary external lights. IR-2 relaxed the standards contained in IR-1 concerning auxiliary external lights on locomotives. IR-2 also contained detailed and specific performance standards regarding the color, intensity, operation, mounting location, and flash rate for the four types of auxiliary external lights. Like IR-1, the second interim rule (IR-2) did not require that any train be equipped with conspicuity measures; the final rule, however, may require such action to be taken by the railroads on or before December 31, 1997.

Ditch Lights

Ditch lights originated on Canadian railroads as a means of illuminating the drainage ditches and adjacent railroad right-of-way to either side of the track, hence the name "ditch" lights. These devices were originally used to detect rock slides and other obstructions on the track and within the railroad right-of-way; more recently, they have seen widespread use as a safety countermeasure for highway-railroad grade crossings.

Ditch lights shall consist of two white lights, each producing a steady beam of at least 200,000 candela, placed at the front of the locomotive, at least 914.40 millimeters (mm) above the top of the rail (2). Ditch lights shall be spaced at least 914.40 mm apart if the vertical distance from the headlight to the horizontal axis of the ditch lights is 1,524 mm or more. If the vertical distance from the headlight to the horizontal axis of the ditch lights is less than 1,524 mm, the ditch lights shall be spaced at least 1,524 mm apart. Ditch lights shall be focused horizontally within 45 degrees of the longitudinal centerline of the locomotive.

Strobe Lights

Strobe lights are a more recent advance in locomotive conspicuity. Strobe lights shall consist of two white stroboscopic lights (33). Each strobe light shall have "effective intensity," as defined by the Illuminating Engineering Society's *Guide for Calculating the Effective Intensity of Flashing Signal Lights* (November 1964), of at least 500 candela. The flash rate shall be at least 40 flashes per minute, but not more than 180 flashes per minute. Strobe lights shall be placed at the front of the locomotive, at least 1,219.20 mm apart and no more than 914.40 mm above the top of the rail.

Crossing Lights

Crossing lights are a variation on the ditch lights previously described. Crossing lights shall consist of two white lights, placed at the front of the locomotive, at least 914.40 mm above the top of the rail (33). Crossing lights shall be spaced at least 914.40 mm apart if the vertical distance from the headlight to the horizontal axis of the ditch lights is 1,524 mm or more. Crossing lights shall be spaced at least 1,524 mm apart if the vertical distance from the headlight to the horizontal axis of the ditch lights is less than 1,524 mm.

Each crossing light shall produce at least 200,000 candela, either steadily burning or alternately flashing (33). The flash rate of crossing lights shall be at least 40 flashes per minute, but not more than 180 flashes per minute. Crossing lights shall be focused horizontally within 15 degrees of the longitudinal centerline of the locomotive.

Oscillating Lights

An oscillating light shall consist of two possible arrangements (33):

1. One steadily burning white light producing at least 200,000 candela in a moving beam that depicts a circle or a horizontal "figure eight" to the front of the locomotive, about the longitudinal centerline of the locomotive; or
2. Two or more white lights producing at least 200,000 candela each, at one location on the front of the locomotive, that flash alternately with beams within five degrees horizontally to either side of the longitudinal centerline of the locomotive.

An oscillating light may incorporate a device that automatically extinguishes the white light if display of a light of another color is required to protect the safety of railroad operations.

The General Code of Operating Rules instructs that when the lead locomotive of a train is equipped with an oscillating white headlight, the light must be turned on when the train is moving (34). The oscillating lights should be turned off when meeting other trains, passing trains, and during switching operations, unless the movement involves "public crossings at grade."

Other Rules Governing Movement of Trains at and Near Highway-Railroad Grade Crossings

Several provisions in the General Code of Operating Rules specifically address the movement of trains at and near highway-railroad grade crossings (34).

Cars Shoved, Kicked, or Dropped

When railroad cars are shoved, kicked, or dropped over road crossings at grade, a crew member must be on the ground at the crossing to warn traffic until the crossing is occupied. Any movement over the crossing must be made only on the signal of the crew member on the ground. Such warnings are not required under two conditions:

1. Crossing gates are in the fully lowered position, or
2. It is clearly seen that no traffic is approaching or stopped at the crossing.

Automatic Crossing Devices

Under any of the following conditions, a train movement must not foul a crossing equipped with automatic warning devices until the device has been operating long enough to provide warning and the crossing gates, if equipped, are fully lowered:

- Train movement has been delayed or stopped within 915 meters of the crossing,
- Train movement is closely following another train movement, or
- Train movement is on other than the main track or the siding.

Train crew members must observe all automatic crossing warning devices and report those that are not operating properly to the train dispatcher or proper authority by the first available means of communication. When a train has been notified that automatic warning devices are not operating properly, the train must not occupy the crossing until vehicular traffic is clear of the crossing.

Protection of Adjacent Tracks

If a train or cut of cars is parted to clear a road crossing or is standing near the crossing, when possible, an employee must be on the ground to warn traffic of trains or engines approaching on adjacent tracks.

Clear of Crossings and Signal Circuits

Cars, engines, or equipment must be left clear of road crossings and crossing signal circuits. If possible, train crews must avoid leaving cars, engines, or equipment standing closer than 76.25 meters from a road crossing when there is an adjacent track.

Actuating Automatic Crossing Signals Unnecessarily

Train crews must avoid actuating crossing signals unnecessarily by leaving switches open or permitting equipment to stand within the controlling circuit. If this cannot be avoided and if the signals are equipped for manual operation, a crew member must manually operate the signal for movement of traffic. A crew member must restore the signals to automatic operation before a train or engine occupies the crossing or before it leaves the crossing.

Blocking Public Crossings

If possible, a standing train or switching movement must avoid blocking a public crossing longer than ten minutes.

3.4 TRAIN DETECTION TECHNOLOGIES

The control equipment for highway-railroad active warning devices governs the physical operation of the devices. Train detection and control logic are the two subsystems that comprise the control equipment. Several different types of train detection systems are employed; however, practically all systems in widespread use for highway-railroad applications rely on track circuitry to provide the control logic with information regarding approaching trains.

The fundamental concept underlying most present-day railway signaling systems, including highway-railroad warning systems, was first embodied in a practical application by Dr. William Robinson in the early 1870s. In its simplest form, a track circuit is an insulated section of track with a relay on one end and a battery or other source of electrical energy on the other end. The basic components of an elementary track circuit include:

- The energy source, typically a battery;
- A limiting resistance, which constrains the current from the battery;
- Rails and rail bonding, both of which offer resistance;
- Ties and ballast, which together offer a path for current leakage between rails;
- Resistance placed in series with the relay; and
- A track relay.

Electric current originates at the positive post of the battery and flows along the path of limited resistance on one rail of the track. From the rail, current flows through the relay winding, through the relay series resistance, and back to the other rail of the track. The other rail is connected to the negative post of the battery completing the circuit. Upon completion of the circuit, the relay is energized and a contact closes to allow operation of the signal mechanism. When the wheels and axles of a train enter the circuit, they provide an alternate path of lower resistance from rail to rail through which the current flows. When the relay is de-energized, the contact opens and the operation of the signal mechanism is altered.

Of course, there are many variations on this fundamental design. Track circuits are one of the only, if not the only, means of train detection recognized as fundamentally safe by railway signal engineers. The development of so-called "off-track" train detection systems has been, and will likely continue to be, the subject of research. Activation of grade crossing warning systems and devices by means other than track circuitry could relieve the railroad industry of significant maintenance responsibilities and costs. However, according to recent USDOT reports and the railroad supply industry, no reliable or economical substitutes exist today that will permit separation of the train detection system from the rails.

4.0 STUDY DESIGN

Crash experience at highway-railroad grade crossings is an indication of a relative hazard. Crash history at grade crossings can help to identify the cause of the crash and what treatments may be used to avoid future crashes. The study of traffic crashes is different from that used to observe other traffic stream parameters. Since crashes occur infrequently and at unpredictable times and locations, they cannot be objectively observed as they occur. Thus, all crash data must be studied through secondary sources (accident reports).

Two basic approaches can be used in a crash analysis; the statistical approach and the case study approach. The statistical approach involves analyzing large samples of crash data for prevailing trends. In the case study approach, a smaller sample of grade crossings is used and an in-depth analysis of each crash is conducted. A combination of the statistical approach is used in this study because of the availability of several databases containing sufficiently comprehensive and reliable information to identify crash causal factors, as well as "quasi" case study approach relying on information from accident narratives to identify primary and secondary contributing factors for the same crashes.

This chapter contains five sections that describe the methods and procedures used. The first section describes the database used for analysis in this study. The second section provides a description of the different sources from which crash data were obtained. The third section outlines the variables and factors included in the analysis. The fourth section discusses the methods and procedures used to determine contributing factors to the crashes studied. The final section describes the data analysis.

4.1 SELECTION OF CRASHES FOR STUDY

The researchers studied all crashes involving a train (or other vehicle traveling on the rails) and a motor vehicle (i.e., train-involved) in Texas in 1992, 1993, and 1994. The total number of crashes is in excess of 1,300 crashes and represents a significant database for study. This database should comprise all train-involved collisions because the Federal Railroad Administration (FRA) requires any collision between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle, or pedestrian at a railroad crossing be documented (20).

4.2 DESCRIPTION OF DATA SOURCES

Crash data for this study were obtained from a variety of sources including the LANSER database, FRA database, accident narrative (ST-3) forms, GO software, and the Texas Department of Transportation inventory files. Descriptions of each data source and the data extracted from each source are provided in the following sections. Some data were extracted from more than one source for validation purposes.

LANSER Database

LANSER (Local Area Network Safety Evaluation and Reporting system) is a microcomputer software package that provides access to crash data records for the State of Texas. The Texas Transportation Institute (TTI), in cooperation with the Texas Department of Transportation (TxDOT), developed LANSER. The crash data used by LANSER originally were entered into a mainframe computer at the Department of Public Safety (DPS). TxDOT's Division of Transportation Planning provided the data to TTI on computer magnetic tape. The researchers identified the train-involved crashes in this database by either coding the object struck as a train or by choosing a railroad train as the first harmful event in the crash.

A significant amount of information for each individual crash is available in the LANSER reports generated in this analysis. Data extracted from LANSER included the following:

- DOT crossing identification number (ex. 765438W);
- Time of day when crash occurred;
- Driver race and gender (White, Black, Hispanic, or unknown and male or female);
- Driver age;
- Total occupants in vehicle;
- Light conditions (daylight, dawn, dark not lighted, dark lighted, and dusk);
- Roadway classification;
- Crash severity (non-injury, possible injury, non-incapacitating, incapacitating, and fatal);
- Train action (moving forward, backing, or standing still); and
- Location type (rural, <2,500,..., >250,000).

FRA Database

In November 1991, the FRA mandated that all railroads complete an inventory of track circuitry at active grade crossings under their maintenance. The data were collected through the completion of FRA Form F 6180.87 (11/91). For each grade crossing, two separate records are generated from the data collected on the form; the master record and the track circuitry record(s). The master record contains identifying and inventory data for the crossing including the name of railroad, DOT/AAR crossing number, milepost or spur designation, street name or highway number, county, state, total number of tracks, active warning devices at the crossing, and the train speeds at the crossing (optional). The track circuitry record contains the control circuit code, the design length from outer limit to crossing (optional), and the service date for each track at the crossing. The data (both circuitry records) for all crossings in Texas with active warning devices were obtained for use in the study analysis.

The acquired data were then matched by location with a train-involved crash in the three-year study period. The data obtained from the master and track circuitry records included the following:

- DOT crossing identification number;
- Proximity of traffic signals (i.e., signals used to control highway traffic over the crossing) to the railroad crossing;
- Control track circuitry; and
- Design length of the track circuit.

The control track circuitry was described using track circuit codes for the predominant (mainline) track approach. Table 1 shows the nine different codes established by the FRA to describe the control logic for track circuits at active crossings.

Accident Narrative Forms (ST-3)

The ST-3 Texas Peace Officer's Accident Report form is a document completed at the scene of an accident by the investigating officer. The ST-3 report form contains pertinent information on type, time, location, units involved, individuals involved, damage to property, and severity of injuries related to the accident being reported. The form also contains an investigator's narrative explaining what happened in the crash. Normally, the narrative gives a physical description of the units involved in the crash and their direction of travel. The narrative frequently states (if the crossing is active) the type of traffic control devices present at the grade crossing and whether they were functioning properly upon arrival at the scene.

The investigator's opinion of factors/conditions contributing to the crash can also be recorded. This opinion is expressed as a number(s) which represents one or more of the 71 factors provided on the form. These factors can also be verbalized in the narrative opinion of what happened. The investigator's narrative is sometimes supplemented by witness, train crew, driver, and passenger statements relating information on what happened in the accident. Finally, the narrative is normally supplemented with a diagram depicting the crash site. These two information sources (i.e., the narrative opinion and site diagram) are not coded into the databases used in this study; therefore, the ST-3 for each crash was reviewed.

Table 1. Track Circuit Codes Description

CODE	DESCRIPTION
A	Conventional Track Circuit
B	Conventional Track Circuit with Timing Sections
C	Audio Frequency Overlay (AFO) Track Circuit
D	AFO with Timing Sections
E	Motion Sensitive Track Circuit
F	Constant Warning Time Track Circuit
G	Manual Operation, e.g., by Key
H	None, Explain (e.g., Operating Rules Proscribe Approach in This Direction on This Track, Train Moves by Special Instructions, etc.)
J	Other, Describe (e.g., Wheel Counter, Presence Detector, Transducer, etc.)

GX Software

I-Net, Inc. developed the GX software package for the FRA. GX is the FRA's personal computer-based highway-railroad grade crossing data maintenance system. The FRA provides the software package to interested States and railroads so they can maintain their crossing inventory and send updates to the National Inventory. The database contains a computerized record of the four-part USDOT-AAR Crossing Inventory Form for each grade crossing. The record includes location and classification data (part I), train counts/speeds and warning devices (part II), physical data (part III), and transportation department information (part IV). Extensive editing and validation checks are incorporated into GX to ensure that the data contained in the system are current and accurate.

TxDOT Railroad Crossing Inventory

The Texas Department of Transportation is responsible for collecting and maintaining information on all highway-railroad grade crossings in the State system. The Traffic Operations Division's Railroad Section (TRF-RR) maintains a computerized database which contains the inventory information on the 13,000-plus public grade crossings in Texas. Records for all grade crossings where a train-involved crash occurred in the 1992-1994 study period were obtained. Information extracted from these records included:

- DOT crossing identification number;
- TxDOT district number;
- Time of day;
- Date; and
- Crash severity.

4.3 FACTORS (VARIABLES) INCLUDED IN DATA ANALYSIS

Study variables were identified by dividing the data into categories. The first category identifies railroad variables. The second category enumerates factors relating to environmental conditions. The third category summarizes variables relating to the physical layout of the highway-railroad grade crossing (i.e., the geometric conditions at and near the crossing). Finally, the fourth category describes driver and passenger factors. The following list summarizes the data which were obtained from the sources described previously:

Railroad Factors

1. *Traffic control system* employed: passive with crossbucks only, passive with crossbucks and stop signs, active with flashing light signals only, active with flashing light signals and cantilevers, active with flashing light signals and automatic gates, or active with flashing light signals, cantilevers, and automatic gates; and
2. *Activation technology* employed (at active crossings): DC track circuit, AC-DC track circuit, audio frequency overlay track circuit, motion sensing track circuit, constant warning time track circuit, or any other type of circuit.

Environmental Factors

1. *Location type*: urban or rural;
2. *Time of day*;
3. *Light conditions*: dawn, day, dusk, dark (lighted) or dark; and
4. *Weather*.

Roadway (Geometric) Factors

1. *Proximity of nearby intersection*: signalized or unsignalized, interconnected or separate with active warning devices;
2. *Parallel roadway proximity*; and
3. *Roadway classification*.

Driver/Passenger Factors

1. *Number of passengers*: occupants of the vehicle other than the driver;
2. *Sex and race of the driver*: male or female, White, Black, Hispanic, or other; and
3. *Age of driver*: young (16-25), mature (26-54), and elderly (55 and above).

4.4 IDENTIFICATION OF CONTRIBUTING FACTORS IN TRAIN-INVOLVED CRASHES

Two procedures were used in identifying factors contributing to train-involved crashes. The first involved obtaining the coded number for contributing factors from the ST-3 accident narratives. The second involved determining the primary contributing factors using a case study review of each individual accident narrative. The following sections explain both procedures in further detail.

Coded Number Factors From ST-3 Narratives

The ST-3 accident narrative forms contain a section where the investigating officer chooses from a numbered list to determine the contributing factors for the units involved in the crash. These contributing factors were obtained from the individual ST-3 accident narrative for all train-involved crashes during the three-year study period. The researchers analyzed the contributing factor numbers to identify those associated with train-involved crashes. A frequency analysis was used to identify the factors that best describe the causal factors in train-involved crashes.

Primary Factors From Case Study Review of ST-3 Narratives

The review of ST-3 accident narratives provided the opportunity to determine the primary contributing factor to a train-involved crash. The coded contributing factors used by the investigating officers do not always accurately describe the causes of the crashes. The investigating officer has the opportunity to write in a factor that is not contained within the 71 coded factors. Officers rarely take advantage of this option. Because of this possibility, the implied contributing factor was determined by a case study review of accident narratives. The following sections describe typical examples of how crashes were classified for primary contributing factors based on a judgement process during the narrative review. The contributing factors are categorized by railroad, environmental, roadway, and driver/passenger groupings.

Railroad Factors

The equipment that controls the warning devices at active grade crossings can contribute to crashes at highway-railroad grade crossings by providing warning times that promote aggressive or risky driver behavior. The following section explains how it was determined that a warning device malfunction was the primary contributing factor.

