FINAL REPORT

Evaluation of Expected Accident Frequency Formulas for Rail-Highway Crossings

Project VC-HR1, FY 98

Report No. ITRC FR 98-2

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September 2000

Illinois Transportation Research Center
Illinois Department of Transportation

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Technical Report Documentation Page

1. Report No. ITRC FR 98-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Expected Accident Frequency Formulas for Rail-Highway Crossings		5. Report Date September 2000
		6. Performing Organization Code
7. Author(s) Yoassry M. Elzohairy and Rahim F. Benekohal		8. Performing Organization Report No.
		10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaing 205 N. Mathews Ave. Urbana, IL 61801		11. Contract or Grant No. VC-HR1, FY98
12. Sponsoring Agency Name and Address Illinois Transportation Research Center, Administrative Office Southern Illinois University at Edwardsville Engineering Building, Room 3026, Edwardsville, IL 62026		13. Type of Report and Period Covered Final Report July 1998 through July 2000
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Illinois Department of Transportation uses an Expected Accident Frequency (EAF) formula as one of the parameters in prioritizing the rail-highway grades crossings that need warning devices upgrade. This study evaluated the effectiveness of the formula and assessed the current 0.02 threshold. Field data were collected from three railroad corridors and 93 crossings in Illinois. Data showed that 21% of the current inventory data have outdated entries for warning devices. The Inventory File for 9,063 public grade crossings along with the 1998-1997 Accident File (2,776 crashes) were used to evaluate the effectiveness of the EAF formula. The results indicated that IDOT formula fell short of identifying the most hazardous crossings that need warning devices upgrade. About 77% of crossings that had an EAF of 0.02 or higher did not experience any crashes. Four potential models (Connecticut, Michigan, California, and USDOT models) were evaluated using Illinois data and none of them consistently outperformed IDOT EAF formula. A new Hazard Index (IHI) formula was developed. The variables used in IHI are ADT, number of trains per day, maximum timetable speed, number of tracks, number of highway lanes, 5-year crash history, and control devices factor. IHI formula identified locations with higher crash rate than IDOT formula did. The revised IHI should be used in combination with other criteria to identify those crossings in needs of safety improvement.

17. Key Words Railroad grade crossing, Rail-Highway Grade Crossings, Expected Accident Frequency, Hazard Index, Prioritizing Railroad Crossing Safety Improvement, Passive and Active Warning Devices, Highway Rail Intersection	18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Services (NTIS), Springfield, Virginia 22161.		
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 172	22. Price

From DOT 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

EVALUATION OF ACCIDENT PREDICTION AND HAZARD INDEX FORMULAS FOR RAILROAD HIGHWAY CROSSINGS

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A study report for
Evaluation of Expected Accident Frequency Formulas for Rail- Highway Crossings
ITRC Project VC-HR1, FY 98

Report prepared for

Illinois Department of Transportation
Through
Illinois Transportation Research Center

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ACKNOWLEDGMENTS

The authors would like to thank the members of Technical Review Panel for their invaluable suggestions, comments and cooperation throughout this study. In particular we appreciate the assistance and cooperation of Darrel Lewis of IDOT who was the project manager for this study and Dr. Steven Hanna Co-Administrator of Illinois Transportation Research Center. We would like to acknowledge the tremendous help from Judy Howe of Illinois Commerce Commission in providing accident and inventory data files. We also acknowledge and thank Rita Morocoima, former Graduate Research Assistant for conducting the literature review for this study. We would like to thank other graduate students Murat Aycin, Mounir Abdel-Aal and Montty Girianna for their help in conducting this study.

EXECUTIVE SUMMARY

Evaluation of Expected Accident Frequency Formulas for Rail-Highway Crossings
ITRC Project VC-HR1, FY 98

Illinois has 9,063 public crossings and is second only to Texas in the total number of highway-railroad grade crossings. The Illinois Department of Transportation (IDOT) currently uses an Expected Accident Frequency (EAF) formula as one of the parameter in prioritizing safety improvement upgrades to the warning device at rail-highway crossings. The EAF formula is over 30 years old and was developed to predict the number of crashes per year at a given crossing. This study evaluated the effectiveness of the EAF formula, examined the appropriateness of adoption of an alternative formula and/or warrants for use in Illinois, and assembled available information for stand alone pedestrian and/or bicycle trail and railroad grade crossings.

Out of the 49 state DOTs surveyed to determine the methodology currently used for prioritization of rail-highway crossing safety improvements, 32 responded to the survey. The results indicated that state DOTs use a variety of hazard indices or accident prediction formulas to compile their annual list of recommended railroad highway crossings for warning device improvements. The threshold used by other DOTs with the accident prediction formula ranged from one crash every ten years to 3 crashes within 5-year period. Other thresholds included: the highest hazard rating as funding allows, no firm minimum but ADT should be greater than 1,000 vehicles per day, project must be in the top 1/3 of the index list, New Hampshire Index > 4,000, and USDOT predicted accidents (PA) >0.075. In addition to the formula, DOTs used other criteria such as adjacent land development, political considerations, near-miss reports from railroad, heavily used truck/bus route, age and condition of equipment and prevalence of restricted sight distance.

Other DOTs used a variety of warning devices for stand alone rail-pedestrian crossings. The list includes: STOP LOOK AND LISTEN sign, STOP sign, Crossbucks, Bells and/or Flashing lights, Crossing arms, Magnetic Railway Pedestrian Gate (MRG) or Grade Separation. For rail-bicycle crossings, the warning devices list includes: WALK YOUR BIKE sign, Mini W10-1 Advance Warning Sign, Pavement Markings or Mazes to force dismounting of bicycle. The criteria that determine which warning device to be used included: visibility, alignments, number and speed of trains, MUTCD or AASHTO guidelines, pedestrian/bike traffic on the trail, crossing angle and crossing surface.

The research team selected two east-west and one north-south rail corridors in Illinois. A stratified random sampling approach was used and 93 crossing were selected for site visits and gathering detailed data. For the sample to be representative of the entire population of the rail crossings, locations were selected so that the frequency distribution of traffic and geometric factors in the sample are similar to the frequency distribution for the entire population of the railroad crossings in Illinois. Approximately 80% of the selected locations were chosen from crossings with crash history and the remaining 20% were chosen from crossings with no crash history. During the site visits traffic and geometric information obtained from DOT Inventory database were verified and updated. The research team also evaluated the sight distance for the four quadrants of each crossing visited. The sight distance data were coded as either "Obstructed" or "Not obstructed" based on whether the field available sight distance is less than AASHTO requirement. Comparison of the field observed warning devices and the devices recorded in DOT Inventory file revealed that twenty of the 93 crossings had their warning devices upgraded. Thus, roughly 21% of crossings in DOT Inventory File need to have their warning devices entries updated. It should be noted that a separate project to update Illinois inventory database is about to be completed this year.

Data from DOT Crossing Inventory File, the FRA Accident/Incident Reporting System and field observations were combined and used to explore the relationship between crash frequency and contributing factors. Five years of data were used in this evaluation. Step-wise regression analyses were conducted to examine the relationship between crash frequency and contributing factors. The number of crashes in five years (AC9397) was used as the dependent variable (response) and all available traffic, geometric, sight distance variables and a number of multiplicative terms were introduced as possible predictors. The variables in the best fit model to the data were: ADT, number of night trains, number of day trains, number of highway lanes, and number of main tracks. It was noticed that the sight distance did not appear as a predictor in any model. This by itself does not suggest that the sight distance is not an important safety factor. Rather, it indicates that the sight distance did not become one of the variables in the model predicting the number of future crashes at the selected railroad crossings.

The Inventory File for 9,063 public grade crossings in Illinois was merged with the 1988-1997 Accident File (2,776 crashes) using the crossing identification number. Data were reduced and the merged file was used to conduct a comprehensive statistical analysis of the variables that may contribute to crash occurrence at railroad crossings in Illinois. Crash statistics were presented in two broad categories: Population-based rates and Traffic-based rates.

The Traffic-based rate was used to evaluate the validity of IDOT EAF formula as well as other alternate formulas. The suitability of the potential hazard index formulas for Illinois conditions was determined based on availability of data needed, ease of use, accuracy of outcome, the amount of input data required, and applicability to all types of land use. Based on these criteria, four potential hazard index formulas were identified for further evaluation for Illinois conditions. These formulas are: Connecticut hazard index (CHI) formula, Michigan New Hampshire index (MNHI), California hazard index (CAHI) formula, and USDOT accident prediction model. The capabilities of these formulas in identifying the crossings with the greatest need for improvements were assessed using three different approaches. The approaches are: comparison of percentage of crossings with crash flagged out by formula and percentage of crash captured, regression analysis of observed versus predicted number of crashes over five years, and comparative analysis of the selected accident prediction/hazard formulas used in other jurisdictions.

The results showed that in the top 200 locations with the highest computed EAF values only 84 locations had crashes. In other words, 58% of the top 200 locations identified by the EAF formula did not have crash history. This is despite the fact that the database used has over 650 crossings with crash history. On the other hand, when all crossings were sorted by observed number of crashes so that the crossing with the highest recorded number of crashes came on the top of the list, the top 200 locations found to have 332 crashes during a five-year period (1993-1997). However, the top 200 locations suggested by IDOT EAF formula were found to have 131 crashes during the same time frame. Thus, the EAF formula was successful in capturing only 131/332 = 39% out of the number of crashes recorded for the top 200 hazardous locations in a five-year period.