Warning Device Malfunction. Active warning devices are normally designed for fail-safe operation; however, at times devices do malfunction. Warning device malfunction was coded as the primary contributing factor to crashes where the failure of the warning device to signal the approach of the train appeared to be responsible for the collision between the train and vehicle. This conclusion was determined from statements in the accident report that indicated the warning devices were not functioning properly during an inspection following the crash.

Environmental Factors

Environmental factors can influence crash experience at highway-railroad grade crossings. The sections below explain how weather conditions and sight distance at the grade crossings were identified as primary contributing factors.

Weather. Severe weather conditions can often be a factor in crashes at all types of intersections. In this study, weather was coded as the primary contributing factor to crashes where severe weather conditions lead to a collision between a train and vehicle. Fog, ice, snow, rain, and glare from sunlight are examples of conditions that can influence the ability of a driver to safely travel through a highway-railroad grade crossing. An example of a crash where weather was determined as the primary contributing factor is shown in Appendix C (Figure C-1).

Sight Distance. The amount of sight distance available to drivers as they approach a highway-railroad grade crossing is a factor that can contribute to collisions between trains and vehicles. Sight distance was coded as the primary contributing factor if the investigating officer's opinion indicated that weeds, trees, buildings, or other objects blocked the view of the motorist. An example of a crash where sight distance was coded as the primary contributing factor is shown in Appendix C (Figure C-2).

Roadway Factors

Geometric properties of the roadway at grade crossings can influence crash experience. The following sections explain how horizontal curvature, stuck on tracks, parallel roadway, and intersection proximity were coded as primary contributing factors.

Horizontal Curve. Horizontal curvature on the approach roadway was classified as the primary contributing factor if the narrative opinion included statements such as "driver failed to negotiate" a turn. If the picture showed a curve leading to the tracks and no other factors were cited, horizontal curvature was coded as the primary contributing factor. Appendix C (Figure C-3) provides an example of a crash where the research team coded horizontal curvature as the primary contributing factor.

Stuck, Stopped, or Stalled on Tracks. Motor vehicles are not designed to operate on railroad tracks or in the loose ballast which normally surrounds the tracks. For this reason, it is easy for vehicles to become stuck on or around the tracks. Stuck, stalled, or stopped on tracks was coded as the primary contributing factor if the investigating officer's opinion or diagram indicated that a vehicle was stuck, stopped, or stalled on the tracks. Appendix C (Figure C-4) shows an example of a crash where the researchers coded stuck/stopped on tracks as the primary contributing factor.

Parallel Roadway. Parallel roadway was coded as the primary contributing factor to crashes where a highway vehicle executed a turning maneuver (left or right turn) to cross railroad tracks that run parallel to the roadway. This factor was determined if the narrative opinion stated that the driver of the vehicle performed a turning maneuver while attempting to cross the railroad tracks. The collision diagram was then examined to determine whether the geometry shown on the diagram indicated that the railroad tracks were parallel to the roadway from which the vehicle executed the turning maneuver. An example of a crash where parallel roadway was coded as the primary contributing factor is shown in Appendix C (Figure C-5).

Intersection Proximity. Intersection proximity was coded as the primary contributing factor in crashes where an intersection in the vicinity of the highway-railroad grade crossing precipitated the collision of the train and motor vehicle. A signalized intersection that is close to the railroad tracks can cause queuing of vehicles back onto the tracks (i.e., a driver is waiting for vehicles in front to proceed during a green phase so that they can vacate the tracks). An illustration of a crash where this scenario was determined to be the primary contributing factor is shown in Appendix C (Figure C-6). Another example where intersection proximity can be considered the primary contributing factor is where a stop controlled intersection is close enough to the tracks that a heavy truck or a pickup truck with a trailer cannot line up safely between the stop bar and the tracks. An example of a crash that illustrates this situation is provided in Appendix C (Figure C-7).

Driver/Passenger Factors

Driver decision-making and performance at highway-railroad grade crossings are critical to safe negotiation of these crossings. The following sections describe tried to beat train, driving around gates, impaired driver, tried to back off tracks, and hit side of train were contributing factors.

Tried to Beat Train. Tried to beat train was coded as the primary contributing factor when either a witness, investigating officer, or the driver involved in the crash indicated that the vehicle accelerated in an attempt to cross the tracks before the train. Other crashes were coded as tried to beat train when the collision diagram showed a vehicle getting hit by the lead engine of the train and the officer indicated there were no skid marks left by the vehicle prior to the entry of the crossing. The researchers recognize that this scenario could also indicate inattentiveness; however, this type of crash was coded as tried to beat train. Figure C-8 in Appendix C provides an example of a crash where tried to beat train was coded as the primary contributing factor.

Driving Around Gates. Driving around gates was coded as the primary contributing factor to crashes where the investigator's opinion or diagram described the driver traveling around the lowered gate arms of the crossing. Figure C-9 in Appendix C provides an example of a typical crash where driving around the gates was determined as the primary contributing factor.

Impaired Driver. Impaired driver was coded as the primary contributing factor to crashes where the driver of the vehicle was under the influence of drugs or alcohol. If the driver was determined to be impaired by the investigating officer (i.e., number factors 45, 67, and 68) then the crash was included in the impaired driver category. Figure C-10, Appendix C, provides an example of a crash where the research team determined the primary contributing factor to be impaired driver.

Tried to Back Off Tracks. Tried to back off tracks was coded as the primary contributing factor when the investigator's narrative or crash diagram depicted a driver attempting to back off the tracks to avoid being hit by the train. For a motorist to attempt to back off the tracks, it is assumed that they failed to recognize the approaching train before it was too late to avoid a conflict. The author acknowledges that the true contributing factors in this type of crash are probably better described as misjudgement of where to stop, inattention, or failure to accurately estimate the rate of train closure. A typical example of a crash where tried to back off the tracks was determined as the primary contributing factor is illustrated in Appendix C (Figure C-11).

Hit Side of Train. Failure to detect, recognize, or expect a train at a highway-railroad grade crossing can cause a driver to hit the side of the train. Darkness is one factor that can contribute to poor visibility of an approaching train. Speeding and driver inattention are also factors that can contribute to late recognition of an approaching train. Finally, a negative expectancy (i.e., not expecting a train) can cause a driver to use poor looking behavior and not detect the train in time to avoid a collision. Figure C-12 in Appendix C shows an example of the hit side of train contributing factor.

4.5 DATA ANALYSIS

This section provides a general description of the methods used in the data analysis. The first section outlines how one- and two-way classification tables were developed to show relative frequencies for most of the variables considered in the analysis. The one-way classification section also provides the results of the comparison of values and trends generated for the Texas crash data in this study to national and statewide values and trends for corresponding factors. The final section presents research hypotheses that were formulated after reviewing the ST-3 accident narratives and results from previous accident studies.

Classification Tables

One- and two-way classification tables were developed for variables considered in the analysis. These tables provide the observed and expected frequencies for the variables related to the crashes in the database. Chi-square tests can be used to determine whether a particular variable is statistically different in relation to the expected value.

One-Way Classification Tables

One-way classification tables are used to identify the relative frequencies for the different components (sub-variables) of a specific crash control variable. The following list shows all of the crash control variables that were analyzed in a one-way frequency analysis:

- Protection type;
- Activation technology (i.e., track circuitry);
- Time of day;
- Light conditions;
- Driver age;
- Driver race and sex;
- Total occupants in vehicle;
- Crash severity;
- Location type; and
- Roadway classification.

Comparison of Factors to National Values/Trends

Descriptive values/trends for each of the factors considered in the one-way classification analysis were compared to corresponding values/trends from national and statewide statistics. The type of protection at the Texas grade crossings with crashes was compared to protection type values for nationwide crashes obtained from the Federal Railroad Administration Accident/Incident Bulletin (36). All other variables that were analyzed as part of the one-way classification were compared to values for all crashes statewide. Specifically, the train-involved crash data analyzed in this study were compared to corresponding crash data for all crashes in the State of Texas obtained from the 1992 and 1993 *Tabulation of Accidents in the State of Texas* report prepared by the Texas Transportation Institute Safety Division (37,38).

Chi-square tests were performed to compare the distribution of the train-involved crashes to the corresponding national or statewide distribution. This type of statistical analysis compares the actual crash frequencies (i.e., the train-involved crash frequencies developed in this study) with the expected crash frequencies (i.e., the corresponding national or statewide crash frequencies) for that same data set. The chi-square test is a technique that can be used to statistically assess the likelihood that a measured distribution (the actual crash frequencies from this study) can be represented by a mathematical distribution (the corresponding national or statewide crash frequencies).

The chi-square table value serves as a pointer on the chi-square scale which differentiates between the two outcomes (i.e., either the distributions are statistically the same or statistically different). If the chi-square calculated value is smaller than the chi-square table value, the research hypothesis is not supported; whereas, if the calculated value is greater, the research hypothesis is supported.

Two-way Classification Tables

Two-way classification tables provide a stratification of frequencies for two crash control variables at one time. The list below provides a description of the different two-way classifications that were performed:

- Driver age versus protection type;
- Light conditions versus driver age;
- Light conditions versus protection type;
- Crash severity versus protection type;
- Crash severity versus activation technology;
- Crash severity versus time of day;
- Crash severity versus light conditions;
- Crash severity versus driver age;
- Crash severity versus driver race and sex;
- Crash severity versus total occupants in vehicle;
- Crash severity versus location type; and
- Crash severity versus roadway classification.

Analysis of Research Hypotheses

Studies on highway-railroad grade crossing crashes and driver behavior were examined as part of the literature review for this research. The literature review and the analysis of the numerous accident narratives provided some insight into potential contributing factors to crashes at highway-railroad grade crossings. This knowledge was utilized to formulate research hypotheses for the analysis portion of this study. The hypotheses are separated into three categories: human factors, geometric factors, and other (miscellaneous). The analysis of the research hypotheses was performed using statistical procedures that compare two population proportions. The methodology used in this testing is described in the proportion testing section following the research hypotheses.

Human Factors

There are many important human factors considerations in the analysis of driver behavior contributing to train-involved crashes. The research hypotheses in this section are divided into risk-taking, misunderstanding, and driver error.

Drivers often exhibit risky behavior while operating a motor vehicle. Risk-taking occurs on all types of facilities, and several studies have documented this type of behavior at highway-railroad grade crossings. The first three research hypotheses relate to driver behavior at highway-railroad grade crossings that can be considered risky:

Hypothesis 1: Because young drivers are more aggressive in many of their actions, it is hypothesized that young driver age groups (16-20 and 21-24) are involved in a greater proportion of crashes where drove around gates is coded as the primary contributing factor.

COMPARE: The relative proportion of young drivers where drove around gates is coded the primary contributing factor to the relative proportion of young drivers for all crashes studied.

Hypothesis 2: Because the male gender tends to be more aggressive than the female gender, it is hypothesized that male drivers are involved in a greater proportion of crashes where tried to beat train is coded as the primary contributing factor.

COMPARE: The proportion of males involved in crashes where tried to beat train is coded the primary contributing factor to the proportion of males involved in all crashes.

Hypothesis 3: Because the perceived risk may change when passengers are in the vehicle, it is hypothesized that one-occupant vehicles (i.e., a driver with no passengers) are involved in greater proportion of crashes where driving around gates is coded the primary contributing factor.

COMPARE: The proportion of one-occupant vehicles for crashes where driving around gates is coded the primary contributing factor to the proportion of one-occupant vehicles for all crashes studied.

The highway-railroad grade crossing is unique because of differences in signing, responsibilities (right-of-way), traffic control devices, and operating characteristics as compared to conventional highway-highway intersections. Numerous studies have documented a general lack of understanding of traffic control devices, responsibilities, and laws at highway-railroad grade crossings. Hypotheses 4, 5, and 6 relate to misunderstanding at highway-railroad grade crossings.

Hypothesis 4: Because older drivers have difficulty with judgement and declining physical abilities, it is hypothesized that older drivers (55 years old and over) are involved in a greater proportion of crashes where stalled, stuck, and stopped too close is coded as the primary contributing factor.

COMPARE: The proportion of older drivers in crashes where stalled, stuck, and stopped too close is coded as the primary contributing factor to the corresponding proportion of older drivers for all crashes.

Hypothesis 5: Because young drivers lack experience with the different types and responsibilities at highway-railroad grade crossings, it is hypothesized that inexperienced drivers (16-24 years old) are involved in a greater proportion of crashes at crossings that have passive protection.

COMPARE: The proportion of inexperienced drivers involved in crashes at passive crossings to the proportion of inexperienced drivers involved in all crashes studied.

Hypothesis 6: Because drivers between 25 and 44 years of age are the most mobile, it is hypothesized that they are involved in a greater proportion of crashes at crossings with active protection.

COMPARE: The proportion of drivers between 25 and 44 years of age involved in crashes at active crossings to the proportion of drivers between 25 and 44 years of age involved in crashes at all crossings.

The majority of crashes at highway-railroad grade crossings involve some type of human error. Hypothesis 7 attempts to investigate a human factors consideration that might be significant.

Hypothesis 7: Because elderly persons often have difficulty seeing well at night, it is hypothesized that elderly drivers (55 years and older) are involved in a higher proportion of crashes where the light conditions are coded as dark (i.e., nighttime).

COMPARE: The proportion of elderly drivers involved in crashes where light conditions are dark to the proportion of elderly drivers involved in all crashes studied.

Geometric Factors

Geometric characteristics of roadways adjacent to highway-railroad grade crossings can influence crash experience. The proximity of intersections and the type of curvature or grade on the approach may significantly affect driver behavior. The hypotheses listed below attempt to examine several geometric factors that may be significant contributors to crashes at grade crossings.

Hypothesis 8: Because large trucks and vehicles towing trailers are considerably longer than conventional passenger cars, it is hypothesized that semi-tractor trailer trucks and pickup trucks with trailers are involved in a greater proportion of crashes where intersection proximity is coded the primary contributing factor.

COMPARE: The proportions of semi-tractor trailer trucks and pickup trucks with trailers where intersection proximity is coded as the primary contributing factor to the corresponding proportions for all crashes in the study.

Hypothesis 9: Passively protected crossings are involved in a greater proportion of crashes where parallel roadway is coded the contributing factor.

COMPARE: The frequency of passive crossings crashes where parallel roadway is coded as the primary contributing factor to the frequency of passive crossings in all other crashes studied.

Miscellaneous Factors

As in most research, some conditions do not seem to fit in a specific category. The following hypotheses investigates two ideas about the crash severity at highway-railroad grade crossings.

Hypothesis 10: Because no warning regarding the approach of a train is given to the motorist at a passive crossing, it is hypothesized that the average severity of crashes occurring at passive crossings is greater (i.e., more severe) than for crashes occurring at active crossings.

COMPARE: The average severity value for crashes occurring at passive crossings to the average severity value for crashes occurring at active crossings.

Hypothesis 11: Because a driver is limited by the effectiveness of vision and headlights at night, it is hypothesized that the average severity of crashes occurring at night (i.e., when the light conditions are coded as dark) is greater than the average severity for crashes occurring during the daytime.

COMPARE: The average severity of crashes occurring at nighttime versus crashes occurring daytime.

Proportion Testing

To test whether significant difference exist between proportions in two different populations, the research team performed a statistical comparison of binomial distributions. The research team used a large sample test procedure to test the hypothesis that the proportion from population 1 is statistically different than the proportion from population 2. A "Z" test statistic was calculated using the equation below. The test statistic was then compared to the table Z statistic with a 95 percent confidence level. If the calculated Z statistic is greater than the table Z statistic, the hypothesis that the proportion of population 1 is statistically different from the proportion of population 2 is supported. If the calculated Z statistic is smaller than the table Z statistic, the hypothesis that the proportions are statistically different is not supported.

$$Z_{CALC} = \frac{\overline{p_1} - \overline{p_2}}{\sqrt{\bar{p}\,\bar{q}\,(\frac{1}{m} + \frac{1}{n})}}$$

where: $\overline{p_1}$ = the proportion from population 1, equal to the number (X) of crashes possessing the characteristic being compared;

$\overline{p_2}$ = the proportion from population 2, equal to the number (Y) of crashes possessing the characteristic being compared;

$\bar{p} = \frac{X+Y}{m+n}$;

$\bar{q} = 1 - \bar{p}$;

m = the number of crashes in population 1; and

n = the number of crashes in population 2.

5.0 STUDY RESULTS

This section presents results of the analyses conducted to identify contributing factors to crashes occurring at highway-railroad grade crossings in Texas. The following sections document the crashes that were selected for study, the identification of contributing factors, the classification of crash variables, the comparison of factors to national values and trends, and the results of the hypotheses testing.

5.1 CRASHES SELECTED FOR STUDY

The primary objective of the crash study was to perform a statewide analysis of train-involved crashes. All train-involved crashes in Texas for 1992, 1993, and 1994 were selected in order to obtain a significant database for study. Table 2 provides a summary of the total number of crashes for the three-year study period. The total number of crashes has increased each year from 415 in 1992 to 477 in 1994.

5.2 IDENTIFICATION OF CONTRIBUTING FACTORS

Two different procedures were performed by the researchers to identify the contributing factors to the train-involved crashes. The first procedure involved an analysis of the investigating officer's coded number factors obtained from the ST-3 accident narratives. The second procedure involved determining the primary contributing factors using a case study review for each individual accident narrative. The following sections present the results of the two procedures used to identify contributing factors for the crashes studied.

Results of Coded Number Factors Analysis

Each ST-3 accident narrative form contains a section where the investigating officer chooses from a numbered list to determine the contributing factors for the crash being investigated. More than one factor may be chosen to describe the causal factors to the crash being investigated. The research team obtained all coded number factors from each ST-3 accident narrative and then entered them into a spreadsheet program. A frequency analysis was performed to determine how often

Table 2. Crashes Selected for Statewide Study

Year	Number of Crashes	Injuries	Fatal
1992	415	196	36
1993	436	203	53
1994	477	199	45
TOTAL	1328	598	134

different factors were coded as contributing factors to the crashes being studied. Table A-1 in Appendix A provides a description and the relative frequency for each individual factor which was coded for one or more of the crashes being studied. Table 3 describes the 10 categories into which the number factors were divided and provides the cumulative frequency of all contributing factors grouped into each individual category. The far left column of Table 3 uses an uppercase letter to designate the category for the contributing factors on the same row.

Category I, failure to yield right-of-way, has a cumulative frequency of 65.28. This frequency is high because contributing factor 31, failure to stop for train, is coded by the investigating officer for the majority of crashes because it is the only number factor with a direct reference to a collision between a train and automobile. Category E, driver inattention, has a cumulative frequency of 36.18 percent suggesting that a significant number of drivers involved in crashes are inattentive to their surroundings and generally unaware of the hazard created by the highway-railroad grade crossing. Category C, disregarding traffic control devices, has a cumulative frequency of almost 16 percent. This relatively high frequency may indicate that drivers do not detect, understand, or choose to obey the warning devices at highway-railroad grade crossings. Category E, impaired driver, has a cumulative frequency of over 14 percent indicating that 1 in every 7 drivers involved in an crash during the three-year study period were impaired by alcohol, drugs, medication, or a lack of sleep.

Table 3. Contributing Factor Number Code Categories and Relative Frequencies

Category	Description (Factors Included)	Cumulative Frequency
A	Defective equipment (9, 10, 11, 12, 13, and 72)	2.50
B	Disabled or parked on railroad tracks (14, 55, and 72)	7.37
C	Disregarding traffic control device (15, 16, 18, 25, 29, and 72)	15.99
D	Speeding (22, 60, and 61)	8.02
E	Impaired driver (40, 45, 47, 62, 67, and 68)	14.14
F	Driver inattention (19 and 20)	36.18
G	Faulty vehicle control (3, 30, 41, and 64)	3.22
H	Driving in wrong lane (23, 44, 57, 69, 70, 71, and 72)	3.19
I	Failure to yield right-of-way (31, 32, 33, 35, 39, 49, and 66)	65.28
J	Other (48, 52, and 72)	7.08

** Total adds to more than 100 because multiple factors are normally coded for each individual crash.

Results of Primary Contributing Factors Coding From Case Study Review

The research team performed a case study review for each individual ST-3 accident narrative to determine the primary contributing factors to train-involved crashes. During the case study review, the primary contributing factor was determined based on a judgement process. Table 4 provides a summary of the results of primary contributing factors for all of the crashes studied. Each cell contains a value which designates the number of crashes during the specified time frame for the primary contributing factor listed in the left column. In most cases only one factor was assigned to an individual crash; however, there were several cases where two factors were coded as co-primary contributing factors. An example of this situation is when a motorist who was determined to be under the influence of alcohol drove around the gates and was hit by a train. The author would code this crash with both driving around gates and impaired driver as contributing factors.

Table 4. Primary Contributing Factor Results

Contributing Factor	Year						Row Totals	
	1992		1993		1994			
	NF	F	NF	F	NF	F	NF	F
Warning Device Malfunction	3	0	4	0	13	1	20	1
Weather	22	3	13	2	20	3	55	8
Sight Distance	6	4	15	1	21	0	42	5
Horizontal Curvature	9	2	12	2	13	1	34	5
Stuck/Stopped on Tracks	35	0	46	4	64	1	145	5
Parallel Roadway	22	7	28	7	30	4	80	18
Intersection Proximity	19	0	22	0	28	1	69	1
Tried to Beat Train	48	8	53	11	54	12	155	31
Driving Around Gates	41	0	41	10	42	8	124	18
Impaired Driver	43	3	57	7	42	4	142	14
Tried to Back Off Tracks	4	1	2	0	7	1	13	2
Dark, Hit Side of Train	40	1	23	2	25	2	88	5
Inattention	45	7	36	4	21	2	102	13
Multiple Tracks	7	1	3	2	14	1	24	4
Other	62	0	81	7	96	11	239	18
Column Totals	406	37	436	59	490	51	1332	147

NF = nonfatal crashes
F = fatal crashes

The analysis revealed that the five most frequently coded primary contributing factors for the 1328 crashes studied were tried to beat train (14.0 percent), impaired driver (11.8 percent), stuck/stopped on tracks (11.3 percent), driving around gates (10.7 percent), and driver inattention (8.7 percent). The five primary contributing factors which were coded most in fatal crashes were tried to beat train (22.8 percent), driving around gates (13.3 percent), parallel roadway (13.3 percent), impaired driver (10.3 percent), and driver inattention (9.6 percent). Note that these results are different from the numbered factor results and that these percentages are based on the best judgement from the review of the accident narrative.

5.3 DATA ANALYSIS RESULTS

This section provides the results of the crash data analysis. The data analysis is divided into four basic sections: one-way classification (includes comparison of study values to national and statewide values), two-way classification, severity index analysis, and hypothesis testing.

One-Way Classification Tables

This section presents the results of the one-way classification for each of the study variables. One-way classification tables for protection type, activation technology, time of day, light conditions, driver age, driver ethnicity and gender, total occupants in vehicle, crash severity, location type, and roadway classification are provided. The left column of each one-way classification table lists the sub-variables for the study variable being analyzed. The middle column of each table provides the relative frequencies (i.e., a percentage showing the relative involvement) for the sub-variable listed on the same row. Finally, the right column of each table shows the corresponding national or statewide frequency values for all crashes obtained from the *1992 FRA Accident/Incident Bulletin* (36) or the 1992 and 1993 *Tabulation of Accidents in the State of Texas* reports that are prepared on an annual basis by the TTI Safety Division (37,38).

This section also presents a statistical comparison of values obtained from the crash data to the corresponding national and statewide values. A Chi-square analysis was performed to determine whether there were any significant differences between the distribution of values for the data in this study and the distribution of values for corresponding national and statewide values. Appendix B provides the Chi-square tables for each comparison performed. Appendix B also provides a table summarizing the results of each comparison.

Protection Type

The type of protection used at highway-railroad grade crossings would seem to have a large influence on the frequency of crashes occurring at the crossing. A passive protection system utilizes static signs and markings to inform the driver that a highway-railroad grade crossing is nearby. An active protection system utilizes the same static signs and pavement markings as the passive systems along with automated warning devices to warn the driver that a train is approaching or occupying the crossing. Active protection systems employ either flashing light signals or automatic gates to indicate the proximity of a train. The flashing light signals can be either cantilever-mounted (on a truss arm which extends over the approaching roadway) or mast-mounted (on a pole at the right pavement edge of each approach).

Table 5 provides the relative frequency of the four protection systems for the crashes studied and all grade crossing crashes nationwide. There is almost a 50/50 split between passive and active protection for the crashes studied. Note that for active crossing protection, more crashes (30.1 percent) occur at crossings with automatic gates than crossings with flashing light signals (20.9 percent). This trend is also interesting because it is the opposite of the national frequency distribution which has more crashes at crossings with flashing lights (30.4 percent) than at crossings with automatic gates (20.5 percent). A proportion test comparing the protection type for the crashes in this study with the protection type used for crossings nationwide reveals that crossings equipped with automatic gates in Texas experience a significantly greater proportion of train-involved crashes at the 95 percent confidence interval. This finding also appears significant because only 18 percent of the crossings in Texas are equipped with automatic gate protection (27). This finding may suggest that Texas drivers are frequently violating the law by driving around lowered automatic gate arms.

This analysis involved comparing the protection type distribution of the crash data in this study to the protection type distribution of all crashes nationwide. The research team obtained the national protection type frequency distribution from the 1992 Federal Railroad Administration Accident/Incident Inventory. Table B-1 in Appendix B provides the results of a Chi-square analysis comparing the protection type distribution for crashes in this study to the protection type distribution for all grade crossing crashes nationwide. Since the calculated Chi-square value (81.63) is greater than the table Chi-square value (6.00), there is evidence of a statistical difference between the protection type distribution for crashes in this study and for all grade crossing crashes nationwide. This result shows that the train-involved crashes at highway-railroad grade crossings analyzed in this study have a significantly different protection type distribution than for all grade crossing crashes nationwide. This difference can be attributed to the disparity between the proportion of crashes at crossings with automatic gates.

Table 5. Protection Type Classification Table

Protection Type	Study Frequency	National Frequency
Passive System	46.2	49.1
Cantilever-Mounted Signals	17.2	30.4
Mast-Mounted Signals	6.5	
Gates	30.1	20.5

Activation Technology

The type of activation technology (i.e., the track circuitry used to detect approaching trains at active crossings) for each crossing in Texas was obtained from the Federal Railroad Administration (FRA). The railroads provided track circuitry data to the FRA in late 1991. A frequency analysis was performed on the data to determine the distribution of activation technology for all active crossings where at least one train-involved crash occurred during the study period. The results of this analysis are provided in the middle column (labeled study frequency) of Table 6. A second analysis was performed to determine the statewide distribution of activation technology for all of the active crossings contained in the FRA database. The results of this analysis are shown in the right column (labeled statewide frequency). There were over 3,600 records containing track circuitry data for all of the active crossings in the State of Texas. A comparison of proportions between the two distributions showed that the AFO with timing sections track circuits experiences a significantly greater proportion of crashes compared to its representation at active crossings statewide.

Table B-2 gives the results of a Chi-square analysis comparing the activation technology distribution for crashes in this study to the activation technology distribution for all active crossings statewide. Since the calculated Chi-square value (38.90) is greater than the table Chi-square value (15.50), there is evidence of a statistical difference between the two distributions. This result indicates that the activation technology distribution involving crashes from this study is statistically different from the distribution of activation technology at all active crossing statewide.

Table 6. Activation Technology Classification Table

Activation Technology	Study Frequency	Statewide Frequency
Conventional	17.3	16.5
Conventional (w/ timing sections)	0.5	0.7
Audio Frequency Overlay (AFO)	8.5	8.0
AFO (w/ timing sections)	0.9	0.4
Motion Sensitive	32.1	31.4
Constant Warning	34.2	36.4
Manual Operation	0.2	0.5
None	1.2	1.3
Other	5.1	4.8

Time of Day

The time of day distribution of crashes occuring at highway-railroad grade crossings may provide insight into the causal factors. The 24-hour day was divided into 3 hour time periods beginning at 12 a.m. in accordance with the time periods used in the NHTSA study (29) discussed in Section 2.0. The proportion of train-involved crashes for each time period is provided in the middle column (study frequency) of Table 7. The right column (statewide frequency) of Table 7 shows the proportion for all crashes statewide. The statistical proportion comparisons between corresponding time periods for the crashes in this study and all crashes statewide revealed that the 12 a.m. to 3 a.m., 3 a.m. to 6 a.m., 9 a.m. to 12 p.m., and 9 p.m. to 12 a.m. time periods experience a significantly greater proportion of crashes compared to their representation in all crashes statewide. This indicates that significantly more crashes occur during the late night time periods at highway-railroad grade crossings compared to all crashes statewide.

The grade crossing crash distribution reaches its peak (16.0 percent) during the 3 p.m. to 6 p.m. time period which coincides with peak afternoon traffic volumes. This finding agrees with previous studies (29) which have found that the afternoon peak period has the highest frequency of crashes. The statewide distribution of all crashes also reaches its peak (23.7 percent) during the 3 p.m. to 6 p.m. time period.

Table B-3 in Appendix B provides the result of a Chi-square analysis comparing the time-of-day distribution for crashes in this study to the time-of-day distribution for all crashes statewide. Since the calculated Chi-square value (119.73) is greater than the table Chi-square value (14.10), there is evidence that the two distributions are statistically significant. This result suggests that the train-involved crashes at highway-railroad grade crossings analyzed in this study have a different time-of-day distribution than for all crashes statewide.

Table 7. Time of Day Classification Table

Time of Day	Study Frequency	Statewide Frequency
12 a.m. - 3 a.m.	10.5	7.2
3 a.m. - 6 a.m.	6.0	3.0
6 a.m. - 9 a.m.	11.4	10.9
9 a.m. - 12 p.m.	15.1	12.0
12 p.m. - 3 p.m.	14.2	17.9
3 p.m. - 6 p.m.	16.0	23.7
6 p.m. - 9 p.m.	14.8	15.1
9 p.m. - 12 a.m.	11.9	11.9

Light Conditions

Light conditions can significantly affect a motorist's ability to safely negotiate a highway-railroad grade crossing. The light conditions at the time of a crash were categorized as daylight, dawn, dark not lighted, dark lighted, and dusk. Table 8 shows the relative frequencies of the crashes studied and statewide crashes for the five different light conditions. Almost 60 percent of the train-involved crashes occurred during daytime conditions with the remaining 40 percent occurring at night. The day/night distribution for all crashes statewide is somewhat different, approximately 70 percent of crashes occurred during daytime conditions and the remaining 30 percent at night. The most obvious difference between the grade crossing crash distribution and the all-traffic crash distribution is that two times as many dark not lighted crashes (22.1 percent and 11.5 percent) occured in the grade crossing crash distribution. A statistical analysis of the dark not lighted crash proportions showed that a significantly greater proportion of crashes at grade crossings occur in dark not lighted conditions compared to all crashes statewide.

Table B-4 in Appendix B shows the results of a Chi-square analysis comparing the light conditions distribution for crashes in this study to the light conditions distribution for all crashes statewide. Since the calculated Chi-square value (159.42) is greater than the table Chi-square value (9.50), there is evidence of a statistical difference between the two distributions. This result shows that the train-involved crashes at highway-railroad grade crossings analyzed in this study have a significantly different light conditions distribution than for all crashes statewide. This is not surprising because as compared to all crashes fewer crashes at grade crossings occur during daytime hours and more occur at night..

Table 8. Light Conditions Classification Table

Light Conditions	Study Frequency	Statewide Frequency
Daylight	58.4	68.3
Dawn	1.8	1.0
Dark Not Lighted	22.1	11.5
Dark Lighted	16.3	17.4
Dusk	1.4	1.8

Driver Age

Crash data were also classified by driver age. The driver age groups used in this analysis are the same as those used in a recent NHTSA study (29). Table 9 provides the classification of crashes for both the grade crossing crashes and for the distribution of all crashes statewide according to driver age group. Drivers between the ages of 25 and 34 are involved in more crashes than any other individual age group (22.9 percent and 25.7 percent respectively); however, the first three age groups (< 16, 16 to 20, and 21 to 24) of the crash distribution combine to give a similar frequency (21.4). This result matches the findings of the NHTSA study which also found that the 25 to 34 age group had the highest involvement rate. The combined 16 to 20 and the 21 to 24 age groups have a frequency of 21.4 percent which is greater than the number of licensed drivers in Texas between the ages of 16 and 24 (15.2 percent). This comparison shows that younger drivers are involved in a higher frequency of crashes at grade crossings than their expected involvement (i.e., their relative percentage within the Texas driving population). A comparison of proportions between the two distributions showed that the elderly driver age groups (i.e., 55 to 64, 65 to 74, and >74) experience a significantly greater proportion of crashes compared to their representation in all crashes statewide at the 95 percent confidence interval. This finding suggests that elderly drivers are more likely to be involved in crashes at highway-railroad grade crossings than all other age groups studied.

Table B-5 in Appendix B gives the results of a Chi-square analysis comparing the driver age distribution for crashes in this study to the driver age distribution for all crashes statewide. Since the calculated Chi-square value (79.06) is greater than the table Chi-square value (17.00), there is evidence of a statistical difference between the driver age distribution for crashes in this study and for all crashes statewide.

Table 9. Driver Age Group Classification Table

Driver Age Group	Study Frequency	Statewide Frequency
< 16	0.1	0.4
16 -20	11.5	13.9
21 - 24	9.8	12.5
25 - 34	22.9	25.7
35 - 44	16.9	18.7
45 - 54	11.5	10.3
55 - 64	8.5	5.8
65 - 74	5.5	3.6
> 74	3.7	2.5
Unknown	9.5	6.6

Driver Ethnicity and Gender

The accident report documents ethnicity (race) and gender (sex) of a driver involved in a crash at a highway-railroad grade crossing. This information was used to develop the driver ethnicity and gender crash classification provided in Table 10. Some of the important findings from this classification are that 76 percent of the known drivers involved in crashes are male. In addition, 64.7 percent of known drivers involved in the crashes studied were White, 12.7 percent Black, and 22.6 percent Hispanic. This distribution appears to be similar to the distribution of licensed drivers in Texas (60.6 percent White, 11.6 percent Black, and 25.6 percent Hispanic).

The most obvious difference between the crash distribution and the statewide distribution is that the frequency values for the grade crossing crashes for each male group are higher and the frequency values for each female group are lower than the corresponding frequency values for all crashes statewide. A statistical analysis of proportions between the two distributions showed that the White male and Hispanic male classification groups experience a significantly greater proportion of crashes compared to their representation in all crashes statewide at the 95 percent confidence interval. This comparison suggests that male drivers, compared to female drivers, experience a greater frequency of highway-railroad grade crossing crashes as compared to all other crashes statewide.

Table B-6 in Appendix B shows the results of a Chi-square analysis comparing the driver ethnicity and gender distribution for crashes in this study to the driver ethnicity and gender distribution for all crashes statewide. Since the calculated Chi-square value (171.59) is greater than the table Chi-square value (15.50), there is evidence of a statistical difference between the driver ethnicity and gender distribution for the crashes in this study and the driver ethnicity and gender distribution for all crashes statewide. This result provides evidence that the train-involved crashes at highway-railroad grade crossings analyzed in this study have a significantly different driver ethnicity and gender distribution than for all crashes statewide. The statistical difference in the distributions can be explained by males experiencing a greater proportion of and females a lesser proportion of grade crossing crashes compared to all crashes statewide.