In addition, the research team divided the database by warning devices. Thus, three separate files were created. The first file contains inventory and crash data for 2,700 crossings with crossbucks. The second file contains inventory and crash data for 1,976 crossings with flashing lights. The third file contains inventory and crash data for 1,747 crossings with gates.

Considering the top 100 locations with crossbucks identified by the EAF formula, only 17% of the locations were found to have crash history. On the other hand, this percentage was 25% and 54% for crossings with flashing lights and gates, respectively. The EAF formula was successful in capturing only 19%, 23% and 50% of the number of crashes recorded for the top 100 hazardous locations with crossbucks, flashing lights and gates, respectively.

To further examine the validity of IDOT EAF formula, the actual number of crashes over five-year (1993-1997) at each crossings were plotted against number of crashes computed by IDOT EAF formula. Had the number of actual crashes perfectly matched the number of computed crashes for all crossings, the relationship would be a regression line with slope equal to one, intercept equal to zero and coefficient of determination (R^2) equal to one. The formula that generates a regression line with slope close to 1, intercept close to zero and high R^2 value would be considered ideal in identifying a high priority location for safety improvement. However, the results revealed that IDOT EAF formula did not satisfy any of the aforementioned statistical tests. The formula seems to work relatively better in identifying gated locations with high crashes rate and falls short in identifying hazardous crossings marked with crossbucks.

Results also revealed that CHI formula identified gated locations with high crash rate relatively better than IDOT EAF formula did (R^2= 18.9% vs 10.6%). The results also showed that there is not much difference between the capability of the MNHI and IDOT EAF formulae in identify the crossings with the highest crash history. CAHI requires the number of crashes in the past 10 years as an input to the model to predict future number of crashes. The accident data for this study is for 10 years only; thus it is not possible to make direct comparison between CAHI and others that use 5-year data as input. When compared to USDOT model, IDOT EAF formula identified locations with comparable crash rate when considering the top 200 locations (1.56 crashes/crossing versus 1.54 crashes/crossing). However, USDOT formula captured a higher number of hazardous crossings than IDOT formula did (89 vs. 84). In addition, the regression lines between observed number of crashes and USDOT predicted number of crashes have a higher R^2 (13.7% vs. 6.7% for all crossings, 2.1% vs. 0.3% for crossbucks, 8% vs. 2.3% for flashing lights and 20.8% vs.10.6% for gates).

To evaluate the threshold of EAF of 0.02, the EAF value for each crossing was computed and compared to the threshold of 0.02. The results showed that close to 60% of the crossings with EAF of 0.02 or higher are gated locations. Only 13% of the locations suggested by IDOT EAF threshold were marked with crossbucks. Over 85% of the crossings suggested by IDOT EAF and marked with crossbucks did not have crash history. Overall, 77% of all crossings suggested by IDOT EAF threshold did not have any crash.

Thus IDOT EAF formula and four other selected formulas did not produce a strong correlation between crashes and related variables. The research team explored the relationship between crash frequency and other traffic and geometric variables using simple and multiple linear regression techniques in the Statistical Analysis System (SAS) software. The three basic algorithms for selecting variables to be used in the formula were: Backward Elimination (BE), Forward Selection (FS) and Stepwise (SW). Nonlinear regression technique was also used.

This study developed a new formula called Illinois Hazard Index (IHI). The following variables are used in IHI: average daily traffic, number of trains per day, maximum timetable speed, number of main and other tracks, number of lanes, average number of crashes per year in the past, and warning devices factor. The formula was developed using the nonlinear regression analysis procedure in SAS. Similar to Connecticut, Michigan New Hampshire and California formulas, the suggested formula computes a hazard index as a surrogate for the number of crashes.

The IHI was compared to IDOT EAF formula using the evaluation criteria set earlier. Results revealed that whether we considered the top 25, 50, 75, 100 or 200 locations identified the formula, the numbers of the hazardous locations identified by IHI are higher than the numbers identified by IDOT EAF. For example, among the top 25 locations suggested by IHI, 20 locations found to have crash history (41 crashes). On the other hand IDOT EAF identified only 16 locations with crash history (21 crashes).

Thus, IHI formula suggested locations with higher crash rate (41/20 = 2.05 crashes/crossing versus 21/16 =1.31 crashes/crossing when using IDOT EAF). The four suggested models showed more or less the same trend.

In addition, the relation between the actual number of crashes and IHI predicted number of crashes is stronger than the corresponding relation when using IDOT EAF. This is because IHI provides higher R^2, slope closer to 1 and intercept near zero. Not only the IHI regression lines show stronger correlation, but also they predict on average the right number of crashes (slope is almost one and intercept near zero). Thus, it is recommended that the new suggested IHI be used in combination with other criteria to identify crossings in needs of safety improvement.

Upon updating the DOT inventory file, it is recommended that the coefficients of the new IHI formula be re-examined. The updated inventory data may also be used to develop a detailed model for urban versus rural or local roads versus state routes. Based on a limited statistical analysis, although developing separate models for daytime versus nighttime or separate models for each warning device did not outperform the IHI model we developed in this study, more detailed studies are needed to fully answer these questions. Data from sites selected for improvement over the past few years should be compared to sites selected by IHI to compare its reliability in selecting crossings in need of improvement.

1. INTRODUCTION

Nationally, Illinois is second only to Texas in the total number of highway-railroad grade crossings. There are 9,063 public grade crossings in Illinois. The main traffic control devices at 3,646 crossings are crossbucks, 2,596 are flashing lights, 2,272 are gates, and 131 are bells, highway signal, stop sign or wigwag. The remaining 418 crossings have no warning devices. About 936 crossings are on state roads and 8,127 are on local roads. In addition there are 2,779 grade separated (bridge) crossings and over 5,000 private crossing.

At public highway-rail grade crossings there are two basic types of warnings: passive and active warning devices. Passive warning devices indicate the presence of an at-grade crossing and the motorist bears the responsibility for determining whether a train is approaching. If a train is detected, the motorist must then decide whether to proceed safely or to stop. On the other hand, active warning devices indicate the presence of an approaching train. Passive warning devices include crossbucks, advance warning signs (round yellow signs indicating" R x R"); and pavement markings. The active warning devices include flashing signals, automatic gates, and other similar devices activated by a train passing over a detection circuit or, in some instances, by manually operated devices.

According to an FHWA report (18), installations of some form of active warning devices at railroad crossings have been shown to reduce the numbers of crashes noticeably. However, because of limited dollar resources, it is not economically feasible to provide this form of warning devices at all grade crossings throughout the state. In addition, the low frequency of the crashes often does not justify the installation of active warning devices. Thus, limited resources have to be allocated in such a way that the expected benefits are maximized.

The Illinois Department of Transportation currently uses an Expected Accident Frequency (EAF) formula as one parameter in prioritizing the need for a higher level of warning device at rail-highway crossings. The EAF formula, originally published in NCHRP Report 50 (1968), was developed using data collected from a number of state highway and regulatory agencies and universities to develop a prediction model for number of crashes per year at a given location. The study concluded that the available data indicated that the most important predictors of crashes at rail-highway crossings are vehicle and train volumes, type of rail-crossing protection, and characteristics of the rural and urban areas in which the crossing is located. The resulting equation combines these conditions into a simple relationship between vehicular traffic, warning device type, and train volume.

The EAF calculated using this relation is currently used with other IDOT procedures for railroad-highway crossing improvements to determine the required level of crossing warning device. Typically, IDOT considers 2 crashes per 100 years (EAF of 0.02) indicative of the need for a possible upgrade in warning device. The Illinois Commerce Commission uses an alternate criterion of train-vehicle product of 3000, which corresponds to an EAF of approximately 0.015.

The Illinois Department of Transportation has identified a need to study the current Illinois EAF formula to evaluate the effectiveness of the formula in determining crossing needs. A need to develop information regarding warning devices for stand alone rail-bicycle or pedestrian trail crossings, a new situation which is growing in importance in Illinois, has also been identified.

This study evaluated the effectiveness of the EAF formula, reviewed hazard index formulas used by other DOTs, made recommendations regarding the use of the EAF and adoption of an alternative formula for use in upgrading rail-highway crossing warning devices, developed a new Illinois Hazard Index (IHI) formula, and complied available information on stand-alone rail-bicycle or pedestrian trail crossings. This report presents the findings and conclusions of the study conducted. This report contains the following chapters:

Chapter 1: Introduction, problem statement and research objective
Chapter 2: Survey of state DOTs on methodology and policies
Chapter 3: Guidelines and design standards for rail-bicycle trail crossings
Chapter 4: Field data collection for evaluation of expected accident frequency formulas
Chapter 5: Crash characteristics at railroad-highway grade crossing in Illinois
Chapter 6: Evaluation and analysis of IDOT EAF formula and alternate formulas
Chapter 7: Suggested formulas for establishing a priority list for railroad grade crossings
Chapter 8: Assessment of IDOT EAF threshold of 0.02
Chapter 9: Presentation of the findings and conclusions of this study

Appendix A: A literature review on the methodologies for prioritizing rail-highway crossing
Appendix B: Crash prediction/hazard index formula existed in literature.
Appendix C: Variables used in crash prediction and hazard index formula
Appendix D: Survey of State DOTs on methodology for prioritizing rail-highway grade crossing

Bibliography.

2. SURVEY OF STATE DOTS ON METHODOLOGY AND POLICIES

A survey of other 49 state DOTs was conducted to determine the methodology currently used for prioritization of rail-highway crossing safety improvements and their policies related to rail-bicycle trail crossings. The participants were asked to provide the latest information on the expected accident frequency formula used by their state, the hazard index and information regarding warning devices for rail-bicycle trail crossings. The survey instrument was designed in collaboration with the Technical Review Panel (TRP). Topics and questions included in the survey were determined in conjunction with the TRP. Based on the identified topics, the research team prepared a preliminary list of questions and forwarded it to TRP for review and comments.

After the subject areas are identified and the general form of the questions were agreed upon, the final questionnaire was prepared. The questionnaire was sent to the TRP for final approval. Revisions needed to accommodate the TRP 's comments and suggestions were made before the questionnaire was mailed to 49 other DOTs.

Participants were asked to complete and return the questionnaire in the self-addressed pre-stamped return envelope. A reminder letter was sent to those who did not respond on time. Out of the 49 state DOTs contacted, 32 returned the questionnaires or responded to the request. Responses were examined for completeness and consistency. Then they were coded in a computer file for further analysis.

The following section presents a review for the Accident Prediction models or Hazard Index formulae used by other states DOT to develop their annual list of recommended railroad highway crossings for warning device improvements.

Review for the Accident Prediction models or Hazard Index formulae used by other states to prioritize of Railroad-Highway Grade crossings

The following section reviews the methodology reported by other State DOTs.

1. New York

New York State reported that NYSDOT has no formal methodology to prioritize of Railroad-Highway Grade crossings

2. Oregon

Railroad-highway crossings in Oregon are prioritized using Jaqua Formula. The threshold used for the Jaqua is limited only by the amount of money available for crossing safety improvement projects. From the table provided by Oregon DOT, we summarized the procedure in the following formula

$$ACC5 = \frac{A \times B \times C}{1610}$$

$$A = \sum_{i=1}^{n} T_i \left(\left(\frac{C_i \times V}{3S_i} \right) + V \right)$$

Where

ACC5 = 5 yr. crash prediction

A = Exposure factor

n = No. of train types

T_i = No. of trains of type i

C_i = No. of cars in train of type i

S_i = Speed of type i train

V = AADT

B = Hazard rating from tables. It depends on number of tracks, number of blind quadrants, speed of vehicles and trains, number of lanes, angle of intersection, curvature of the roadway, approach grade, existence of entrances and exists to streets and street intersections near crossing.

C = Protection factor. It depends on the type of warning devices currently at the crossings and type of area (urban vs. rural).

This Train-Vehicle Accidents Prediction Formula can not be evaluated based on the data available in Illinois inventory file. This is because Jaqua Formula needs additional data that does not exist in Illinois current inventory file such as:

1. Daily average train movements by type and length of train.
2. Speed of each type of train
3. Number of blind quadrants
4. Angle of intersection of track and roadway
5. Approach grade
6. Speed of vehicles

<u>3. Arkansas Hazard rating formula</u>

Arkansas Highway and Transportation Department (AHTD) uses a hazard rating index. In addition, diagnostic team reviews are used as guidelines to determine which crossings will be considered for safety improvements. Thresholds are not used. AHTD looks at crossings with the highest hazard ratings and programs as many as funding allows. The Hazard Rating Formula is

Hazard Rating of Crossing = Highway Traffic Points × Railway Traffic points × Accident Record Points

Highway Traffic Points	= maximum 5 points and it depends on the ADT
Railway Traffic Points	= maximum 5 points. The number of trains represents up to 75% of these points. The remaining up to 25% depends on the number of side and main lines tracks at crossing
Accident record Points	= maximum 4 points based on the number of crashes in 15 years.

Our exploration of the relation between the number of crashes, ADT, and number of tracks as will be discussed in this report shows that the relationship are more complicated than assigning points.

<u>4. Wisconsin</u>

Wisconsin Department of Transportation uses the FHWA Rail-Highway Crossing Resource Allocation Procedure. The input data required for the procedure consists of the number of predicted crashes, safety effectiveness of flashing lights and automatic gates, improvement costs, and amount of available funding. The number of annual predicted crashes is derived from the USDOT Accident Prediction Model. Effectiveness factors are the percent reduction in crashes occurring after the implementation of the improvement. These factors are given in Table 34 page 104 of the USDOT FHWA Railroad-Highway Grade Crossing Handbook. The cost of the improvement includes both installation and maintenance costs.

WisDOT gives serious consideration for improved warning devices for those crossings with an expected crash frequency more often than one in ten years.

5. North Carolina Investigative Index Model

NCDOT uses Investigative Index (I.I.) formula in the selection process for railroad-highway grade crossing signal projects. The I.I formula has three terms to represent exposure, crash history and sight distance as follows

$$I.I = \frac{PF \times ADT \times TV \times TSF \times TF}{160} + (70 \times A/Y)^2 + SDF$$

Where:

PF = Protection Factor, 1.0 for No Warning Devices or Crossbucks, 0.50 for Traffic Signal, 0.20 for Flashing lights and 0.10 for gates

ADT = Average daily Traffic. When school buses use crossing, add (No. of school bus passengers/1.2) to ADT. When passenger trains use crossing multiply ADT by 1.2. (Note: 1.2 = Average vehicle Occupancy).

TV = Train Volume

TSF = Train Speed Factor = Max allowable train speed/50 + 0.8

TF = Track Factor, determined from a given table based on the number of through tracks and number of total tracks

A/Y = Train-Vehicle Crashes per Year. This model uses a 10-year history of crashes.

SDF = Sight Distance Factor = 16×SUM(SDF_n)/4

SDF_n = Sight Distance Factor for Quadrant n
= 0 ,2, 4 for clear, average and poor sight respectively.

Threshold varies by amount of funding available each fiscal year.

To evaluate this model using Illinois Inventory and Crash data, more data are needed regarding the number of school bus passengers that use each crossing and the sight distances in the four quadrants of each crossing.

6. Commonwealth of Virginia

VDOT has now replaced the Expected Accident Rate (EAR) methodology that was developed in the National Cooperative Highway Research Program Report #50 with the USDOT Accident Prediction Model.

Crossings are ranked using the USDOT accident prediction. The list of candidate locations is then readjusted by considering the following additional factors as determined through an engineering review: vehicle type, sight distance, roadway geometrics and adjacent land use development. A final priority ranking, referred to as a Priority Index, is determined through an analysis of the previously defined office and site reviews. Once this index is determined per location, they are placed in order of the highest to the lowest. Crossings from the list will be considered for safety improvement until all Federal funds are exhausted for each year's allocation.

7. South Dakota Hazard Index

SDDOT is in the process of reviewing the procedures for prioritizing rail-highway grade crossings safety improvement and expects minor changes. The office of Planning and Programs in SDDOT assembles a list of rail-highway grade crossing projects to determine need and priority. Crossings are rated by the following hazard index formula

$$Hazard\ \ Index = \frac{TV \times ADT \times PF \times OF}{5}$$

Where:

TV	= Number of Trains/day
ADT	= Average Daily Traffic
PF	= Crossing Protection Factor
OF	= Obstruction Factor

SDDOT was contacted via e-mail and Fax to provide their current PF and OF factors. As this report was ready for reproduction, no response was received.

8. New Jersey

NJDOT does not use Crash frequency formulas in developing warning device improvements. However, crash history is considered when determining the appropriate devices. Each grade crossing is handled on a case by case basis. Warning device improvements are addressed when requested by the operator or municipality or if within the project limits of a state roadway project. Railroad-Highway Grade Crossing Handbook is used for guidance

9. Maryland

Priorities are set using the Accident Prediction Formulae from the FRA. Regarding the threshold associated with the formula, MDDOT has no firm minimums. However, MDDOT tries to avoid spending money on crossing with ADT less than 1000.

10. Iowa

Iowa DOT classifies crossings using the Accident Prediction Formulae from the FRA. The threshold used is 0.075.

11. Arizona

ADOT has an indexing system using the ADT, vehicle speed, No of train /day, train speed and a factor for current warning devices. Crossing must be in the top 1/3 of the index list to be considered for improvement. ADOT was repeatedly contacted by Fax to provide a copy of the formula used to compute the index and chart/table necessary to determine the factors for current warning devices. As this document was ready for reproduction, no response was received.

12. Michigan

MDOT uses the New Hampshire Index Formula. The index is computed as follows:

$$HI = V \times T \times PF$$

Where:
V = AADT, Annual average daily traffic
T = Average daily train traffic
PF = Protection Factor and can be determined from the following table

1.00	Reflectorized Crossbuck with or without a Yield Sign
0.80	Stop sign
0.75	Stop and Flag Procedures
0.30	Flashing-Light Signals
0.27	Flashing-Light Signals with cantilever Arms
0.24	Flashing-Light Signals with cantilever Arms and traffic Signal Interconnect
0.11	Flashing-Light Signals with Half-Roadway Gates
0.08	Flashing-Light Signals with Cantilever Arms and Half-roadway Gates
0.05	Flashing-Light Signals with Cantilever Arms, Half-Roadway Gates, and Traffic Signal Interconnection
The addition of warranted motion sensor or predictor circuitry further reduces the protection factor by 0.02	

A system of flashing-light signals may be warranted in lieu of existing crossbuck signs, stop or yield signs, wig-wag signals, bell or manual warning when the New Hampshire Index exposure factor exceeds 4000.

13. Louisiana

Louisiana Department of Transportation and Development (La DOTD) uses a modified New Hampshire rating as the basic tool to determine which crossings will be considered for safety improvements. LaDOTD has not set threshold to be used with the formula.