Table 10. Driver Ethnicity and Gender Classification Table

Driver Ethnicity and Gender	Study Frequency	Statewide Frequency
White Male	43.4	35.9
White Female	14.8	25.0
Black Male	8.1	7.6
Black Female	3.3	5.0
Hispanic Male	16.5	14.0
Hispanic Female	3.8	6.2
Other Male	0.8	1.3
Other Female	0.1	0.6
Unknown	9.2	4.6

Total Occupants in Vehicle

The accident report records the number of occupants (driver and any passengers) in the vehicle at the time of the crash. The research team utilized this information to generate the classification for total occupants in vehicle provided in Table 11. From the table, it can be seen that three out of every four crashes involved one-occupant (i.e., driving alone) vehicles, and only a small percentage (approximately 3 percent) of crashes involved a vehicle with more than 3 occupants. A statistical analysis of proportions between the two distributions revealed that one-occupant vehicles experience a significantly greater proportion of crashes compared to the representation in all crashes statewide at the 95 percent confidence interval. This finding means that significantly more railroad crashes involve one-occupant vehicles and significantly fewer involve multiple occupant vehicles.

Table B-7 in Appendix B displays the results of a Chi-square analysis comparing the total occupants in vehicle distribution for crashes in this study to the total occupants in vehicle distribution for all crashes statewide. Since the calculated Chi-square value (36.38) is greater than the table Chi-square value (12.60), there is evidence of a statistical difference between the total occupants in vehicle distribution for crashes in this study and for all crashes statewide. This result suggests that the distribution for total occupants in vehicles obtained for this study is different from the same distribution for all crashes statewide.

Table 11. Total Occupants in Vehicle Classification Table

Number of Occupants	Study Frequency	Statewide Frequency
1	75.4	68.7
2	17.0	19.3
3	4.4	6.8
4	1.8	3.2
5	1.1	1.3
6	0.1	0.5
7	0.1	0.1

Crash Severity

The severity of crashes at highway-railroad grade crossings was a major focus of this analysis. The research team coded crash severity into five categories: non-injury, possible injury, non-incapacitating, incapacitating, and fatal. The most severe category for the persons involved in each train-involved crash is coded on the crash report as the severity for the crash. For example, if a vehicle with three occupants is involved in a crash where two people are uninjured and one is incapacitated, the severity of the crash would be coded as incapacitating. The crash severity data were classified by the five categories shown in Table 12. Although 1 of every 2 crashes occurring at highway-railroad grade crossings produces no injuries, 1 in 10 crashes produces a fatal injury. This value appears significant, especially when compared to only 1 in 100 crashes resulting in a fatal injury for the statewide distribution for all crashes.

A statistical analysis of the proportion of fatal crashes reveals that a significantly greater proportion of fatal crashes occurred at highway-railroad grade crossings compared to all crashes statewide at the 95 percent confidence interval. This finding is also supported by the Operation Lifesaver data provided in the background section of this research. It is also important to note that 1 of every 4 train-involved crashes causes a serious injury (incapacitating or fatal) to one or more of the occupants in the vehicle. This frequency (incapacitating or fatal injuries) also appears significant from the standpoint that a driver is almost 5 times as likely to experience a serious injury in a grade crossing crash when compared to all crashes statewide. Again, a statistical analysis of the proportion of incapacitating crashes reveals that a significantly greater proportion of incapacitating crashes occur at highway-railroad grade crossings compared to all crashes statewide.

Table B-8 in Appendix B provides the results of a Chi-square analysis comparing the crash severity distribution for crashes in this study to the crash severity distribution for all crashes statewide. Since the calculated Chi-square value (1999.87) is greater than the table Chi-square value (9.50), there is evidence of a statistical difference between the crash severity distribution for crashes in this study and for all crashes statewide. This indicates that the train-involved crashes at highway-railroad grade crossings analyzed in this study have a significantly different crash severity distribution than for all crashes statewide. This finding demonstrates that crashes at highway-railroad grade crossings are significantly more severe compared to all crashes statewide.

Table 12. Crash Severity Classification Table

Crash Severity	Study Frequency	Statewide Frequency
Non-Injury	44.6	54.2
Possible Injury	16.8	27.8
Non-incapacitating	15.0	12.8
Incapacitating	13.5	4.5
Fatal	10.1	0.7

Location Type

The location type of the crashes studied was determined by the population group where the crash occurred. The research team utilized nine different location types ranging from rural to cities over 250,000 in population to classify the crash data. Table 13 provides the relative frequency of crashes classified by location type for the crashes studied in this research and all crashes statewide. From the crashes studied, almost 28 percent occurred at a rural type locations. This frequency is almost two times greater than the frequency values for any of the other eight location types. The next highest involvement being 15.8 percent occurring at cities over 250,000 in population.

One trend that can be noted when comparing the frequency values for the two distributions is that location types with low populations (25,000 and under) have higher frequencies for the crashes studied in this research (i.e., at grade crossings) than for all crashes statewide. This result is particularly true for the rural areas and towns under 2,500 which have a combined frequency of 40.4 percent for the grade crossing crashes studied in this research and only 19.2 percent for all crashes statewide.

A statistical analysis of proportions between the two distributions showed that these location types (rural, <2,500, 2,500 to 5,000, 5,000 to 10,000, and 10,000 to 25,000, respectively) experience a significantly greater proportion of crashes compared to their representation in all crashes statewide at the 95 percent confidence interval. The opposite trend is true for the location types with higher populations (25,000 to over 250,000); the crashes studied in this research have lower frequencies than for all crashes statewide. This outcome is particularly true for the large urban areas (over 250,000) where only 15.8 percent of the grade crossing crashes occurred compared to 38.6 percent for all crashes statewide. An additional statistical analysis of proportions between the location types with populations of 25,000 or greater revealed that the 100,000 to 250,000 and the 250,000 and over location types experience a significantly lower proportion of crashes compared to their representation in all crashes statewide. These finding suggest a higher proportion of highway-railroad crashes occur in rural areas as compared to all crashes statewide.

Table 13. Location Type Classification Table

Location Type	Study Frequency	Statewide Frequency
Rural	27.8	15.7
Town under 2,500	12.6	3.5
2,500 - 5,000	5.6	2.7
5,000 - 10,000	5.6	3.8
10,000 - 25,000	12.7	10.5
25,000 - 50,000	4.6	5.5
50,000 - 100,000	9.9	10.4
100,000 - 250,000	5.3	9.1
Over 250,000	15.8	38.6

Table B-9 in Appendix B gives the results of a Chi-square analysis comparing the location type distribution for crashes in this study to the location type distribution for all crashes statewide. Since the calculated Chi-square value (698.85) is greater than the table Chi-square value (15.50), there is evidence of a statistical difference between the location type distribution for crashes in this study and for all crashes statewide. This means that the train-involved crashes at highway-railroad grade crossings analyzed in this study occur in significantly different locations than for all crashes statewide.

Roadway Classification

The accident report includes the type of roadway at the highway-railroad grade crossing. The research team used the roadway class information to develop the roadway classification provided in Table 14. Only 1.1 percent of the crashes studied occurred at highway-railroad grade crossings on interstate facilities. This low number can be best explained by the fact that almost all railroad crossings on interstate facilities are grade separated, and, those that are not, are very likely to have the most sophisticated types of active protection. Fifty-four percent of the crashes studied occurred on city streets compared to the next highest of 20 percent on county roads. A statistical analysis of proportions between the two populations showed that the farm to market, county road, and city street roadway classes experience a significantly greater proportion of crashes compared to their representation in all crashes statewide at the 95 percent confidence interval. This finding seems to support previous findings that a high proportion of crashes at highway-railroad grade crossings occur in rural areas (where the majority of farm to market and country road lane miles are located) versus urban areas.

Table B-10 in Appendix B displays the results of a Chi-square analysis comparing the roadway class distribution for crashes in this study to the roadway class distribution for all crashes statewide. Since the calculated Chi-square value (846.96) is greater than the table Chi-square value (9.50), there is evidence of a statistical difference between the location type distribution for crashes in this study and for all crashes statewide. This finding suggests that the train-involved crashes at highway-railroad grade crossings analyzed in this study occur in significantly different locations than for all crashes statewide.

Table 14. Roadway Classification Table

Roadway Class	Relative Frequency	Statewide Frequency
Interstate	1.1	12.5
U.S. and State Highway	10.3	28.1
Farm to Market	14.2	8.9
County Road	20.0	5.5
City Street	54.4	44.8

Two-Way Classification Tables

The research team prepared two-way classification tables, also referred to as contingency tables, to further analyze the crash data. This section presents the results of the two-way classification for different combinations of the study variables. Two-way classification tables were produced for the following: light conditions versus protection type, driver age versus protection type, light conditions versus driver age, crash severity versus protection type, crash severity versus activation technology, crash severity versus time of day, crash severity versus light conditions, crash severity versus driver age, crash severity versus driver ethnicity and gender, crash severity versus total occupants in vehicle, crash severity versus location type, and crash severity versus roadway class are provided.

All of the two-way classification tables follow a consistent format. The first row and first column of each table provide the description of each of the sub-variables included in the two study variables being analyzed. The sub-variables contained in the columns have two sub-columns containing numbers for the column and total frequencies. The left sub-column contains the relative frequency for the two sub-variables according to the total for the sub-variable in that respective column. The right sub-column shows the relative frequency for the two sub-variables according to the total number of crashes studied.

Driver Age vs. Protection Type

Table 15 is a two-way classification of driver age and type of protection system. The table reveals one interesting trend. Every driver age group except the 55 to 64 age group has a higher total crash frequency at active systems compared to passive systems.

Light Conditions vs. Driver Age

Table 16 provides the results of a two-way classification of light conditions and driver age. Significant observations can be made by comparing some of the column totals in this table to the one-way classification totals for all crashes studied given in Table 9. The 16 to 20 driver age group has a higher percentage of crashes with dark not lighted light conditions (14.6 percent) than in all crashes studied (11.5 percent). The 21 to 24, 25 to 34, and 35 to 44 driver age groups all have a higher percentage of crashes with dark lighted light conditions (12.8, 29.0, and 19.5 percent respectively) than in all crashes studied (9.8, 22.9, and 16.9 percent respectively). It also is important to note that the older driver age groups (55 to 64, 65 to 74,74 and up) are involved in a higher proportion of crashes at night (19.1 percent) compared to all crashes studied (17.7 percent).

Light Conditions vs. Protection Type

Table 17 provides a two-way classification of the light conditions and type of protection system for all crashes studied. After reviewing the frequency values, several interesting observations can be made. The first observation is that almost the same amount (28.9 percent compared to 29.9 percent) of the total crashes occur during daytime conditions at passive and active protection systems. The second important observation is that more total crashes occur at night (both dark light conditions) at active systems than at passive systems. The final observation is that more total crashes at active systems occur at illuminated crossings (12.4 percent) than at unilluminated crossings (10.4 percent).

Table 15. Driver Age vs. Protection Type Classification Table

Driver Age Group	Passive System		Active System	
	Column %	Total %	Column %	Total %
< 16	0.0	0.0	0.3	0.2
16 - 20	9.8	4.5	11.8	6.4
21 - 24	10.2	4.7	9.5	5.1
25 - 34	23.2	10.6	21.8	11.8
35 - 44	16.9	7.7	16.8	9.1
45 - 54	12.4	5.7	11.0	5.9
55 - 64	9.8	4.5	7.6	4.1
65 - 74	5.1	2.3	5.8	3.2
> 74	3.3	1.5	4.2	2.3
Unknown	9.3	4.3	11.2	6.1
TOTALS	100.0	45.8	100.0	54.2

Table 16. Light Conditions vs. Driver Age Classification Table

Driver Age Group	Daylight		Dawn		Dark not Lighted		Dark Lighted		Dusk	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
< 16	0.0	0.0	0.0	0.0	0.3	0.1	0.5	0.1	0.0	0.0
16 - 20	10.3	6.1	12.5	0.2	14.6	3.2	11.8	1.9	5.3	0.1
21 - 24	8.8	5.2	4.2	0.1	10.5	2.3	12.8	2.1	10.5	0.1
25 - 34	22.5	13.2	20.8	0.4	16.6	3.6	29.0	4.7	15.8	0.2
35 - 44	16.9	9.9	16.7	0.3	14.2	3.1	19.5	3.2	31.6	0.4
45 - 54	13.2	7.8	25.0	0.4	7.8	1.7	8.6	1.4	15.8	0.2
55 - 64	10.5	6.1	4.2	0.1	6.8	1.5	4.5	0.7	5.3	0.1
65 - 74	7.3	4.3	12.5	0.2	3.1	0.7	1.8	0.3	5.3	0.1
> 74	5.2	3.0	0.0	0.0	2.0	0.4	0.9	0.2	5.3	0.1
Unknown	5.3	3.1	4.2	0.1	20.7	4.5	10.9	1.8	5.3	0.1
TOTALS	100.0	58.4	100.0	1.8	100.0	22.1	100.0	16.3	100.0	1.4

Table 17. Light Conditions vs. Protection Type Classification Table

Light Conditions	Passive System		Active System	
	Column %	Total %	Column %	Total %
Daylight	62.7	28.9	55.5	29.9
Dawn	2.1	1.0	1.3	0.7
Dark Not Lighted	25.2	11.6	19.2	10.4
Dark Lighted	7.7	3.5	23.0	12.4
Dusk	2.3	1.1	1.0	0.5
TOTALS	100.0	46.1	100.0	53.9

Crash Severity vs. Protection Type

Table 18 provides the results of a two-way classification between the crash severity and the protection type at the crossing. After examining the frequency values, the point can be made that passive protection systems account for a higher frequency of the fatal crashes than the three different active systems combined. A higher percentage of crashes resulting in injury or fatality occur at passive crossings (48.8 and 54.5 percent, respectively) when compared to the one-way frequency for all crashes studied in Table 5 (46.2 percent).

Crash Severity vs. Activation Technology

Table 19 gives the results of a two-way classification of crash severity and activation technology. The motion sensitive and audio frequency overlay circuit types both appear to have slightly higher frequencies in terms of involvement in fatal crashes. The constant warning time (CWT) circuit appears to perform well in that the relative frequency (26.9 percent) of fatalities is less than the relative frequency (34.2 percent) in all crashes. These findings might suggest that constant warning time circuits improve driver behavior and consequently crash experience at active crossings.

Crash Severity vs. Time of Day

Table 20 provides the results of the crash severity versus time of day two-way classification. The highest frequency of fatal crashes occurs during the 9 a.m to 12 p.m. and 3 p.m. to 6 p.m. time groups. The highest frequency of incapacitating crashes occurs during the 3 p.m. to 6 p.m. time frame. Finally, the highest frequency of non-incapacitating crashes occurs during the 6 p.m. to 9 p.m. time frame.

Table 18. Crash Severity vs. Protection Type Classification Table

Protection Type	Non-Injury		Injury		Fatal	
	Column %	Total %	Column %	Total %	Column %	Total %
Passive System (Crossbuck)	41.8	18.9	48.8	21.6	54.5	5.6
Cantilever-Mounted Signals	16.1	7.3	18.7	8.3	15.6	1.6
Mast-Mounted Signals	6.7	3.0	6.6	2.9	5.7	0.6
Automatic Gates	35.5	16.1	25.9	11.5	24.4	2.5
TOTALS	100.0	45.3	100.0	44.3	100.0	10.3

Table 19. Crash Severity vs. Activation Technology Classification Table

Activation Technology	Non-Injury		Injury		Fatal	
	Column %	Total %	Column %	Total %	Column %	Total %
Conventional	16.9	8.8	11.1	4.6	15.4	1.1
Conventional (w/ timing sections)	1.0	0.5	0.0	0.0	0.0	0.0
Audio Frequency Overlay (AFO)	8.2	4.3	10.5	4.3	11.5	0.8
AFO (w/ timing sections)	0.1	0.1	1.3	0.5	3.9	0.3
Motion Sensitive	30.3	15.8	37.9	15.5	42.3	2.9
Constant Warning Time	39.5	20.6	37.3	15.2	26.9	1.9
Other	3.6	1.9	2.0	0.8	0.0	0.0
TOTALS	100.0	52.0	100.0	40.9	100.0	7.0

Table 20. Crash Severity vs. Time of Day Classification Table

Time Period	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
12 - 3 a.m.	11.8	5.3	4.0	0.8	13.0	2.0	13.9	1.9	6.7	0.7
3 - 6 a.m.	5.9	2.7	6.2	1.1	6.0	0.9	7.8	1.1	3.7	0.5
6 - 9 a.m.	9.9	4.5	11.6	2.0	12.0	1.9	13.4	1.8	14.2	1.5
9 - 12 p.m.	15.7	7.0	14.8	2.5	14.0	2.1	11.7	1.6	19.4	2.0
12 - 3 p.m.	12.9	5.7	19.7	3.3	13.0	2.0	11.1	1.5	16.4	1.7
3 - 6 p.m.	15.5	6.9	18.4	3.1	13.0	2.0	15.6	2.1	19.4	2.0
6 - 9 p.m.	13.9	6.3	17.4	3.0	17.0	2.6	12.3	1.7	14.1	1.5
9 - 12 a.m.	14.3	6.4	7.6	1.3	11.5	1.8	14.0	1.9	5.9	0.6
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Crash Severity vs. Light Conditions

Table 21 provides the results of the two-way classification of crash severity and light conditions. Several observations can be drawn from the frequency values shown in the table. The first observation is that the majority (69.4 percent) of fatal crashes occur during daytime conditions. The frequency of fatal crashes during daytime conditions (69.4 percent) is also greater than the frequency of all crashes during daytime conditions (58.4 percent). The final observation is that twice as many fatal crashes occur at crossings without illumination (dark not lighted) than at crossings with illumination (dark lighted).

Table 21. Crash Severity vs. Light Conditions Classification Table

Light Conditions	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
Daylight	55.5	24.8	66.4	11.1	55.3	8.3	53.6	7.2	69.4	7.0
Dawn	1.3	0.6	2.2	0.4	3.0	0.5	1.7	0.2	1.5	0.2
Dark	24.5	10.9	15.2	2.6	21.1	3.2	26.3	3.5	18.7	1.9
Dark Lighted	17.4	7.8	13.9	2.3	19.6	2.9	17.3	2.3	9.0	0.9
Dusk	1.3	0.6	2.2	0.4	1.0	0.2	1.1	0.2	1.5	0.2
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Crash Severity vs. Driver Age

Table 22 shows the results of the crash severity versus driver age two-way classification. Several interesting trends were revealed upon comparison of the driver age values for fatal crashes to the driver age values for all crashes studied. Several driver age groups (16 to 20, 35 to 44, 55 to 64, 65 to 74, and greater than 74) appear to be involved in a greater proportion of the fatal crashes when compared to the corresponding frequency of involvement in all crashes. All of the same driver age groups (except for the 35 to 44 age group) have a greater frequency of involvement in incapacitating crashes compared to the corresponding frequency of involvement in all crashes.

Crash Severity vs. Driver Ethnicity and Gender

Table 23 provides the results of the two-way classification of crash severity and driver ethnicity and gender. One observation is that both White males and females appear to be involved in a significantly greater proportion of incapacitating and fatal crashes when compared to the involvement in all crashes. All other ethnic groups studied (i.e., Black male and female, and Hispanic male and female) have a lower frequency of involvement in incapacitating and fatal crashes compared to the frequency in all crashes studied. These findings might support the contention that crashes at highway-railroad grade crossings are more of a rural problem (because a higher proportion of Whites tend to live in rural location types compared to other ethnic groups).

Table 22. Crash Severity vs. Driver Age Classification Table

Driver Age	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
< 16	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.1	0.0	0.0
16 - 20	8.9	4.0	11.7	1.9	13.0	1.9	16.7	2.2	13.5	1.3
21 - 24	8.4	3.7	12.5	2.1	8.5	1.4	14.4	1.8	6.7	0.6
25 - 34	22.7	10.2	24.4	3.9	27.0	3.7	21.7	2.8	16.3	1.5
35 - 44	14.5	6.3	18.7	3.1	21.5	3.1	16.1	1.9	20.0	1.9
45 - 54	11.1	5.0	12.1	2.0	12.5	1.7	11.7	1.4	11.1	0.9
55 - 64	7.2	3.0	9.9	1.7	6.5	1.0	9.1	1.2	14.8	1.4
65 - 74	4.7	2.0	6.9	1.1	4.5	0.6	6.1	0.7	8.1	0.8
> 74	3.4	1.5	2.5	0.5	4.0	0.7	2.9	0.4	7.9	0.9
Unknown	19.3	8.7	1.3	0.2	3.5	0.5	0.6	0.1	0.7	0.1
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Table 23. Crash Severity vs. Driver Ethnicity and Gender Classification Table

Driver Ethnicity & Gender	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
White Male	38.8	17.4	40.7	7.0	49.5	17.4	47.8	6.4	52.2	5.2
White Female	11.4	5.1	16.9	2.9	13.4	2.0	22.2	3.0	18.7	1.8
Black Male	6.9	3.1	14.3	2.4	5.9	0.9	8.3	1.1	6.0	0.6
Black Female	2.3	1.0	6.9	1.2	3.0	0.4	2.8	0.4	3.0	0.3
Hisp. Male	18.3	8.2	14.7	2.5	17.3	2.6	12.8	1.7	14.9	1.5
Hisp. Female	3.1	1.4	4.3	0.7	5.4	0.8	3.9	0.5	3.7	0.4
Other Male	0.5	0.2	0.4	0.1	1.5	0.2	1.7	0.2	0.7	0.1
Other Female	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0
Unknown	18.5	8.3	1.7	0.3	3.5	0.5	0.6	0.1	0.7	0.1
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Crash Severity vs. Total Occupants in Vehicle

Table 24 gives the results of the two-way classification of crash severity versus total occupants in vehicle. One observation that can be made is that a greater percentage of vehicles with multiple occupants are involved in all severity categories (except non-injury) when compared to the frequency of involvement in all crashes.

Table 24. Crash Severity vs. Total Occupants in Vehicle Classification Table

Tot. Occ. in Vehicle	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
1	83.0	37.1	72.3	12.4	70.8	10.6	68.9	9.2	61.9	6.1
2	11.2	5.0	19.9	3.4	18.3	2.7	23.3	3.1	27.6	2.7
3	3.3	1.5	5.6	1.0	5.9	0.9	5.6	0.7	3.7	0.4
4	1.5	0.7	1.3	0.2	3.0	0.4	1.1	0.1	3.7	0.4
5	0.8	0.4	0.9	0.1	1.0	0.1	1.1	0.1	3.0	0.3
6	0.2	0.1	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Crash Severity vs. Location Type

Table 25 provides the results of the two-way classification of crash severity and location type. The most significant observation that can be made is that a greater proportion of non-incapacitating (29.1 and 15.1 percent), incapacitating (33.5 and 12.8 percent) and fatal (41.0 and 23.9 percent) crashes occur in rural and town under 2,500 location types when compared to the frequency of involvement in all crashes (27.8 and 12.6 percent respectively). This indicates that the majority of serious crashes at highway-railroad grade crossings occur in rural locations with low populations. In contrast 50,000 to 100,000, 100,000 to 250,000, and the over 250,000 location types are mostly under represented in non-incapacitating (10.5, 3.1, and 13.1 percent), incapacitating (9.5, 6.1, and 10.6 percent) and fatal (0.0, 1.5, and 8.2 percent) crashes compared to the rate of involvement in all crashes (9.9, 5.3, and 15.8 percent respectively). This finding supports the contention that crashes at highway-railroad grade crossings are more of a problem in rural locations than in urban locations.

Crash Severity vs. Roadway Classification

Table 26 shows the results of the crash severity versus roadway class two-way classification. The primary finding from this analysis was that a greater proportion of the incapacitating (22.3 percent) and fatal (33.6 percent) crashes occur on county roads compared to their relative involvement in all crashes (20.0 percent). This discovery supports the contention that crashes at grade crossings are more of a problem in rural than urban locations.

Table 25. Crash Severity vs. Location Type

Location Type	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
Rural	25.3	11.3	20.6	3.5	29.1	4.4	33.5	4.5	41.0	4.1
< 2500	11.1	5.0	7.2	1.2	15.1	2.3	12.8	1.7	23.9	2.4
2500-5,000	6.6	2.9	4.5	0.8	3.5	0.5	6.1	0.8	6.0	0.6
5-10,000	4.4	2.0	8.5	1.4	7.0	1.1	5.6	0.8	4.5	0.5
10-25,000	12.1	5.4	13.0	2.2	13.6	2.0	12.8	1.7	13.4	1.4
25-50,000	4.4	2.0	8.1	1.4	5.0	0.8	2.8	0.4	1.5	0.2
50-100,000	11.0	4.9	13.5	2.3	10.1	1.5	9.5	1.3	0.0	0.0
100-250,000	6.4	2.9	5.4	0.9	3.5	0.5	6.1	0.8	1.5	0.2
> 250,000	18.7	8.4	19.3	3.2	13.1	2.0	10.6	1.4	8.2	0.8
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Table 26. Crash Severity vs. Roadway Class Table

Roadway Class	Non-Injury		Possible Injury		Non-Incapacitating		Incapacitating		Fatal	
	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %	Col %	Tot %
Interstate	1.2	0.5	2.2	0.4	0.5	0.1	1.1	0.2	0.0	0.0
US / St. Hwy	10.8	4.8	9.0	1.5	14.6	2.2	10.6	1.4	3.7	0.4
Farm to Mar.	14.2	6.3	12.1	2.0	12.6	1.9	19.0	2.6	14.2	1.4
County Road	18.4	8.2	13.9	2.3	20.1	3.0	22.3	3.0	33.6	3.4
City Street	55.5	24.8	62.8	10.5	52.8	7.8	46.9	6.3	48.5	4.9
TOTALS	100.0	44.6	100.0	16.8	100.0	15.0	100.0	13.5	100.0	10.1

Average Severity Calculations

Researchers calculated a severity index in order to compare the severity of crashes for a crash control variable (i.e., driver age, light conditions, etc.). The index was calculated by assigning each severity type a severity code as shown in Table 27. The index was calculated using Equation 1. The severity index is basically a weighted average (weighted by the severity codes) which calculates an average severity for the crashes of a particular condition. A severity index value is calculated for each sub-variable of a specific crash variable. For example, five severity index values for the light conditions crash variable (i.e., one for each sub-variable: daylight, dawn, dark not lighted, dark lighted, and dusk) are calculated using Equation 1. The baseline severity index, the average severity for all, can be calculated using Equation 2. The values calculated using Equation 1 can then be compared to the baseline severity index to measure whether or not the severity index value for a particular sub-variable is higher (more severe on average) or lower (less severe on average) than the baseline value for all crashes studied.

$$Severity\ Index = \frac{NI_i * (1) + PIN_i * (2) + NC_i * (3) + IC_i * (4) + FL_i * (5)}{T_i} \qquad [1]$$

where: NI_i = the number of non-injury crashes for sub-variable i;
PIN_i = the number of possible injury crashes for sub-variable i;
NC_i = the number of non-incapacitating crashes for sub-variable i;
IC_i = the number of incapacitating crashes for sub-variable i;
FL_i = the number of fatal crashes for sub-variable i; and
T_i = the total number of crashes for sub-variable i equivalent to $(\sum NI_i + PIN_i + NC_i + IC_i + FL_i)$.

Table 27. Severity Type Coding for Severity Index Calculation

Severity Type	Severity Code
Non-Injury (NI)	1
Possible Injury (PI)	2
Non-Incapacitating (NC)	3
Incapacitating (IC)	4
Fatal (FL)	5

$$Baseline\ Index = \frac{NI_t * (1) + PIN_t * (2) + NC_t * (3) + IC_t * (4) + FL_t * (5)}{T_t} \qquad [2]$$

where: NI_t = the total number of non-injury crashes for all crashes studied;
PIN_t = the total number of possible injury crashes for all crashes studied;
NC_t = the total number of non-incapacitating crashes for all crashes studied;
IC_t = the total number of incapacitating crashes for all crashes studied;
FL_t = the total number of fatal crashes for all crashes studied; and
T_t = the total number of crashes studied which is equivalent to $(NI_t + PIN_t + NC_t + IC_t + FL_t)$.

Severity Index Values for Driver Age Groups

Researchers calculated severity index values for each driver age group displayed in Table 28. The baseline severity index for all crashes studied was determined to be 2.28. Only the 25 to 34 and unknown driver age groups have severity indices which are below the baseline value. All of the remaining driver age groups have severity indices above 2.28 (i.e., more severe crashes than average), with the over 74 age group on average having the most severe crashes. The higher calculated severity indices for the older age groups (55-64, 65-74, and over 74) is not surprising, largely because of increased frailty of the body with age.

Severity Index Values for Light Conditions

Researchers calculated severity index values for each light condition sub-variable displayed in Table 29. Severity index values for the daylight (2.33) and dawn (2.42) sub-variables were calculated to be greater than the baseline value (2.28). Crashes occurring at dawn were on average computed as the most severe.

Table 28. Severity Index Values Based on Driver Age

Driver Age Group	Severity Index
16 - 24	2.47
25 - 34	2.19
35 - 44	2.41
45 - 54	2.35
55 - 64	2.54
65 - 74	2.48
> 74	2.62
Unknown	1.19

Table 29. Severity Index Values Based on Light Conditions

Light Conditions	Severity Index
Daylight	2.33
Dawn	2.42
Dark not Lighted	2.23
Dark Lighted	2.16
Dusk	2.21

Severity Index Values for Location Types

Researchers calculated severity index values for each location type sub-variable given in Table 30. Severity index values for the rural (2.52), town under 2,500 (2.64), 5,000 to 10,000 (2.35), and 10,000 to 25,000 (2.33) sub-variables were calculated to have a higher average severity compared to the baseline value (2.28). Crashes occurring in rural location types (rural and town under 2,500) were on average computed to be the most severe.

Severity Index Values for Roadway Classes

Researchers computed severity index values for each roadway class sub-variable shown in Table 31. Severity index values for the farm to market (2.35) and county road (2.55) sub-variables were calculated to be greater than the baseline value (2.28). In agreement with previous findings, crashes occurring on county roads (2.55) were on average computed to be the most severe. Crashes at railroad-grade crossings on Interstate facilities have the lowest average severity, which is not surprising considering these facilities have the most sophisticated types of active protection due to the high exposure.

Table 30. Severity Index Values Based on Location Type

Location Type	Severity Index
Rural	2.52
Town Under 2,500	2.64
2,500 - 5,000	2.19
5,000 - 10,000	2.35
10,000 - 25,000	2.33
25,000 - 50,000	2.00
50,000 - 100,000	1.92
100,000 - 250,000	1.96
Over 250,000	1.93

Table 31. Severity Index Values Based on Roadway Classification

Roadway Classification	Severity Index
Interstate	1.87
U.S. & State Highway	2.13
Farm to Market	2.35
County Road	2.55
City Street	2.19

Severity Index Values for Total Occupants in Vehicle

Severity index values were computed for each total occupants in vehicle sub-variable provided in Table 32. Severity index values for the 2 occupant (2.71), 3 occupant (2.45), 4 occupant (2.64), and 5 occupant (2.87) sub-variables were calculated to be greater than the baseline value (2.28). Only one-occupant vehicles had an average severity which was lower than the baseline value. Crashes occurring with 5 total occupants in the vehicle were computed to be the most severe crashes on average. This finding is not surprising; the more occupants, the greater the probability of someone getting hurt.

Table 32. Severity Index Values Based on Total Occupants in Vehicle

Total Occupants in Vehicle	Severity Index
1	2.14
2	2.71
3	2.45
4	2.64
5	2.87

Severity Index Values for Driver Ethnicity and Gender

The research team calculated severity index values for each driver ethnicity and gender sub-variable displayed in Table 33. Severity index values for the White male (2.42), White female (2.57), Black female (2.31), and Hispanic female (2.40) sub-variables were calculated to have higher average severities than the baseline value (2.28). Only Black and Hispanic males had an average severity which was lower than the baseline value. Crashes involving White females were computed as the most severe crashes on average.

Severity Index Values for Protection Type

The research team calculated severity index values for each protection type sub-variable displayed in Table 34. Severity index values for the passive system (2.42) and cantilever-mounted signals (2.37) sub-variables were calculated to be greater than the baseline value. Similar to previous findings, crashes at crossings with passive systems were computed to be the most severe crashes on average.

Severity Index Values for Activation Technology Type

Researchers calculated severity index values for each activation technology type sub-variable displayed in Table 35. Only Audio Frequency Overlay with timing sections (3.00) had more severe crashes than the baseline value (2.28). Motion sensitive and Audio Frequency Overlay sub-variables are very close to the average severity for all crashes studied. One explanation for these three circuit types having more severe crashes on average when compared to the other circuit types is that they tend to produce variable warning times. If different warning times are produced for variable train speeds, drivers may become confused and proceed when it is not safe to do so.

Table 33. Severity Index Values Based on Driver Ethnicity and Gender

Driver Ethnicity and Gender	Severity Index
White Male	2.42
White Female	2.57
Black Male	2.22
Black Female	2.31
Hispanic Male	2.13
Hispanic Female	2.40

Table 34. Severity Index Values Based on Protection Type

Protection Type	Severity Index
Passive System	2.42
Cantilever-Mounted Signals	2.37
Mast-Mounted Signals	2.26
Automatic Gates	2.10

Table 35. Severity Index Values Based on Activation Technology Type

Activation Technology	Severity Index
Conventional	1.93
Conventional (with timing sections)	1.0
Audio Frequency Overlay	2.26
AFO (with timing sections)	3.00
Motion Sensitive	2.25
Constant Warning Time	2.01
Other	1.6

One somewhat surprising finding was that conventional track circuits had low severity index values indicating good performance in terms of the severity of crashes at crossings equipped with this activation technology. One explanation for this performance may be attributed to the location of many of these circuit types. Railroad companies try to install conventional circuits at crossings where train speeds are fairly uniform. This type of installation results in the circuits operating like a constant warning time circuit because they provide uniform warning times. Constant warning time circuits seem to also perform well in terms of the average severity of crashes. The effectiveness of constant warning time circuits is not surprising because previous research studies have concluded that the uniform warning time that these circuits provide improves driver behavior.

Results of Hypothesis Testing

This section presents the results of the hypotheses testing provided in Section 4.0. In order to make this section more reader-friendly, each research hypothesis is stated at the beginning of the paragraph which discusses the outcome of the comparisons.

Hypothesis 1: Because young drivers are more aggressive in many of their actions, it is hypothesized that young driver age groups (16-20 and 21-24) are involved in a greater proportion of crashes where "drove around gates" is coded as the primary contributing factor.

This hypothesis was supported at the 95 percent confidence level. In order to determine whether the driving around gates age distribution was different from the age distribution for all crashes studied, the research team performed a Chi-square analysis. Table 36 provides the calculations for the Chi-square analysis. There is evidence of a statistical difference between the age distribution for the driving around gates contributing factor and the age distribution for all crashes studied. Therefore, the distributions are statistically different and the hypothesis that younger drivers are more aggressive cannot be rejected.

Hypothesis 2: Because the male gender tends to be more aggressive than the female gender, it is hypothesized that male drivers are involved in a greater proportion of crashes where tried to beat train is coded as the primary contributing factor.