14. California

To develop an annual list of recommended rail-highway crossings for warning device improvements, the State of California shares the responsibility with two agencies: the California Public Utilities Commission (PUC) and the California Department of Transportation (Caltrans). The PUC is responsible for requesting and ranking project nominations while Caltrans administers the funds and service contracts to proceed with the improvements. All crossing improvement projects in the State of California are subject to the following Hazard Index Formula. The resulting HI is rounded to tenth

$$HI = \frac{V \times T \times PF}{1000} + AH$$

Where:

V = number of vehicles
T = Number of trains
PF = warning signal factor, 1.0 for warning devices No.1 (Stop sign or Crossbuck), 0.67 for warning devices No.3 (Wigwag), 0.33 for warning devices No.8 (Flashing Lights) and 0.13 for warning devices No.9 (Gates)
AH = crash history
=Total number of Crashes within the last ten years × 3

There are no thresholds, the priority list nominations are comparative in nature only.

15. New Mexico

New Mexico State Highway and Transportation Department uses a Modified New Hampshire Formula

$$HI = \frac{Train\ \ ADT \times Hwy\ \ ADT \times PF}{100} \times SD_f \times T_s \times AH_f$$

PF = Protection Factor:
= 0.11 Gates
= 0.20 Lights
= 0.34 Wig-Wags

= 0.58 Signs
= 1.00 X-Bucks
= 2.00 None

SD_f = Sight Distance Factor
= 1.0 no Restrictions
= 1.2 Restrictions at 1 quadrant
= 1.5 Restriction at more than one quadrant

Ts = Train Speed (mph)

AH_f = Crash History Factor = (A+B+C)
A = 0.10 for each Property Damage crash
B = 0.20 for each injury crash
C = 0.30 for each fatal crash

NMDOT doesn't set any thresholds to be used with this formula.

16. Washington State Priority Matrix

Washington State uses two basic processes to prioritize and select projects for funding under the Railroad Crossing improvements program

1. The Priority Matrix
2. The Field Review Matrix

1. The Priority Matrix:

Criteria	Deficiency Rating (Points)
Accidents	
Any accident occurrence within the past 5 years generates	10
Lack of accident history receives	0
Sight Distance	
Sight distance less than the required design distance generates	9
Adequate sight distance receives	0
ADT	
ADT > 5000 generates	8
1500 ADT 5000 generates	4
ADT < 1500 receives	0

Crossing Angle and Number of Tracks	
A. Crossing angle 00 to 60 (measured from parallel to the rail line)	
Single track generates	6
Multiple Tracks generates	8
B. Crossing angle 61 to 80 (measured from parallel to the rail line)	
Single track generates	5
Multiple ,Tracks generates	7

These scores added up provide a first order ranking of potential projects. After projects are initially ranked, the top ranking projects (with a margin to allow funding a maximum number of projects based on available funds) are field reviewed.

2. The Field Review Matrix

Criteria	Deficiency Rating (Points)
Routes	
Designated Bike/Ped Route generates	5
Hazardous Material Rail/Truck generates	10
Heavy Truck Traffic (15% or more) Route generates	5
Heavily Used Bus Route generates	10
Roadway Items	
Traffic Signal within 200' of RR Crossing generates	5
Hump Crossing and/or Poor Roadway Grade generates	5
Poor Vehicle Storage Area in Vicinity generates	5
Railroad Safety Items	
Railroad Engineer Recorded Misses	5
Train Speed 0-25 mph generates	5
Crossing Safety Items	
Closure of Existing Crossing Included in Proposal generates	10

The Priority points and the Field Review points are added together to determine the final ranking of projects.

17. State of Utah

UDOT picks the top 20 crossings from the FRA list that is provided to them by AMB Associates, Inc. AMB Associates uses the USDOT formula to calculate the number of predicted crashes. A team from UDOT goes out with the railroad and holds surveillance at these top 20 crossings to identify and prioritize the crossings for warning device improvements.

18. North Dakota

NDDOT prioritized main line crossings based on a Sufficiency Rating System which defined a perfect railway/highway grade crossing and gave it a par rating of 100 as follows:

1. Railroad conditions	Par	20
2. Highway Conditions	Par	14
3. Exposure Factor	Par	30
4. Visibility Factor	Par	36
	Par	100

Points were subtracted form this par rating points for various undesirable conditions. The lower the rating, the higher the priority for signalization. No cut-off points were established to determine when gates are needed or when crossbucks would be adequate.

19. Missouri Department of Transportation

MoDOT uses Exposure Index (EI) formula to rank the highway/rail crossings. The EI is a two part equation. The first is a relationship of the train-vehicular factors. The second is a relationship of the highway approach sight distances.

The traffic index (TI) is the major component for this exposure index. It is determined as Follows:

$$TI = T \times TS \times V \times VS \times 10^{-4}$$

where

T = number of daily train movements
TS = maximum allowable train speed
V = average daily traffic
VS = normal vehicular operating speed

To calculate the Sight Distance Obstructions (SDO), subtract the actual sight distance from the required sight distance. Percent of the obstruction (P) is then determined by dividing the sight distance obstruction by the required sight distance. The percent of obstruction is multiplied by the traffic index factor to obtain the sight distance factor.

The exposure index (EI) is determined by totaling the traffic index factor and the sight distance factor.

The threshold MoDOT uses with the formula is 3 crashes within a 5-year period.

20. Nevada Department of Transportation

NDOT uses the following hazard index formula. Crossings that are high on the list are prioritized, considering available funding and the cost/benefit ratio.

$$HI = TADT \times HADT \times PF \times AF$$

Where:

TADT = Train ADT
HADT = Highway ADT
PF = Warning Factor, 0.10 for gates, 0.60 for Flashing Lights and 1.0 for Passive.
AF = Crash Factor
= (No of Fatal Crashesρ1.0+ No of PI Crashesρ0.10+ No of PD Crashesρ0.05)+1
PI = Personal Injury
PD = Property Damage

A surface Rating Index (SRI) number is also calculated from the following formula

$$SRI = \frac{(SAR \times 0.10)^4}{ADT^{0.30} \times RC \times 100}$$

SAR = Surface Average Rating
RC = Road Coefficient
= 1.0 for US and State routes, 0.60 for other paved roads and 0.10 for dirt roads.

21. Florida Final Crash Prediction Equation

The following formula was developed for prioritizing highway railroad grade crossing safety improvements

$$P = \frac{2 \times e^t}{1 + e^t}$$

Where

$$t = -9.21 + 1.14 \times \log_{10}(A(T + 0.50)) + 0.014 \times V + 0.008 \times S - 0.63 \times L$$

t = A temporary value used to simplify the mathematical expression
A = Average Daily Traffic (ADT)
T = Average number of trains per day
V = Posted vehicle speed limit
S = Maximum train speed
L = 1 for active warning devices, 0 for passive devices or no warning devices
P = Predicted number of crashes per year

The predicted number of crashes per year (P) is adjusted for crash history. The following adjustment for crash history is only calculated when the crash history is greater than the crash prediction.

$$P' = P\sqrt{\frac{H}{PY}}$$

Where,

P\` = Crash prediction adjusted for crash history
H = Number of crashes for the six year history or since the last warning device upgrade
Y = Number of years of crash history

A safety Hazard Index that ranges from 0 to 90 was derived based on the crash prediction. A highway railroad grade crossing with a crash prediction of 0.05 or one crash each 20 years would have a safety hazard index of 70. A safety hazard index of 70 or greater will not be considered for an improvement. A safety hazard index of 60, or one crash every nine years, would be considered marginal. The safety Hazard Index is calculated as follows:

$$I = 90 \times \left(1 - \sqrt{\frac{P'}{MAXP}}\right) - 5 \times \log_{10}(B + 1) \times F$$

Where,

I = Safety Hazard Index
P` = Crash prediction adjusted for crash history
MAXP = Maximum value for crash prediction (currently 1.0)
B = Number of school buses
F = Warning device factor, 1.0 for active, 2.0 for passive

22. Connecticut

Priority is established by ranking the crossings by the Hazard Index calculated by the following formula (an adaptation of the New Hampshire Index):

$$HI = \frac{(T+1)\times(A+1)\times AADT \times PF}{100}$$

Where:
T = Train movements per day
A = No. of vehicle/train crashes in last 5 years
AADT = Annual Average Daily traffic
PF = Protection Factor from the following table

PF	Devices
1.25	Passive Warning Devices
1.00	Stop Sign Control
0.75	Stop and Protect Control
0.75	Manually Activated Traffic Signal
0.25	Railroad Flashing Lights
0.25	Traffic Signal Control with Preemption
0.01	Gates with Railroad Flashing Lights
0.001	Inactive Rail Line

The highest priority is assigned to the crossing with the highest calculated index.

23. Maine

Maine Department of Transportation uses USDOT model to predict number of crashes. A score is assigned based on predicted crashes per year. Another score on a scale from 1 to 10 is assigned for each crossing based on operational and site characteristics. A maximum of 20-point score is assigned for each crossing based on sight distance and traffic conditions. Finally, a maximum of 10-point score is assigned based on the surface condition.

24. South Carolina

South Carolina Department of Transportation uses USDOT Accident Prediction Formula. In addition, hazardous material hauling on roadway, school bus crossings, passenger rail service, sight distance and whether consolidation is a feasible alternative are the criteria SCDOT uses to identify needs for warning device improvements.

SCDOT starts at top priority of the listing and treats as many crossings as funding allows.