The research team investigated this hypothesis comparing the frequency of males involved in tried to beat train crashes to the frequency of males involved in all crashes studied. The results of the comparison show that male drivers are involved in a greater proportion of crashes where tried to beat train is the primary contributing factor (82.0 percent) when compared to all crashes studied (75.8 percent). A statistical analysis confirmed that this proportion is significantly greater (especially with the 16 to 20 year old age group) at the 95 percent confidence level. This finding may support the generally recognized premise that male drivers are more aggressive and take more risks when driving.

Hypothesis 3: Because the perceived risk may change when there are passengers in the vehicle, it is hypothesized that one-occupant vehicles (i.e., a driver with no passengers) are involved in greater proportion of crashes where driving around gates is coded the primary contributing factor.

The research team investigated this hypothesis by comparing the one-occupant proportion for crashes where driving around gates was coded the primary contributing factor to the one-occupant proportion for all crashes studied. The basic rationale behind this hypothesis is that drivers are more willing to take a risk (i.e., drive around lowered gate arms) when they are alone in the vehicle. A statistical analysis revealed that the research hypothesis is not supported at the 95 percent confidence level. A second analysis was performed to determine whether the occupants distribution for driving around gates crashes was different from the occupants distribution for all crashes studied. The results of a Chi-square analysis (Table 37) indicate that there is no evidence of a statistical difference between the driving around gates occupants distribution and the occupants distribution for all crashes studied.

Table 36. Hypothesis 1 (Driver Age)

Driver Age	Driving Around Gates Percentage f(g)	All Crash Percentage f(a)	f(g)	f(a)	f(g)-f(a)	$(f(g)-f(a))^2$	$\frac{(f(g)-f(a))^2}{f(a)}$
16 - 20	8.2	11.5	108.9	152.7	-43.9	1924.4	12.60
21 - 24	13.9	9.8	185.0	130.1	54.9	3014.6	23.17
25 - 34	25.4	22.9	337.4	304.1	33.3	1110.9	3.65
35 - 44	16.4	16.9	217.7	224.4	-6.7	45.3	0.20
45 - 54	12.3	11.5	163.3	152.7	10.6	111.5	0.73
55 - 64	9.8	8.5	130.6	112.9	17.7	314.8	2.79
65 - 74	3.3	5.5	43.5	73.0	-29.5	870.2	11.92
> 74	2.5	3.7	32.7	49.1	-16.5	271.6	5.53
Unknown	8.2	9.5	108.9	126.2	-17.3	299.6	2.37

Chi-Square Calculated = 62.97
Chi-Square Table (8 , 0.05) = 15.50

Table 37. Hypothesis 3 (Vehicle Occupancy)

Tot. Occ. in Vehicle	Driving Around Gates Percentage f(g)	All Crash Percentage f(a)	f(g)	f(a)	f(g)-f(a)	$(f(g)-f(a))^2$	$\frac{(f(g)-f(a))^2}{f(a)}$
1	76.4	75.4	1014.9	1001.3	13.6	184.5	0.18
2	17.9	17.0	237.5	225.8	11.8	138.5	0.613
3	4.1	4.4	54.0	58.4	-4.4	19.8	0.33
4	0.8	1.8	10.8	23.9	-13.1	171.8	7.19
5	0.8	0.1	10.8	14.6	-3.8	14.5	0.99

Chi-Square Calculated = 9.30
Chi-Square Table (6 , 0.05) = 9.50

Hypothesis 4: Because older drivers have difficulty with judgement and declining physical abilities, it is hypothesized that older drivers (55 years old and over) are involved in a greater proportion of crashes where stalled, stuck, and stopped too close is coded as the primary contributing factor.

The research team tested this hypothesis by comparing the proportion of older drivers involved in stalled, stuck, or stopped too close crashes to the proportion of older drivers involved in all crashes studied. Somewhat surprisingly, the analysis shows that older driver age groups are not more likely to be involved in stalled, stuck, or stopped too close crashes (14.8 percent) when compared to all crashes (17.7 percent). Further analysis was performed to determine whether or not female drivers were more likely to be involved in these type of crashes. The results of this analysis indicate that female drivers are involved in a significantly greater proportion of crashes where stalled, stuck, or stopped too close is the primary contributing factor (36.9 percent) when compared to all crashes studied (24.0 percent).

Hypothesis 5: Because young drivers lack experience with the different types and responsibilities at highway-railroad grade crossings, it is hypothesized that inexperienced drivers (16-24 years old) are involved in a greater proportion of crashes at crossings which have passive protection.

The research team examined this hypothesis by comparing the proportion of drivers age 16 to 24 involved in crashes at passive crossings to the proportion of drivers age 16 to 24 involved in all crashes studied. The results of the analysis show that drivers age 16 to 24 have a lower proportion of involvement at passively protected crossings (20.0 percent) when compared to drivers age 16 to 24 in all crashes (21.3 percent). This indicates that this hypothesis is not supported because a lower percentage of inexperienced drivers are involved in crashes at passive crossings compared to the involvement in all crashes studied.

Hypothesis 6: Because drivers between 25 and 44 years of age are the most mobile, it is hypothesized that they are involved in a greater proportion of crashes at crossings with active protection.

This hypothesis was investigated by comparing the frequency of drivers between 25 and 44 years of age involved in crashes at active crossings to the frequency of drivers between 25 and 44 years of age involved in all crashes studied. The comparison reveals that the frequency of drivers between 25 and 44 years of age involved in crashes at active crossings (38.6 percent) is lower than the corresponding frequency for all crashes studied (39.8 percent). This result indicates that this hypothesis is not supported because drivers between 25 and 44 years of age are not involved in a greater proportion of crashes at active crossings compared to all crashes.

Hypothesis 7: Because elderly persons often have difficulty seeing well at night, it is hypothesized that elderly drivers (55 years and older) are involved in a higher proportion of crashes where light conditions are dark (i.e., at night).

This hypothesis was tested by comparing the proportion of elderly drivers involved in crashes where the light conditions were dark to the proportion of elderly drivers involved in all crashes studied. The results of the analysis indicate that the proportion of elderly drivers involved in crashes during the nighttime (19.1 percent) is higher than the percentage of elderly drivers involved in all crashes (17.7 percent). A statistical comparison of these proportions indicates that the hypothesis is not supported at the 95 percent confidence level. While the two proportions may not be statistically different, it should be noted that the higher percentage is probably an indication that elderly drivers have problems at nightimet.

Hypothesis 8: Because large trucks and vehicles towing trailers are considerably longer than conventional passenger cars, it is hypothesized that semi-tractor trailer trucks and pickup trucks with trailers are involved in a greater proportion of crashes where intersection proximity is coded the primary contributing factor.

The research team tested this hypothesis by comparing the vehicle type proportions for crashes where intersection proximity is the primary contributing factor to the vehicle type proportions for all crashes studied. The frequency analysis revealed that 30.9 percent of the vehicles involved in crashes where intersection proximity is the primary contributing factor were semi-tractor trailers or pickup trucks with trailers. Only 11.2 percent of the vehicles for all crashes studied were semi-tractor trailers or pickup trucks with trailers. A statistical comparison of the two proportions shows that the research hypothesis is supported at the 95 percent confidence level. This result indicates that semi-tractor trailers and pickup trucks with trailers are involved in a significantly greater proportion of crashes where intersection proximity is coded the primary contributing factor. This finding is not surprising because the length of these vehicle types seems to make them more prone to this type of crash.

Hypothesis 9: A greater proportion of crashes where parallel roadway is coded the contributing factor occur at *passively protected crossings.*

The research team analyzed this hypothesis by comparing the proportion of passive crossings for parallel roadway crashes to the proportion of passive crossings for all crashes studied. The results show that 52.1 percent of the parallel roadway crashes occurred at passive crossings compared to 46.2 percent for all crashes studied. A statistical comparison of these two proportions reveals that the research hypothesis is not supported at the 95 percent confidence level. This analysis shows that while a greater proportion of parallel roadway crashes occur at passively protected crossings, the difference is not statistically significant..

Further analysis reveals that cantilever-mounted signals are also involved in a significantly greater proportion of parallel roadway crashes (28.2 percent) when compared to involvement in all crashes (17.2 percent). This finding may suggest that motorists turning from a parallel roadway are not detecting the signal located above the crossing (i.e., they may have to make an unnatural and difficult head or eye movement upwards to detect the signal indication). The final analysis of parallel roadway crashes indicates that the city streets roadway class is also involved in a significantly greater proportion of parallel roadway crashes (65.2 percent) when compared to all crashes studied (54.4 percent). This result is somewhat expected because it seems intuitive that more railroad tracks are aligned parallel to roadway facilities in urban locations, where right-of-ways are more restricted, compared to rural locations.

Hypothesis 10: Because no warning regarding the approach of a train is given to the motorist at a passive crossing, it is hypothesized that the average severity of crashes occurring at passive crossings is greater (i.e., more severe) than for crashes occurring at active crossings.

Researchers tested this hypothesis by comparing the severity index values. The severity index value for passive crossings was found to be 2.42 which is greater than the value for all active crossing protection types (2.37 for cantilever-mounted signals, 2.26 for mast-mounted signals, and 2.10 for automatic gates). The index values seem to indicate that crashes at passive crossings are more severe on the average than crashes at active crossings.

Hypothesis 11: Because a driver is limited by the effectiveness of vision and headlights at night, it is hypothesized that the average severity of crashes occurring at night (i.e., light conditions are dark) is greater than the average severity for crashes occurring during daytime.

The research team examined this hypothesis by comparing the severity index values. The severity index value for crashes occurring at night was determined to be 2.23 for dark not lighted and 2.16 for dark lighted. The severity index value for daytime crashes was calculated as 2.33. The index values suggest that the average severity of crashes at night is not greater than the average severity for crashes during daytime.

Summary of Hypothesis Testing

The research team formulated several hypotheses based on the literature review of driver behavior and results of previous accident studies. Only research hypotheses 2 (male drivers try to beat the train more often than female drivers), 8 (large trucks are involved in crashes related to intersection proximity), and 10 (crashes at nighttime are more severe than at daytime) were found to be statistically supported using proportion comparison testing. A summary of the results of the hypotheses described in the previous sections is provided in Appendix D.

6.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations developed through this research. Researchers conducted a statewide study to identify contributing factors to train-involved crashes in the state of Texas. Based on the findings of this study, recommendations for practical safety improvements and public education material will be made.

6.1 CONCLUSIONS

This section summarizes the most significant findings of the statewide crash analysis performed in this research. The conclusions are divided into sections covering railroad factors, environmental factors, roadway factors, and driver/passenger factors.

Railroad Factors

1. Over 30 percent of the crashes studied occurred at crossings with automatic gates compared to 20 percent nationwide. This finding suggests that motorists in Texas are more likely to drive around lowered gate barriers and become involved in train-involved crashes.

2. Passive protection systems account for more fatalities than all three active systems studied. Passively protected grade crossings also account for more than 70 percent of crashes with multiple fatalities. These findings and the severity index comparison suggest that crashes at passive crossings are more severe compared to active crossings.

3. Motion sensitive and Audio Frequency Overlay (AFO) circuits experience a higher frequency of crashes when compared to the proportion installed at active crossings statewide. AFO with timing sections experience a significantly greater proportion of crashes compared to the proportion installed at active crossings statewide. One potential explanation is that these circuits may provide variable warning times which adversely affect driver behavior and the subsequent crash experience.

4. Conventional and constant warning time track circuits perform well in terms of the average severity of crashes (i.e., the severity index values are lower than the baseline value for all crashes). One rationalization for their good performance may be that they provide uniform warning time which provides benefits in terms of driver behavior and subsequent crash experience. Conventional track circuits are not designed to provide uniform warning time; however, the application of these circuits in Texas tends to be at grade crossings with fairly uniform train speeds. Therefore, these circuits tend to perform somewhat like a constant warning time circuit because they provide a fairly uniform warning time.

5. The train-involved crashes studied in this research have significantly greater proportions of incapacitating and fatal crashes compared to all crashes in the state of Texas. This finding

shows that crashes at highway-railroad grade crossings are more severe compared to all crashes statewide.

Environmental Factors

1. Rural (town under 2,500; 2,500 to 5,000; 5,000 to 10,000; and 10,000 to 25,000) location types experience significantly greater proportions of train-involved crashes compared to all crashes statewide. This finding supports the contention that train-involved crashes in Texas are more of a rural problem (approximately 65 percent of the crashes studied occurred in areas with populations of 25,000 or less compared to 36 percent of all crashes statewide).

2. The average severity for crashes during daylight conditions was determined to be greater than for crashes occurring at night. This finding was somewhat surprising but could possibly be explained by a greater amount of automobile traffic and railroad traffic during daylight hours.

3. The highest frequency for total Texas crashes and fatal crashes studied in this report occurred between 3 p.m. and 6 p.m. The NHTSA fatal crash study supports this finding by concluding that the 3 p.m. to 6 p.m. time period experienced the greatest proportion of all fatal highway-railroad grade crossing crashes nationwide (29).

4. In this study the late night time periods (i.e., 9 p.m. to 12 a.m., 12 a.m. to 3 a.m., and 3 a.m. to 6 a.m.) experience significantly greater proportions of the grade crossing crashes compared to all crashes statewide.

Roadway Factors

1. County and farm to market roadway facilities experience a significantly greater proportion of train-involved crashes compared to all crashes statewide. This finding seems to also support the idea that train-involved crashes are more of a problem in rural locations in Texas.

2. The analysis of parallel roadway crashes showed that significantly greater proportions of crashes occurred at grade crossings protected by cantilever signals and on city street roadway facilities. The greater proportion of cantilever signals is not surprising because motorists may have difficulty detecting this type of signal after making a turn onto the side street.

3. The analysis revealed that a significantly greater proportion of semi-tractor trailer trucks and vehicles towing trailers are involved in crashes where intersection proximity is the primary contributing factor compared to the frequency of involvement in all crashes studied.

Driver/Passenger Factors

1. Inexperienced drivers (i.e., the 16 to 20 and 21 to 24 driver age groups) are involved in significantly greater proportions of crashes where either tried to beat train (especially males 16 to 20) or impaired driver (especially males 21 to 24) were the primary contributing factors. These findings show that inexperienced drivers (especially males) are willing to take risks at highway-railroad grade crossings.

2. Elderly drivers (55 and older) are involved in a significantly greater proportion of crashes at highway-railroad grade crossings compared to the proportion of involvement in all crashes. A related finding is that elderly drivers have a higher frequency of involvement in crashes at night compared to their proportion of involvement in all other crashes at night.

3. White and Hispanic males are involved in a significantly greater proportion of train-involved crashes compared to all crashes statewide. One potential explanation is that males exhibit more aggressive and risky behavior and are therefore involved in a greater proportion of crashes.

6.2 RECOMMENDATIONS

Based on the findings of this research, the authors offer the following recommendations for potential safety improvements and public education strategies. The authors also present recommendations for additional research.

1. Because a significantly greater proportion of crashes occur at crossings with automatic gates in Texas (30.1 percent) than the national average (20.1 percent), enforcement efforts should be increased to help deter motorists from driving around lowered gates. Both police presence and automated techniques (i.e., video surveillance) could be utilized.

2. Constant warning time circuits performed well in terms of the relative involvement in all crashes and fatal-only crashes. Based on this performance, it is recommended that constant warning time circuits be installed in favor of motion sensitive when funding levels permit.

3. It appears that train-involved crashes in Texas are more of a rural problem. Public education efforts should concentrate on rural and small town locations where grade crossing safety is a concern.

4. Parallel roadway crashes at crossings with flashing light signals may be reduced if additional signal displays are oriented parallel to the roadway so that the drivers can receive the information regarding the presence of a train prior to attempting a turn across the tracks.

5. Where the storage capacity (i.e., the distance from the stop bar at the intersection to 1.52 meters (5 feet) from the nearest rail of the tracks) is inadequate for semi-tractor trailer trucks and vehicles towing trailers to be safely stored, supplemental signing should be used to inform drivers of these types of vehicles to stop prior to the grade crossing.

6. A significantly greater proportion of crashes occur in dark not lighted conditions at highway-railroad grade crossings compared to all crashes statewide. The Texas Department of Transportation should work with railroad companies to have railcars and locomotives equipped with reflective paint, tape, or buttons. This improvement may help reduce the frequency of crashes at night for motorists who run into the side of a train already occupying the grade crossing. Another possible improvement which may reduce the frequency of train-involved crashes at night is the illumination of more grade crossings.

Areas for Further Research

1. A more in-depth investigation of parallel roadway and intersection proximity crashes should be conducted to identify treatments to improve safety where highway-railroad grade crossings run parallel to roadway facilities or are in close proximity to roadway intersections.

2. Because crashes at passive crossings are more severe, future research should be conducted to determine whether distinct advance warning signs should be developed to help motorists distinguish between passive and active grade crossings.

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APPENDIX A

LISTING OF CODED NUMBER CONTRIBUTING FACTORS

Table A-1. Contributing Factor Number Code Descriptions and Relative Frequencies

Category	Number Factor	Description	Relative Frequency
G	3	Backed without safety	0.31
A	9	Defective or no trailer brakes	0.15
A	10	Defective or no vehicle brakes	0.76
A	11	Defective steering mechanism	0.08
A	12	Defective or slick tires	0.23
A	13	Defective trailer hitch	0.08
B	14	Disabled in traffic lane	1.76
C	15	Disregarded stop and go signal	0.99
C	16	Disregarded stop sign or light	2.14
C	18	Disregarded warning sign at construction	0.15
F	19	Distraction in vehicle	2.82
F	20	Driver inattention	33.36
D	22	Failed to control speed	5.50
H	23	Failed to drive in single lane	0.46
C	25	Failed to heed warning sign	4.89
C	29	Failed to stop at proper place	2.82
G	30	Failed to stop for school bus	0.23
I	31	Failed to stop for train	62.75
I	32	Failed to yield ROW - emergency vehicle	0.08
I	33	Failed to yield ROW - open intersection	0.76
I	35	Failed to yield ROW - stop sign	1.15
I	39	Failed to yield ROW - yield sign	0.38
E	40	Fatigued or asleep	1.30
G	41	Faulty evasive action	2.60
H	44	Followed too closely	0.08
E	45	Had been drinking	6.11
E	47	Ill driver	0.31
J	48	Impaired visibility	3.13

Table A-1. Contributing Factor Number Code Descriptions and Relative Frequencies (Continued)

Category	Number Factor	Description	Relative Frequency
I	49	Improper start from parked position	0.08
J	52	Oversize vehicle or load	0.15
B	55	Parked in traffic lane	0.61
H	57	Parked in no passing zone	0.08
D	60	Speeding - unsafe (under limit)	0.76
D	61	Speeding - over limit	1.76
E	62	Taking medication	0.08
G	64	Turned improperly - wide right	0.08
I	66	Turned when unsafe	0.08
E	67	Under influence - alcohol	6.03
E	68	Under influence - drug	0.31
H	69	Wrong side - approach or intersection	0.31
H	70	Wrong side - not passing	0.31
H	71	Wrong way - one way road	0.08
B, C, H, J	72	Other factor (officer written explanation)	16.87

APPENDIX B

CHI-SQUARE COMPARISON TABLES

Table B-1. Protection Type Chi-Square Comparison

Protection Type	Crash Percentage	National Percentage	f(a)	f(n)	f(a)-f(n)	$(f(a)-f(n))^2$	$\frac{(f(a)-f(n))^2}{f(n)}$
Passive System	46.2	49.1	613.5	652.1	-38.6	1490.0	2.29
Flashing Signals	23.7	30.4	314.7	403.7	-89.0	7921.0	19.62
Automatic Gates	30.1	20.5	399.7	272.2	127.5	16256.3	59.72

Chi-Square Calculated = 81.63
Chi-Square Table (2 , 0.05) = 6.00

Table B-2. Activation Technology Chi-Square Comparison

Activation Technology	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
Conventional	17.3	16.5	605.7	635.1	-29.4	862.5	1.36
Conv (w/ timing)	0.5	0.7	25.7	18.4	7.3	53.9	2.93
AFO	8.5	8.0	293.7	312.0	-18.4	336.9	1.08
AFO (w/ timing)	0.9	0.4	14.7	33.0	-18.4	336.9	10.21
Motion Sensitive	32.1	31.4	1152.7	1178.4	-25.7	660.3	0.56
Const. Warning	34.2	36.4	1336.2	1255.5	80.8	6522.5	5.20
Man. Operation	0.2	0.5	18.4	7.3	11.0	121.3	16.62
None	1.2	1.3	47.7	44.1	3.7	13.5	0.31
Other	5.1	4.8	176.2	187.2	-11.0	121.3	0.65

Chi-Square Calculated = 38.90
Chi-Square Table (8 , 0.05) = 15.50

Table B-3. Time of Day Chi-Square Comparison

Time of Day	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
12 a.m. - 3 a.m.	10.5	7.2	139.4	95.6	43.8	1920.5	20.09
3 a.m. - 6 a.m.	6.0	3.0	79.7	39.8	39.8	1587.2	39.88
6 a.m. - 9 a.m.	11.4	10.9	151.4	144.8	6.6	44.1	0.31
9 a.m. - 12 p.m.	15.1	12.0	200.5	159.4	41.2	1694.8	10.63
12 p.m. - 3 p.m.	14.2	17.9	188.6	237.7	-49.2	2414.3	10.16
3 p.m. - 6 p.m.	16.0	23.7	212.5	314.7	-102.3	10456.3	33.23
6 p.m. - 9 p.m.	14.8	15.1	196.5	200.5	-4.0	15.9	0.08
9 p.m. - 12 a.m.	11.9	11.9	158.0	131.5	26.6	705.4	5.36

Chi-Square Calculated = 119.73
Chi-Square Table (8 , 0.05) = 14.10

Table B-4. Light Conditions Chi-Square Comparison

Light Conditions	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
Daylight	58.4	68.3	775.6	907.0	-131.5	17284.9	19.06
Dawn	1.8	1.0	23.9	13.3	10.6	112.9	8.49
Dark Not Lighted	22.1	11.5	293.5	152.7	140.8	19815.6	129.77
Dark Lighted	16.3	17.4	216.5	231.1	-14.6	213.4	0.92
Dusk	1.4	1.8	18.6	23.9	-5.3	28.2	1.18

Chi-Square Calculated = 159.42
Chi-Square Table (4 , 0.05) = 9.50

Table B-5. Driver Age Chi-Square Comparison

Driver Age Group	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
< 16	0.1	0.4	1.3	5.3	-4.0	15.9	3.0
16 - 20	11.5	13.9	152.7	184.6	-31.9	1015.8	55.27
21 - 24	9.8	12.5	130.1	166.0	-35.9	1285.7	7.75
25 - 34	22.9	25.7	304.1	341.3	-37.2	1382.7	4.05
35 - 44	16.9	18.7	224.4	248.3	-23.9	571.4	2.30
45 - 54	11.5	10.3	152.7	136.8	15.9	254.0	1.86
55 - 64	8.5	5.8	112.9	77.0	35.9	1285.7	16.70
65 - 74	5.5	3.6	73.0	47.8	25.2	636.7	13.32
> 74	3.7	2.5	49.1	33.2	15.9	254.0	7.65
Unknown	9.5	6.6	126.2	87.6	38.5	1483.2	16.93

Chi-Square Calculated = 79.06
Chi-Square Table (9 , 0.05) = 17.0

Table B-6. Driver Race and Sex Chi-Square Comparison

Driver Race and Sex	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
White Male	43.4	35.9	576.4	476.8	99.6	9920.2	20.81
White Female	14.8	25.0	196.5	332.0	-135.5	18348.3	55.27
Black Male	8.1	7.6	107.6	100.9	6.6	44.1	0.44
Black Female	3.3	5.0	43.8	66.4	-22.6	509.7	7.68
Hispanic Male	16.5	14.0	219.1	185.9	33.2	1102.2	5.93
Hispanic Female	3.8	6.2	50.5	82.3	-31.9	1015.8	12.34
Other Male	0.8	1.3	10.6	17.3	-6.6	44.1	2.55
Other Female	0.1	0.6	1.3	8.0	-6.6	44.1	5.51
Unknown	9.2	4.6	122.2	61.1	61.1	3731.7	61.08

Chi-Square Calculated = 171.59
Chi-Square Table (8 , 0.05) = 15.50

Table B-7. Total Occupants in Vehicle Chi-Square Comparison

Total Occupants in Vehicle	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
1	75.4	68.7	1001.3	912.3	89.0	7916.7	8.68
2	17.0	19.3	225.8	256.3	-30.5	932.9	3.64
3	4.4	6.8	58.4	90.3	-31.9	1015.8	11.25
4	1.8	3.2	23.9	42.5	-18.6	345.7	8.13
5	1.1	1.3	14.6	17.3	-2.7	7.1	0.41
6	0.1	0.5	1.3	6.6	-5.3	28.2	4.27
7	0.1	0.1	1.3	1.3	0	0	0

Chi-Square Calculated = 36.38
Chi-Square Table (6 , 0.05) = 12.6

Table B-8. Crash Severity Chi-Square Comparison

Crash Severity	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
Non-injury	44.6	54.2	592.3	719.8	-127.5	16253.2	22.58
Possible injury	16.8	27.8	223.1	369.2	-146.1	21339.4	57.80
Nonincapacitating	15.0	12.8	199.2	170.0	29.2	853.6	5.02
Incapacitating	13.5	4.5	179.3	59.8	119.5	14285.0	238.88
Fatal	10.1	0.7	134.1	9.3	124.8	15583.0	1675.59

Chi-Square Calculated = 1999.87
Chi-Square Table (4 , 0.05) = 9.50

Table B-9. Location Type Chi-Square Comparison

Location Type	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
Rural	27.8	15.7	369.2	208.5	160.7	25820.6	123.84
Town under 2,500	12.6	3.5	167.3	46.5	120.9	14604.2	11.00
2,500 - 5,000	5.6	2.7	74.4	35.9	38.5	1483.2	41.31
5,000 - 10,000	5.6	3.8	74.4	50.5	23.9	571.4	11.31
10,000 - 25,000	12.7	10.5	168.7	139.4	29.2	853.6	6.12
25,000 - 50,000	4.6	5.5	61.1	73.0	-12.0	142.9	1.96
50,000 - 100,000	9.9	10.4	131.5	138.1	-6.6	44.1	0.32
100,000 - 250,000	5.3	9.1	70.4	120.9	-50.5	2546.6	21.06
Over 250,000	15.8	38.6	209.8	512.6	-302.8	91678.2	178.85

Chi-Square Calculated = 698.85
Chi-Square Table (8 , 0.05) = 15.50

Table B-10. Roadway Class Chi-Square Comparison

Roadway Class	Crash Percentage	Statewide Percentage	f(a)	f(s)	f(a)-f(s)	$(f(a)-f(s))^2$	$\frac{(f(a)-f(s))^2}{f(s)}$
Interstate	1.1	12.5	14.6	166.0	-151.4	22919.5	138.07
U.S. & State Highway	10.3	28.1	136.8	373.2	-236.4	55877.4	149.73
Farm to Market	14.2	8.9	188.6	118.2	70.4	4953.9	41.91
County Road	20.0	5.5	265.6	73.0	192.6	37079.4	507.94
City Street	54.4	44.8	722.4	594.9	127.5	16253.2	27.32

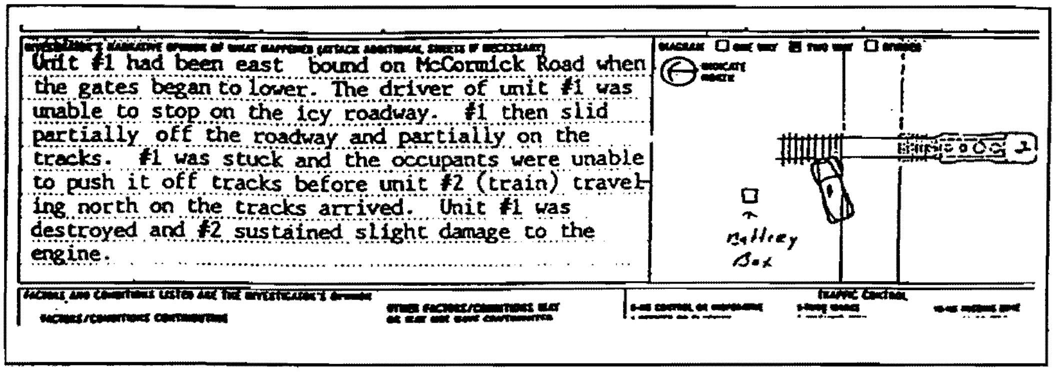
Chi-Square Calculated = 846.963
Chi-Square Table (4 , 0.05) = 9.50

Table B-11. Chi-Square Analysis Summary

Distribution Compared	Calculated Chi-Square Value	Table Chi-Square Value	Statistically Different	Statistically Similar
Protection Type	81.63	6.00	✓	
Activation Technology	38.90	15.50	✓	
Time of Day	119.73	14.10	✓	
Light Conditions	159.42	9.50	✓	
Driver Age	79.06	17.00	✓	
Driver Race and Sex	171.59	15.50	✓	
Total Occupants in Vehicle	36.38	12.60	✓	
Crash Severity	1999.87	9.50	✓	
Location Type	698.85	15.50	✓	
Roadway Class	846.96	9.50	✓	

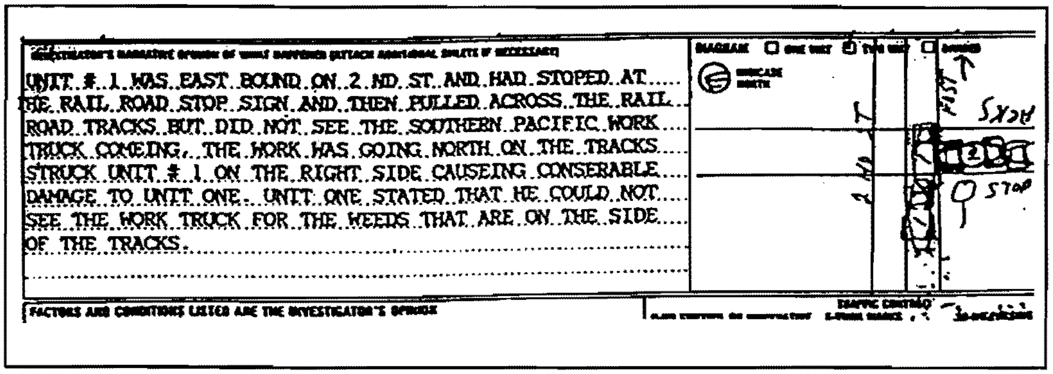
APPENDIX C

CONTRIBUTING FACTOR EXAMPLES



Unit #1 had been east bound on McCormick Road when the gates began to lower. The driver of unit #1 was unable to stop on the icy roadway. #1 then slid partially off the roadway and partially on the tracks. #1 was stuck and the occupants were unable to push it off tracks before unit #2 (train) traveling north on the tracks arrived. Unit #1 was destroyed and #2 sustained slight damage to the engine.

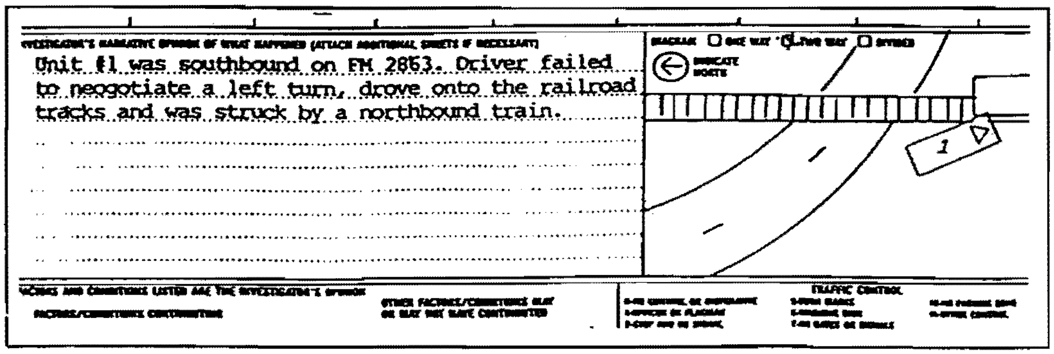
Figure C-1. Weather Contributing Factor Example



UNIT # 1 WAS EAST BOUND ON 2 ND ST AND HAD STOPED AT THE RAIL ROAD STOP SIGN AND THEN PULLED ACROSS THE RAIL ROAD TRACKS BUT DID NOT SEE THE SOUTHERN PACIFIC WORK TRUCK COMEING, THE WORK WAS GOING NORTH ON THE TRACKS STRUCK UNIT # 1 ON THE RIGHT SIDE CAUSEING CONSERABLE DAMAGE TO UNIT ONE. UNIT ONE STATED THAT HE COULD NOT SEE THE WORK TRUCK FOR THE WEEDS THAT ARE ON THE SIDE OF THE TRACKS.

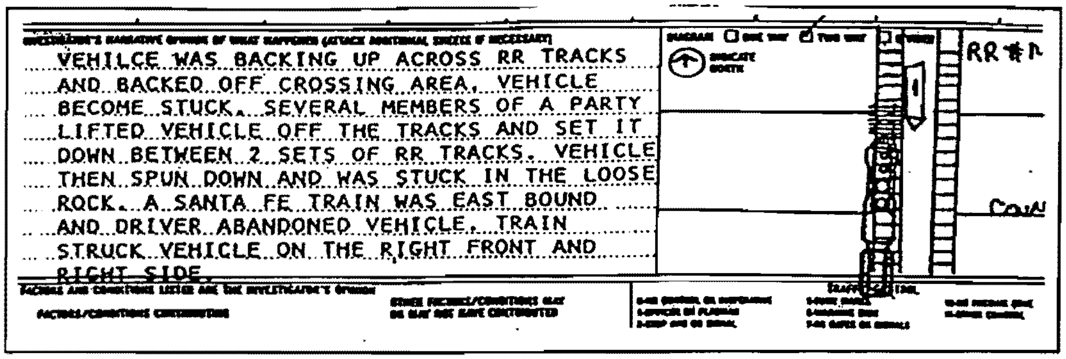
FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

Figure C-2. Sight Distance Contributing Factor Example



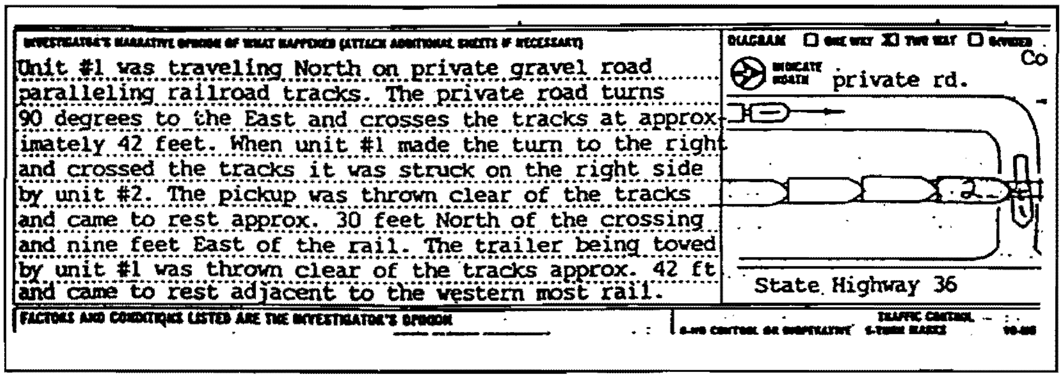
Unit #1 was southbound on FM 2863. Driver failed to neogotiate a left turn, drove onto the railroad tracks and was struck by a northbound train.