25. Alabama

ALDOT uses the USDOT accident prediction formula to prioritize its public at-grade crossings. ALDOT goes down the list to determine which crossings get improved. ALDOT receives sufficient funds to improve 30-35 per year.

26. Alaska

Alaska DOT computes the Accident Prediction Value (APV) using the procedures from the Rail-Highway Crossing Resource Allocation Procedure- User's Guide, Second Edition FHWA-IP-86-11. The allocation model arrives at an APV of 0.10 (one crash every ten years) as the cost-effective threshold value for considering going from passive devices to active protection. The calculated hazard index is compared to threshold values in the following table to determine the type of traffic control system that should be installed.

Alaska Policy on Railroad/Highway Crossings- Changes in Level of Protection

Existing Traffic Control Device	Hazard Index	Recommended action for improvement
Passive	0.08 - 0.12	*See note below
	0.12 - 0.15	Flashing lights
	0.15 - 0.23	Flashing lights or gates and flashing lights
	0.23 - 12.4	Gates and flashing lights
	12.4 - 18.5	Gates and flashing lights or grade separation
	> 18.5	Grade separation

Flashing lights	0.12 - 0.18	*See note below
	0.18 - 3.7	Gate and flashing lights
	3.7 - 5.6	Gates and flashing lights or grade separation
	> 5.6	Grade separation
Gates	1.32 - 1.98	*See note below
	> 1.98	Grade separation

* Note: When the calculated hazard index falls within this range the decision may be to do nothing, improve the existing traffic control system, install a different type of traffic control system, or make some other improvement at the crossing.

27. Mississippi

Mississippi DOT sent us a letter indicating that all the information requested in the survey is covered under section 409. Therefore MDOT did not provide the information to University of Illinois because the information becomes public.

28. Idaho

The USDOT Accident Prediction Equation is used in the State of Idaho. All crossings with a potential of one or more crashes in ten years are reviewed. Field reviews are held if there has not been a review in the past 3 years.

29. Kansas

Kansas uses the following Design Hazard Rating Formula

$$HR = \frac{A \times (B + C + D)}{4}$$

IF computed Hazard Rating (HR) is less than 0, it is set to 0.

$$A = \frac{HT \times (2 \times NFT + NST)}{400}$$

HT = Highway Traffic
NFT = Number of fast trains
NST = Number of slow trains. Switch trains are not included in NST.

$$B = 2 \times \sqrt[3]{\frac{8000}{\text{sum of maximum sight distance 4 ways}}}$$

$$C = \sqrt{\frac{90}{angle\ of\ intersection}}$$

D	No. of main tracks
1.00	1
1.50	2
1.80	3
2.00	4

30. Texas

The Texas Priority Index Formula:

$$PI = V \times SV_f \times T \times (S \times 0.10) \times P_f \times A^{1.15} \times 0.01$$

where:

V = average daily traffic

SV_f = average daily school bus traffic – a factor weighted according to the range of school
bus traffic reported as follows:

- 0 buses = 1.00
- 1 - 3 buses = 1.20
- 4 - 10 buses = 1.60
- 11 + buses = 2.0

T = number of trains in a 24-hour period

S = maximum speed of the trains

P_f = protection factor — a factor weighted according to the type of existing traffic control device as follows:

- gates = 0.10
- cantilever flashers = 0.15
- mast flashers = 0.70
- crossbuck, other = 1.00

A = number of auto-train involved crashes in the last five years to the 1.15 power (when $A = 0$ or $A = 1$, then $A = 1$)

All locations with more than one track where main line and switching movements occur over the same crossing and at different speeds, a priority index is calculated for both the main line traffic and switching traffic, then added together to equal the total priority index for the crossing.

31. Indiana

INDOT uses the Federal DOT formulas for accident predictions along with crash history for the past five years, and are presently using the 1998 FRA equation coefficients. INDOT has no particular threshold for predicted crash rates when prioritizing potential projects. Instead, it relies on benefit/cost ranking as a means for setting project priorities, subject to the amount of funds available for improvements. Further, INDOT has no restrictions on jurisdiction of roadway or railroad owner when picking projects and thus examines all potential projects on a statewide basis for the most cost effective projects for potential crash reduction. Where local agencies are willing to close a crossing (typically at little or no actual cost to INDOT) in exchange for upgrading another, INDOT does factor the crash reduction benefit of the closure when doing the benefit/cost ranking of the potential upgrades.

32. Ohio

The contact person from Ohio DOT called and reported that they have no program for bicycle crossings. Nothing else was reported.

Summary

The procedures other DOTs use to develop their annual list of recommended railroad highway crossings for warning device improvements included: no formal methodology, hazard index/accident prediction formula, top crossings listed by USDOT rating system, and top 20 crossings from FRA list.

The criteria other DOTs use to prioritize the crossing for warning devices improvements included higher hazard index/predicted accident, benefit/cost, site review of vehicle types (school bus, mass transit), engineering judgement and crossing geometry, public concern/complaint, service condition, and site distance.

Two sets of variables are used in hazard index or accident prediction formula:
1. Factors that do not exist in Illinois Inventory/Accident file:
   - Daily average train movements by type and length of train.
   - Speed of each type of train
   - Number of blind quadrants
   - Posted vehicle speed limit
   - Angle of intersection
   - Curvature of the roadway
   - Approach grade
   - Driveways and street intersections near crossing.
   - Average daily school bus traffic
   - Number of school bus passengers
   - Surface type
   - Heavy Truck Traffic
   - Factor for hazardous material hauling on roadway

2. Factors that exist in Illinois Inventory/Crash file:

   Average Daily Traffic
   Average Daily train movement (day through, day switch, night through, night switch)
   Number of tracks
   Number of lanes
   Type of warning devices currently at the crossing
   Type of area (Urban vs. rural)
   Crash history, e.g.; Number of crashes in the past *n* years

The following are examples of the threshold used by other DOTs with the hazard index or accident prediction formula:

   The highest hazard rating as funding allows
   One crash every ten years
   No firm minimum, but ADT should be greater than 1,000 vpd
   Project must be in the top 1/3 of the index list
   New Hampshire Index > 4,000
   USDOT predicted accidents (PA) >0.075
   3 crashes within 5 year period
   One crash every nine years

The other criteria DOTs use in addition to the formula were as follows:

   Adjacent land development
   Political considerations
   Near-miss reports from railroad
   Heavily used truck/bus route
   Age and condition of equipment
   Restricted sight distance

3. GUIDELINES AND DESIGN STANDARDS FOR RAIL-BICYCLE TRAIL CROSSINGS

General

Bicycling is an important mode of transportation, used separately or with other modes of transportation. The Intermodal Surface Transportation Efficiency Act (ISTEA) placed increased importance on the use of the bicycle and called on each state Department of Transportation to encourage its use. Transportation Equity Act for the 21st Century (TEA-21) continues and expands provisions to improve facilities and safety for bicycles and pedestrians. The eligibility of the National Highway System Designation Act (NHS) funds is broadened to include pedestrian walkways, and safety and educational activities are now eligible for Transportation Enhancements (TE) funds. Other changes ensure the consideration of bicyclists and pedestrians in the planning process and facility design.

This section of the report reviews the guidelines and design standards of rail-bicycle trail crossings developed by selected state and local agencies. The information gathered from the literature and other state DOTs on handling the stand-alone rail-pedestrian, rail-bicycle and other unique railroad crossings are complied and presented here. A list of warning devices used at these crossings is prepared. The key parameters used for determining the warning devices to be installed at such locations are identified. Ideas to improve hazardous railroad crossings for bicyclists are provided. The material included in this study represent the state-of-the-art, as well as current practice, in safety improvement of stand-alone rail-pedestrian, rail-bicycle and other unique railroad crossings. Also covered are the national standards that have been used by state agencies.

Overall, there is a wealth of information available on bicycle facility development, but an absence of information related to rail-bicycle trail crossings. Bicycling facilities were addressed fairly heavily in the 1970's, while rail-bicycle trail crossings are just now beginning to receive consideration in transportation planning.

Within the following sections, rail-bicycle trail crossing guidelines, standards, and programs are described under the headings of national and state. The text is ordered from A to Z, with no preference given toward best practices. The descriptive text does, however, provide qualitative evaluations of each individual plan or program, and summarizes those aspects of each document that differ from other manuals currently in use across the nation.

A. National Studies, Guidelines, and Standards

A.1. AASHTO Guide for the Development of Bicycle Facilities

The *Guide for the Development of Bicycle Facilities* (19) published by the American Association of State Highway and Transportation Officials, is the key reference for bicycle facility designers. It has been adopted, in part or in its entirety, by state and local agencies. In conjunction with the *Manual on Uniform Traffic Control Devices* (MUTCD) (20), it is often the only reference publication used to plan and design safer and more convenient bicycle facilities.

The Guide for the Development of Bicycle Facilities was first published in 1981 (23), based on a 1974 (22) AASHTO publication entitled *Guide to Bicycle Routes.* In 1991, AASHTO's Task Force on Geometric Design updated the document. The 1999 Guide (21) have been recently published to replace the 1991 edition. The guide includes planning considerations, design and construction guidelines, and operation and maintenance recommendations in both metric and English units.

The 1999 edition has been expanded to cover accessibility issues on shared use paths. The design chapter presents an extensive discussion of separated, off-road bicycle paths. General design considerations and provisions for bicycle parking are also briefly covered. It is comprehensive and presents sound guidelines that will be valuable in achieving good design that is sensitive to the needs of both bicyclists and other users. Minimums are given only where further deviation from desirable values would result in unacceptable safety compromises.

The *Guide* includes photographs of properly designed bicycle facilities. The bike path section presents technical charts and graphs that provide engineering minimums for design factors such as curve radii, stopping distances, length of vertical curves and lateral clearances on horizontal curves.

A.2. Manual on Uniform Traffic Control Devices

The purpose of traffic control devices and warrants for their use is to help ensure highway safety by providing for the orderly and predictable movement of all traffic, motorized and non-motorized, throughout the national highway transportation system. For this reason the *Manual on Uniform Traffic* Control Devices (MUTCD) was developed.

This national manual for streets and highways sets forth the basic principles that govern the design and usage of traffic control devices, such as signs, pavement markings, signals and islands. Included within the MUTCD are specifications for traffic controls for bicycle facilities.

The standards presented in this manual are required by statute, in virtually all states, to conform to a state manual that shall be in conformance with the national MUTCD. In this way, the publication is used for planning and designing all bicycle and pedestrian facilities across the country.

As blanket publications intended to serve as reference material for the entire country, the AASHTO *Guide and MUTCD* fulfill their purpose. However, they lack specific details for solving unique urban situation design problems such as stand-alone rail-pedestrian/bicycle trail crossings.

B. State Agency Plans

The following section is based on the survey we sent to other DOTs asking about how they manage stand-alone rail-bicycle trail crossings. Out of 32 states DOTs that responded to the survey 23 provided response to this question. The following sections present the responses.

B.1. Alabama Department of Transportation

The State of Alabama has one stand-alone rail-pedestrian crossing. No criteria are set to determine the kind of warning devices to be used for stand-alone crossings.

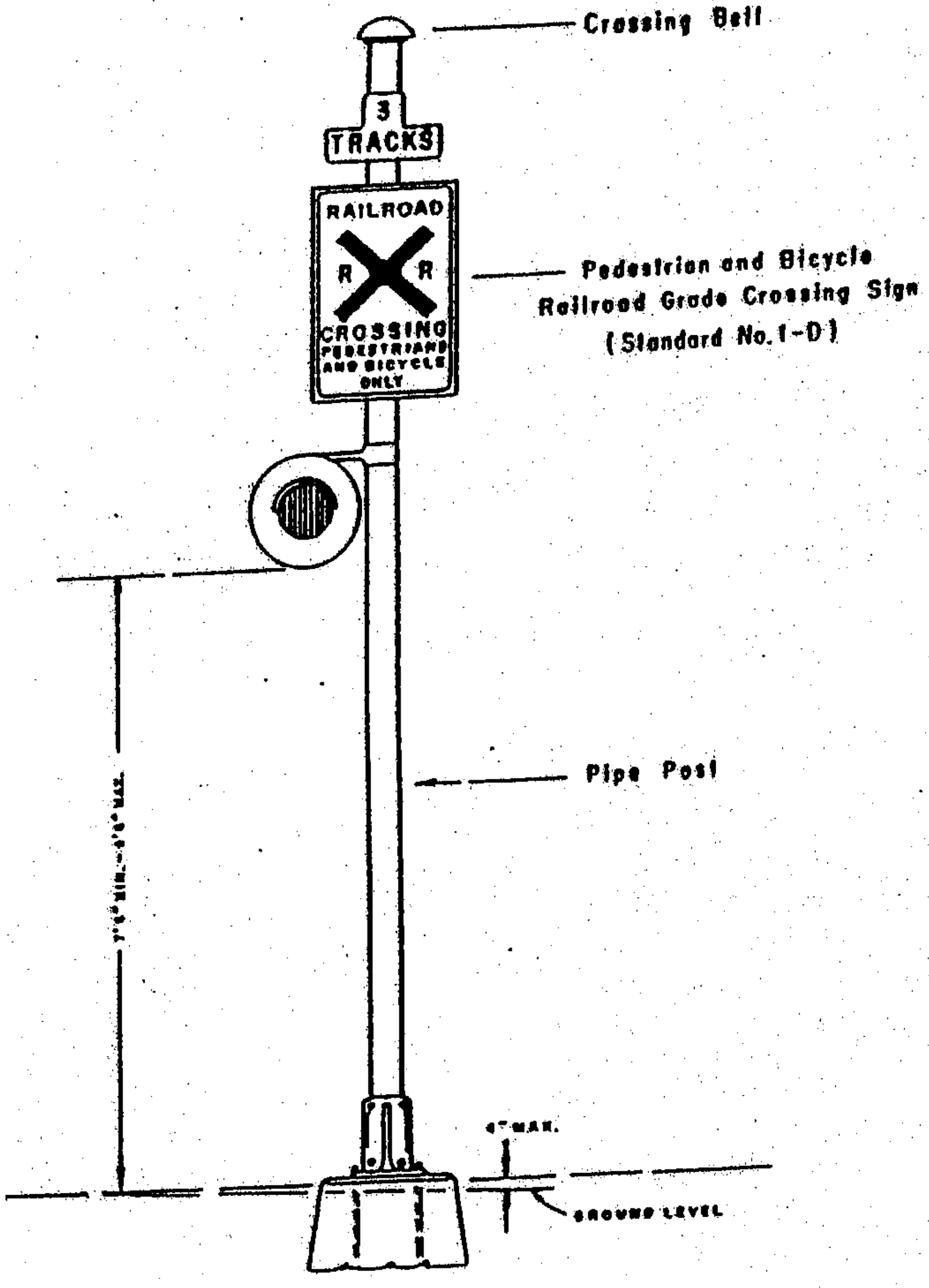
B.2. Arizona Department of Transportation

The State of Arizona has 3 stand-alone rail-pedestrian crossings. No special warning devices is used at these crossings because they are grade-separated.

B.3. California Department of Transportation

There are a total of 374 rail-pedestrian/bicycle crossings in the State of California. This total includes some private, and grade separated rail-pedestrian/bicycle crossings. There is no distinction between pedestrian or bicycle crossings designation in Caltrans current file system. The recommended warning device for such crossings is a standard No 10 as shown in Figure 3.1.

During field investigation, the Public Utilities Commission (PUC) engineer makes the determination regarding the kind of warning devices to be used for the stand-alone crossings. This depends on the individual crossing geometrics and safety needs assessment.



Source: General Order No. 75-C

Public Utilities Commission (PUC) of the State of California

Figure 3.1.Pedestrian and bicycle crossing protection flashing light type (Standard No. 10)

B.4. Connecticut Department of Transportation

There are two rail-pedestrian crossings in the State of Connecticut. These crossings are marked with Railroad Flashing Lights. Connecticut Department of Transportation uses the MUTCD and the FHWA Railroad Handbook as a guide to determine the kind of warning devices to be used for the stand-alone crossings.

B.5. Florida Department of Transportation

There are locations in Florida where pedestrian traffic is very high and pedestrian gates are warranted. Prior to recommending the installation of pedestrian gates at a railroad crossing an engineering study is performed. If the study demonstrates that pedestrians are obeying the normal signal, then the pedestrian gates are not warranted. FDOT checks the following criteria prior to recommending the installation of pedestrian gates at a railroad crossing:

Multiple track crossing where a pedestrian may attempt to cross from behind a stopped or parked train into the path of a second train.

a) When pedestrian traffic during an average day is greater than 100 in each of any four hours or 190 in any one hour or when the crossing is in close proximity to a school that has notable pedestrian traffic utilizing the crossing.

b) There are a minimum of two scheduled trains per day or at least one in each of the peak hours used in 'b' above.

B.6. Idaho Department of Transportation

There are 13 rail-pedestrian crossings in Idaho. These crossings are marked with passive signing. A field review team determines the kind of warning devices to be used for the stand-alone crossings.

B.7. Indiana Department of Transportation

There are 66 stand-alone pedestrian crossings in Indiana. INDOT does not use federal safety funds for projects at those pedestrian crossings. Nor does INDOT have any data to suggest how many are pedestrian-only or a combination of pedestrian, bicycles or other users. In the past 20 years there has been only one reported crash at a pedestrian crossing.

A few new multi-use recreational "trail crossings" have been constructed in the past few years. However, those have generally been constructed close enough to other public road crossings that the trail is more nearly like a sidewalk adjacent to a public roadway. In those instances there may be an advance warning sign and crossbuck on the trail itself, and in a couple instances INDOT has also installed barriers or jogs in the trail that require user (especially bikes) to come close to a full stop as they approach the crossing thus allowing more opportunity for them to observe and react to any approaching trains.

INDOT has not set criteria for stand-alone trail/pedestrian crossings. There have been only a few such instances in recent years and each has been evaluated on a case-by-case basis.

B.8. Iowa Department of Transportation

There are a number of rail-pedestrian crossings as well as rail-bicycle trail crossings in Iowa (respondent did not know how many). Those crossings are marked with either stop signs and/or crossing arms. Those crossings are handled on a project-by-project basis to determine the kind of warning devices to be installed. For this purpose, Iowa DOT considers items such as the traffic on the trail, the physical situation (sight distance), and number of trains.