Figure C-3. Horizontal Curvature Contributing Factor Example



VEHILCE WAS BACKING UP ACROSS RR TRACKS
AND BACKED OFF CROSSING AREA. VEHICLE
BECOME STUCK. SEVERAL MEMBERS OF A PARTY
LIFTED VEHICLE OFF THE TRACKS AND SET IT
DOWN BETWEEN 2 SETS OF RR TRACKS. VEHICLE
THEN SPUN DOWN AND WAS STUCK IN THE LOOSE
ROCK. A SANTA FE TRAIN WAS EAST BOUND
AND DRIVER ABANDONED VEHICLE. TRAIN
STRUCK VEHICLE ON THE RIGHT FRONT AND
RIGHT SIDE.

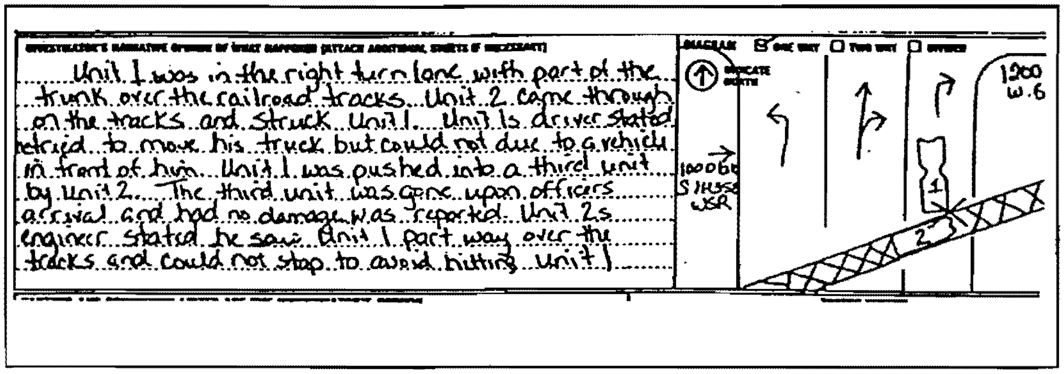
Figure C-4. Stuck on Tracks Contributing Factor Example



Unit #1 was traveling North on private gravel road
paralleling railroad tracks. The private road turns
90 degrees to the East and crosses the tracks at approx-
imately 42 feet. When unit #1 made the turn to the righ
and crossed the tracks it was struck on the right side
by unit #2. The pickup was thrown clear of the tracks
and came to rest approx. 30 feet North of the crossing
and nine feet East of the rail. The trailer being towed
by unit #1 was thrown clear of the tracks approx. 42 ft
and came to rest adjacent to the western most rail.

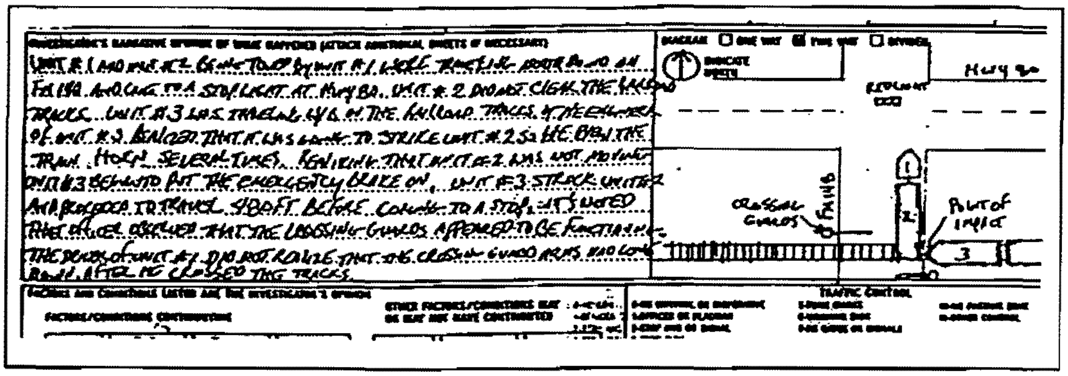
FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

Figure C-5. Parallel Roadway Contributing Factor Example



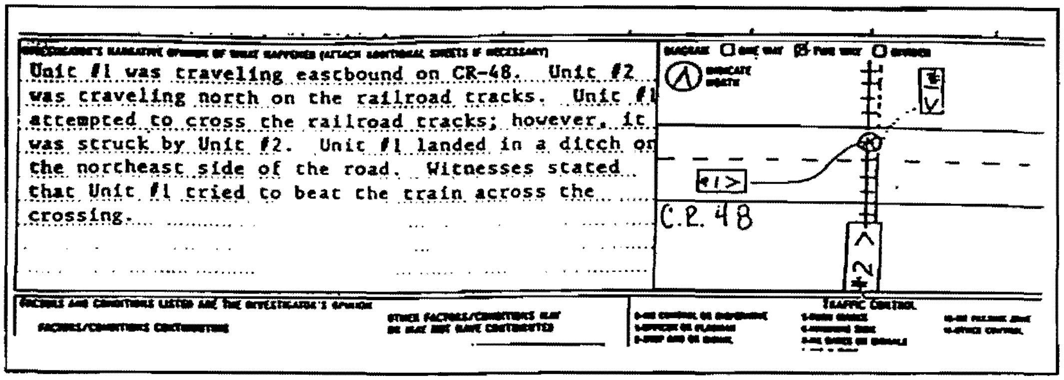
Unit 1 was in the right turn lane with part of the
trunk over the railroad tracks. Unit 2 came through
on the tracks and struck Unit 1. Unit 1s driver stated
he tried to move his truck but could not due to a vehicle
in front of him. Unit 1 was pushed into a third unit
by Unit 2. The third unit was gone upon officers
arrival and had no damage was reported. Unit 2s
engineer stated he saw Unit 1 part way over the
tracks and could not stop to avoid hitting Unit 1

Figure C-6. Intersection Proximity (Queuing on Tracks) Contributing Factor Example



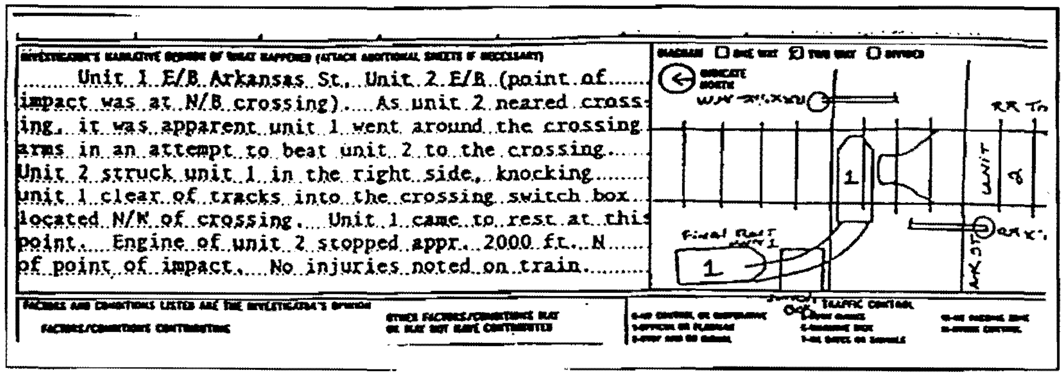
UNIT #1 AND UNIT #2 BEING TOWED by UNIT #1 WERE TRAVELING NORTH BOUND ON FM 1960 AND CAME TO A STOPLIGHT AT HWY 90. UNIT #2 DID NOT CLEAR THE RAILROAD TRACKS. UNIT #3 WAS TRAVELING W/B ON THE RAILROAD TRACKS. THE ENGINEER OF UNIT #3 REALIZED THAT IT WAS GOING TO STRIKE UNIT #2 SO HE BLEW THE TRAIN HORN SEVERAL TIMES. REALIZING THAT UNIT #2 WAS NOT MOVING UNIT #3 ENGINEER PUT THE EMERGENCY BRAKE ON. UNIT #3 STRUCK UNIT #2 AND PROCEEDED TO TRAVEL 480FT. BEFORE COMING TO A STOP. IT'S NOTED THAT OFFICER OBSERVED THAT THE CROSSING GUARDS APPEARED TO BE FUNCTIONING. THE DRIVER OF UNIT #1 DID NOT REALIZE THAT THE CROSSING GUARD ARMS HAD COME DOWN AFTER HE CROSSED THE TRACKS.

Figure C-7. Intersection Proximity (Inadequate Storage) Contributing Factor Example



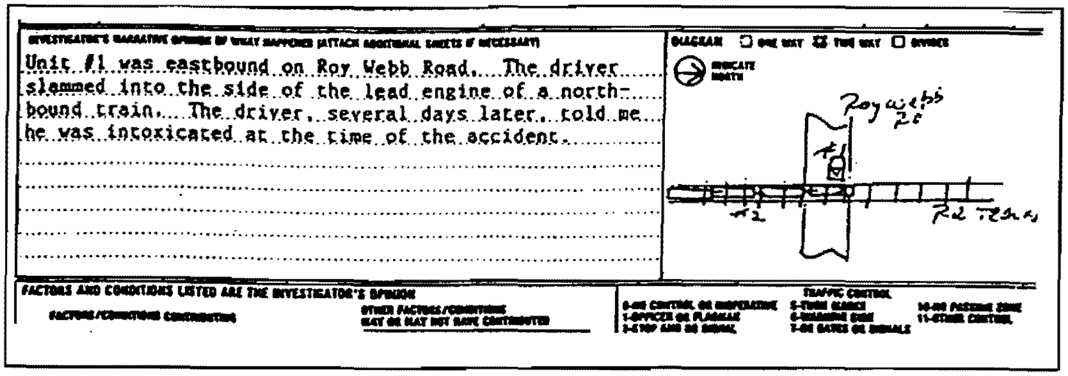
Unit #1 was traveling eastbound on CR-48. Unit #2 was traveling north on the railroad tracks. Unit #1 attempted to cross the railroad tracks; however, it was struck by Unit #2. Unit #1 landed in a ditch on the northeast side of the road. Witnesses stated that Unit #1 tried to beat the train across the crossing.

Figure C-8. Tried to Beat Train Contributing Factor Example



Unit 1 E/B Arkansas St. Unit 2 E/B (point of impact was at N/B crossing). As unit 2 neared crossing, it was apparent unit 1 went around the crossing arms in an attempt to beat unit 2 to the crossing. Unit 2 struck unit 1 in the right side, knocking unit 1 clear of tracks into the crossing switch box located N/W of crossing. Unit 1 came to rest at this point. Engine of unit 2 stopped appr. 2000 ft. N of point of impact. No injuries noted on train.

Figure C-9. Driving Around Gates Contributing Factor Example



INVESTIGATOR'S NARRATIVE OPINION OF WHAT HAPPENED (ATTACH ADDITIONAL SHEETS IF NECESSARY)

Unit #1 was eastbound on Roy Webb Road. The driver slammed into the side of the lead engine of a northbound train. The driver, several days later, told me he was intoxicated at the time of the accident.

DIAGRAM ☐ ONE WAY ☒ TWO WAY ☐ DIVIDED

INDICATE NORTH

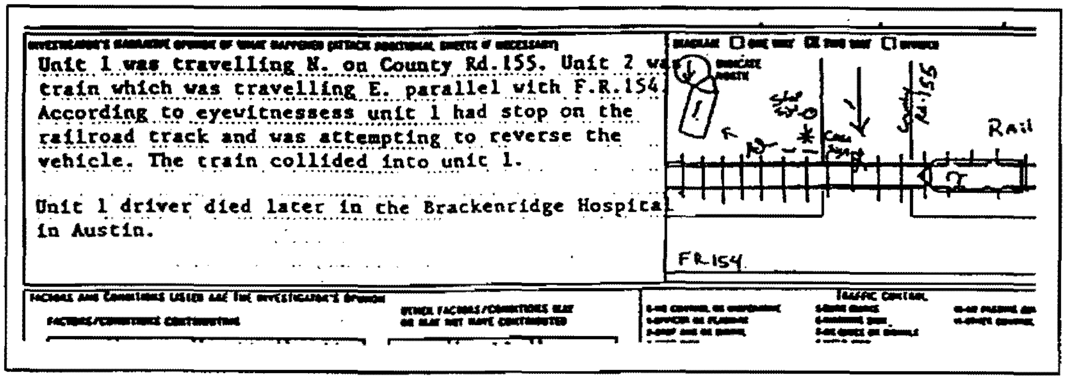
FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

FACTORS/CONDITIONS CONTRIBUTING

OTHER FACTORS/CONDITIONS MAY OR MAY NOT HAVE CONTRIBUTED

TRAFFIC CONTROL

Figure C-10. Impaired Driver Contributing Factor Example



INVESTIGATOR'S NARRATIVE OPINION OF WHAT HAPPENED (ATTACH ADDITIONAL SHEETS IF NECESSARY)

Unit 1 was travelling N. on County Rd.155. Unit 2 wa train which was travelling E. parallel with F.R.154. According to eyewitnessess unit 1 had stop on the railroad track and was attempting to reverse the vehicle. The train collided into unit 1.

Unit 1 driver died later in the Brackenridge Hospital in Austin.

DIAGRAM ☐ ONE WAY ☒ TWO WAY ☐ DIVIDED

INDICATE NORTH

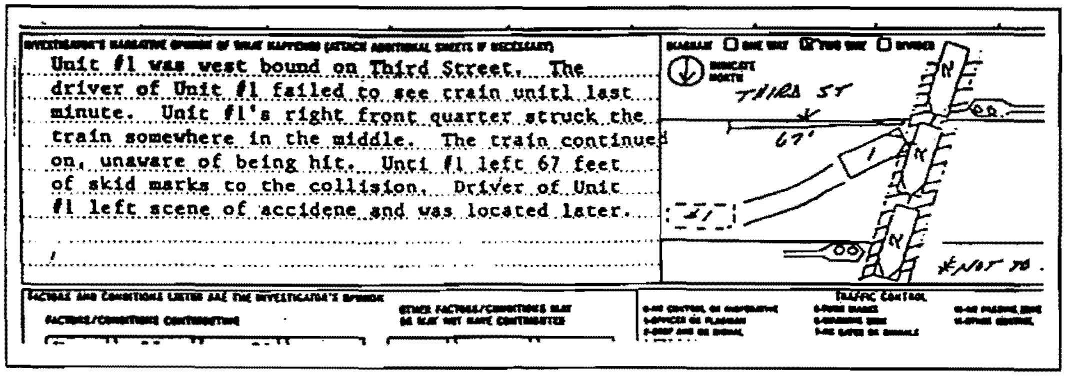
FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

FACTORS/CONDITIONS CONTRIBUTING

OTHER FACTORS/CONDITIONS MAY OR MAY NOT HAVE CONTRIBUTED

TRAFFIC CONTROL

Figure C-11. Tried to Back Off Tracks Contributing Factor Example



INVESTIGATOR'S NARRATIVE OPINION OF WHAT HAPPENED (ATTACH ADDITIONAL SHEETS IF NECESSARY)

Unit #1 was west bound on Third Street. The driver of Unit #1 failed to see train unitl last minute. Unit #1's right front quarter struck the train somewhere in the middle. The train continued on, unaware of being hit. Unci #1 left 67 feet of skid marks to the collision. Driver of Unit #1 left scene of accidene and was located later.

DIAGRAM ☐ ONE WAY ☒ TWO WAY ☐ DIVIDED

INDICATE NORTH

FACTORS AND CONDITIONS LISTED ARE THE INVESTIGATOR'S OPINION

FACTORS/CONDITIONS CONTRIBUTING

OTHER FACTORS/CONDITIONS MAY OR MAY NOT HAVE CONTRIBUTED

TRAFFIC CONTROL

Figure C-12. Hit Side of Train Contributing Factor Example

APPENDIX D

SUMMARY OF HYPOTHESES TEST RESULTS

Table D-1. Hypothesis Analysis Results

#	Research Hypothesis	Supported	Not Supported	Reason
1	Young driver age groups (16-24) are involved in a higher proportion crashes where driving around gates is the primary contributing factor		✓	$Z_{CALC} = 0.22$
2	A greater proportion of male drivers are involved in tried to beat train contributing factor crashes	✓		$Z_{CALC} = 1.87$
3	One-occupant vehicles are involved in a higher frequency of crashes where driving around gates is the primary contributing factor		✓	$Z_{CALC} = 0.26$
4	Elderly drivers (55 years and over) are more likely to be involved in crashes where stalled, stuck, or stopped too close is the contributing factor		✓	14.8% < 17.7%
5	A higher percentage of inexperienced drivers (16 to 24 years old) are involved in crashes at passive crossings		✓	20.0% < 21.3%
6	Drivers between 25 and 44 years of age have a greater frequency of involvement in crashes at active crossings		✓	38.6% < 39.8%
7	Elderly drivers are involved in a greater proportion of crashes where light conditions are dark (i.e., at night)		✓	$Z_{CALC} = 0.70$
8	Semi-tractor trailer trucks and trucks with trailers are more frequently involved in crashes where intersection proximity is the primary contributing factor	✓		$Z_{CALC} = 4.91$
9	Passively protected crossings are involved in a higher percentage of crashes where parallel roadway is the primary contributing factor		✓	$Z_{CALC} = 1.12$
10	The average severity of crashes occurring at passive crossings is greater than the average severity of crashes occurring at active crossings	✓		2.42 > 2.37, 2.26, & 2.16
11	The average severity of crashes occurring at night is greater than the average severity for crashes occurring during daylight conditions		✓	2.20 < 2.33