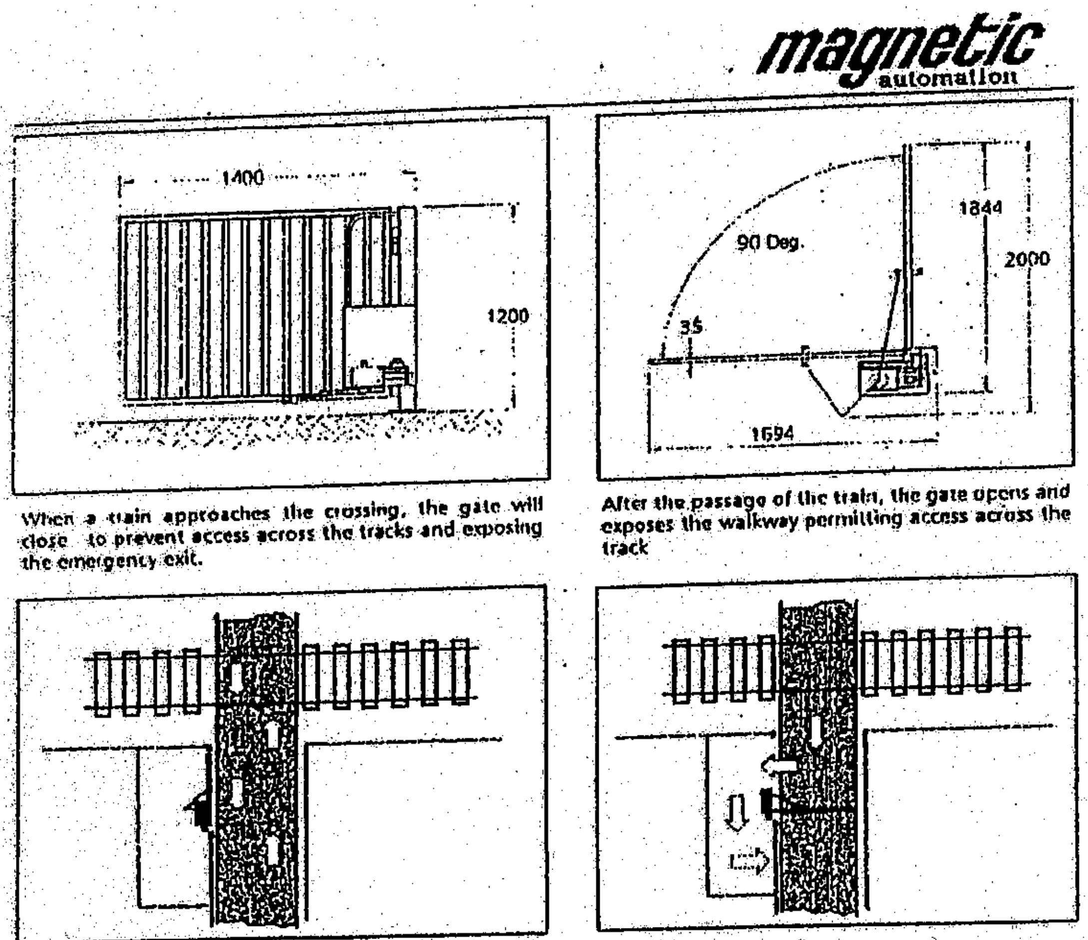
B.9. Kansas Department of Transportation

There are one at-grade and four grade separated rail-pedestrian crossings in Kansas. The Magnetic Railway Gates (MRG) as shown in Figure 3.2 are design for the control of pedestrian traffic through level and foot crossings, where safety and high usage are of importance. Railroad company and trail sponsor have to agree on the installation of the MRG at the stand-alone crossings.

When a train approaches the crossing, a Sonalert located in the drive mechanism sounds, followed by the closing of the gate to prevent access across the tracks and exposing the emergency exit. After the passage of the train, the Sonalert stops and the gate opens under power, once again exposing the walkway permitting access across the tracks and at the same time closing off the emergency exit. Under power failure conditions, the gate will automatically close under spring tension.

B.10. Louisiana Department of Transportation

There are a number of rail-pedestrian crossings as well as rail-bicycle trail crossings in Louisiana (respondent did not know how many). The kind of warning devices to be used for the stand-alone crossings is determined by LaDOTD with Railroad.



NOTE: Metric Dimensions (mm) (Approximate Cost = $5000/gate; Sonalert optional)

Provided by Kansas DOT (from Karen Anderson, Crossing Technologies, Inc literature)

Figure 3.2. Magnetic Railway Pedestrian Gate (MRG)

B.11. Maryland Department of Transportation

There are 3 rail-pedestrian crossings, one rail-bicycle trail crossings and 3 golf cart crossings in Maryland. Rail-pedestrian and golf cart crossings are marked with passive signing whereas rail-bicycle trail crossings are marked with flashing lights with gates. MDOT does not set standards to determine the kind of warning devices to be used for the stand-alone crossings.

B.12. Maine Department of Transportation

There are 2 rail-pedestrian crossings in Maine. Those crossings are marked with active warning devices. Maine DOT use the same criteria for highway crossings to determine the kind of warning devices to be installed in the stand alone crossings.

B.13. Michigan Department of Transportation

There are roughly 25 rail-pedestrian crossings, 15 rail-bicycle trail crossings and number of snowmobile crossings in Michigan. Rail-pedestrian crossings are marked with crossbucks, bells and/or flashing light signals, or mini advanced warning signs (W10-1). For rail-bicycle trail crossings, a 90^0 angle is desired and the crossings are marked with "Walk your Bike" signs, Mini W10-1 advance warning signs, pavement markings, or mazes to force dismounting of bicycles. For other stand-alone crossings, there is no particular standard. However, mini stop signs typically found in field.

MDOT examine the following criteria to determine the kind of warning devices used for the stand alone crossings

- Nature of use: predominately pedestrian vs. bicycle
- Proximity to roadway automatic warning devices
- Crossing angle/crossing surface (potential for slippery crossing surface).

Non-motorized trails standards are still emerging. Use of mazes in Michigan is declining due to lack of effectiveness and maintenance costs.

B.14. Nevada Department of Transportation

There is one grade separated rail-pedestrian crossing in Nevada. When determining the warning devices for the stand-alone crossings, the MUTCD is used.

B.15. New Jersey Department of Transportation

There are a total of 23 rail-pedestrian and rail-bicycle trail crossings in New Jersey. Used warning devices varies by location. Eight of those locations are marked with gates, lights, bells. Four are marked with crossbucks only. One location is marked with W10-1 (Stop, Look & Listen). The ten remaining locations have no warning devices.

NJDOT uses the same criteria for vehicle crossings to determine the kind of warning devices to be installed in the stand alone crossings.

B.16. New Mexico Highway and Transportation Department

There is only one rail-bicycle trail crossings in New Mexico. This crossing is not under the jurisdiction of the New Mexico Highway and Transportation Department. That crossing is marked with crossbucks. The criteria used to determine the kind of warning devices to be installed for the stand-alone crossings are site specific.

B.17. North Carolina Department of Transportation

There are 62 rail-pedestrian crossings and a number of rail-bicycle trail crossings in North Carolina. No further information was reported in the survey.

B.18. Oregon Department of Transportation

Oregon has a few recreational trail grade crossings. Approximately, ten rail-pedestrian crossings and five to ten rail-bicycle trail crossings exist in Oregon. ODOT has used a Z configured rail-pedestrian crossing which forces a highway user to look both directions along the track. In some cases, ODOT has used a flashing light signal with the lights mounted vertically to differentiate the crossing from a vehicle type crossing. ODOT has used passive signing for rail-bicycle trail crossings and in a couple of instances, the automatic devices described for the rail-pedestrian crossings above.

ODOT basically looks at the situation and determines what type of warning devices is needed. Visibility of an approaching track is a key element in the determination of the warning devices. Lack of visibility along the tracks causes ODOT to lean more to active devices.

B.19. South Dakota Department of Transportation

SDDOT does not keep an inventory of stand-alone crossings. There are very few in the state (two rail-pedestrian crossings and a few golf cart crossings). Rail-pedestrian crossings are marked with special Look sign. When determining the warning devices for the stand-alone crossings, the MUTCD is used.

B.20. Texas Department of Transportation

The Federal Railroad Administration crossing inventory identifies 31 pedestrian at-grade crossings in Texas. The national inventory does not differentiate between pedestrian and bicycle crossings. The type of warning device and criteria used to the determine the type of warning device used for "stand-alone" pedestrian/bicycle rail crossings are determined by the responsible road and/or park authority with input from the operating railroad. TxDOT does not have specific criteria for this type of crossing and is relying on AASHTO guidelines.

TxDOT had very limited experience in providing warning devices at ped/bike rail crossings. In recent months, TxDOT has been working on some hike and bike trail projects in the Houston and San Antonio area under federal transportation enhancement projects. Warning devices at the hike and bike crossings are addressed on a case by case basis. Generally, active warning devices were provided only if the adjacent highway crossing was already equipped with active warning.

B.21. Utah Department of Transportation

There is only one rail-bicycle trail crossings in Utah. Rail-bicycle trail crossings are marked with passive signs only. The criteria used to determine the kind of warning devices to be installed for the stand-alone crossings are train speed and volume.

B.22. Virginia Department of Transportation

There are 40 rail-pedestrian crossings in Virginia. This rail-bicycle trail crossings are not part of the State inventory. The kind of warning devices installed at the stand-alone crossings and the criteria used to determine them are decided by the railroad companies.

B.23. Wisconsin Department of Transportation

There are a number of rail-pedestrian crossings, rail-bicycle trail crossings and snowmobile crossings in Wisconsin. Rail-pedestrian crossings are principally marked with crossbucks. Rail-bicycle trail crossings are principally marked with crossbucks but occasionally marked with STOP signs.

WisDOT examines the following criteria to determine the kind of warning devices to be used for the stand alone crossings:

Sight distance on crossing approaches
Alignments
Speeds of trains.

Summary of Guidelines and Standards

State and local agencies across the United States use differing guidelines and design standards for stand-alone rail-pedestrian/bicycle trail crossings. This section focuses on the similarities and differences, and gives references to sources of information on rail-bicycle trail crossings.

The following is a list of the warning devices state DOTs use for rail-pedestrian crossings:

1. STOP LOOK AND LISTEN sign
2. STOP sign
3. Crossbucks, bells and/or flashing lights
4. Crossing arms
5. Magnetic Railway Pedestrian Gate (MRG)
6. Grade separation.

The following is the list of warning devices State DOTs use for rail-bicycle crossings:

1. All of the above except no. 5
2. WALK YOUR BIKE sign
3. Mini W10-1 Advance Warning Sign
4. Pavement markings
5. Mazes to force dismounting of bicycle.

The criteria that determine which warning device should be used can be summarized as follows:

1. Visibility
2. Alignments
3. Number and Speed of Trains
4. MUTCD
5. Same as for vehicle crossings
6. Pedestrian/bike traffic on the trail

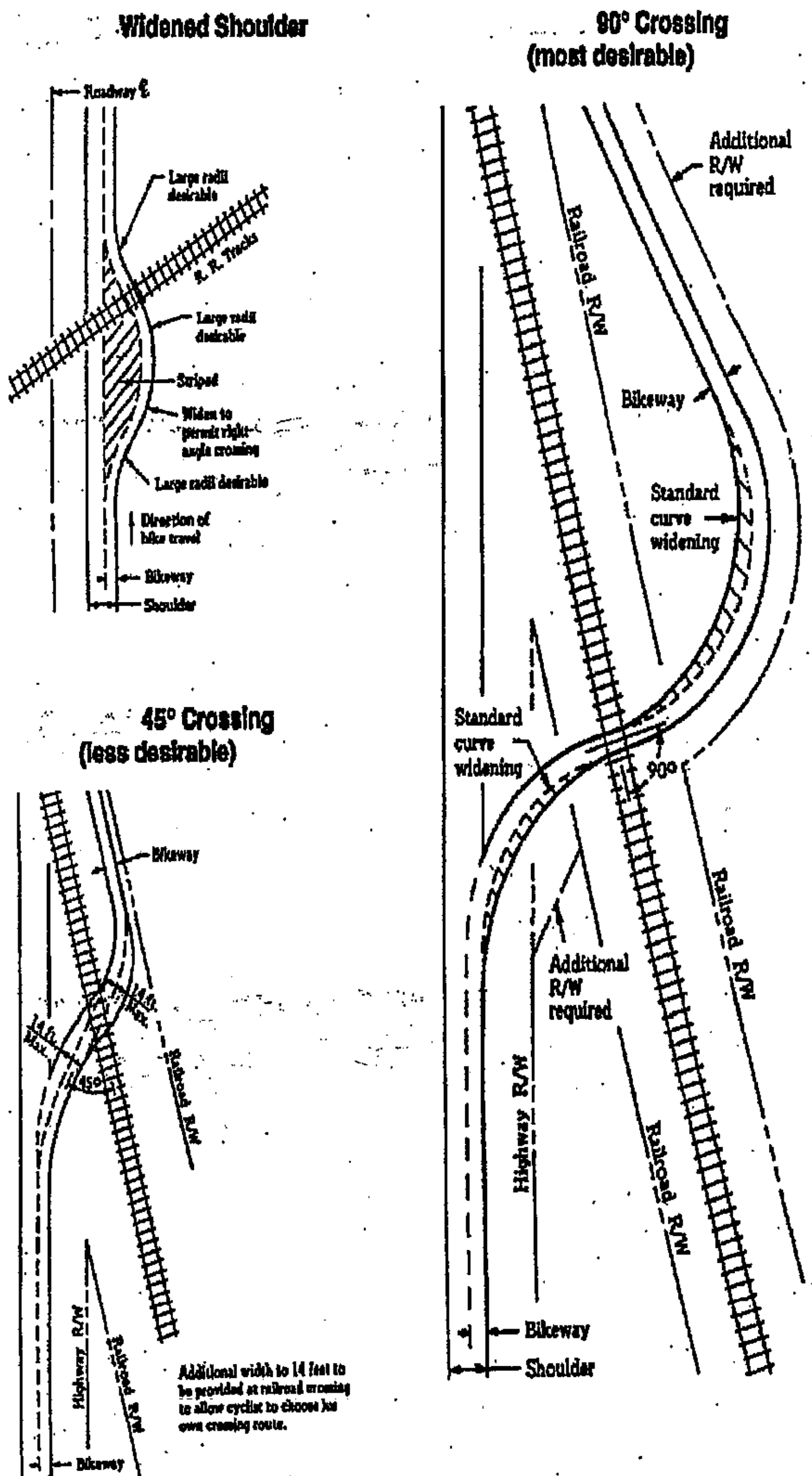
7. Crossing angle
8. Crossing surface
9. AASHTO guidelines.

Common Problems at Rail-Bicycle Trails Crossings and their Remedies

Where railroad tracks intersect roadways at angles two additional considerations should be considered. First, the paving of tapered approaches on either side of the crossing will allow bicyclists to cross the tracks closer to a right angle. Secondly, in higher bicycle use areas the use of a rubberized railroad-crossing mat improves the problem significantly. Rubberized crossings are used by some communities in the curb lanes of many track crossings, regardless of the tracks' angles.

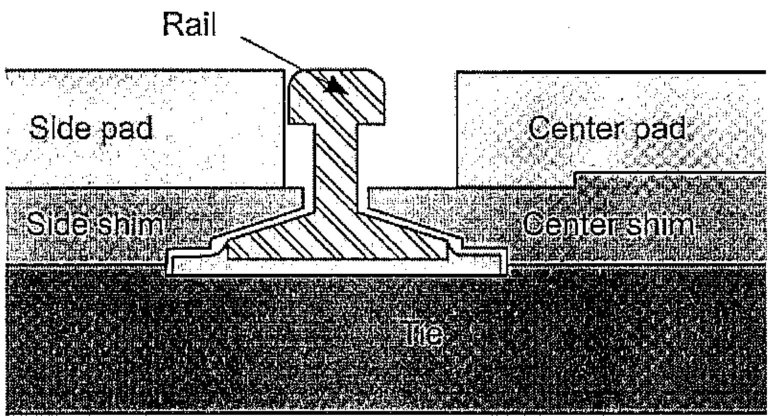
Angled railroad crossings can cause bicyclists to crash, particularly if the tracks and roadway don't meet smoothly. Right angle crossings are best, since they aren't likely to divert the bicycle's front wheel. But re-routing a railroad line to accommodate bicyclists generally is not a feasible solution. Instead, there are several workable approaches to improving the situation. Railroad-highway grade crossings should ideally be at a right angle to the rails. However, since this is not always possible, several local and state plans offer useful graphics that depict how to cross tracks at skewed intersections. Some of the most complete illustrations are presented here, come from Minnesota. These graphics depict three alternatives for bikeway/ railroad crossings. Figure 3.3 depicts a widened roadway shoulder and supplemental pavement striping. Figure 3.3 also illustrates having a bikeway cross tracks independently of the roadway--- at a 90° crossing with standard curve widening, and at a 45° angle with widened bike path pavement to allow bicyclists to cross as close to 90° as possible.

Second, if cost considerations allow, providing smooth rubberized railroad crossings (Figure 3.4) eliminates the problem entirely. While these are expensive to install, they have the advantage of significantly reducing long-term maintenance costs. If it is financially impossible to improve a hazardous crossing in the near future, the possibility of providing warning signs such as the one presented in Figure 3.5 should be considered. Some cities, such as Seattle, Washington, install sections of rubberized crossing in the outside lanes, where bicyclists are likely to ride. This can save costs for installations that solely benefit the bicyclists. On slow-speed rail lines, an even less expensive alternative can work well. Several cities have installed flangeway filler, which provides a smooth crossing at reduced cost. However, according to the 1998 FHWA report No. FHWA-RD-98-105 page 63, "*Installing a flangeway fill, works only on very low speed rail lines. Since a passing train's wheels must compress the dense fill material, the train must be moving slowly.*"



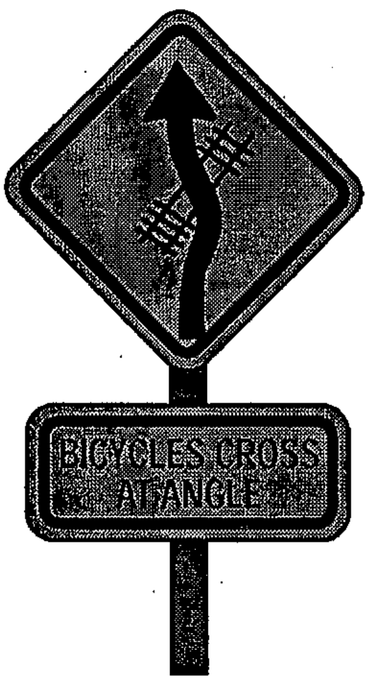
Source: MINNESOTA BIKEWAY DESIGN MANUAL

Figure 3.3. Bikeways cross tracks independently of the roadway at skewed intersections.



Source: Implementing Bicycle Improvement at the Local Level
USDOT, FHWA Report No. FHWA-RD-98-105

Figure 3.4. Rubberized railroad crossing, a more durable long-term solution than timber crossings.



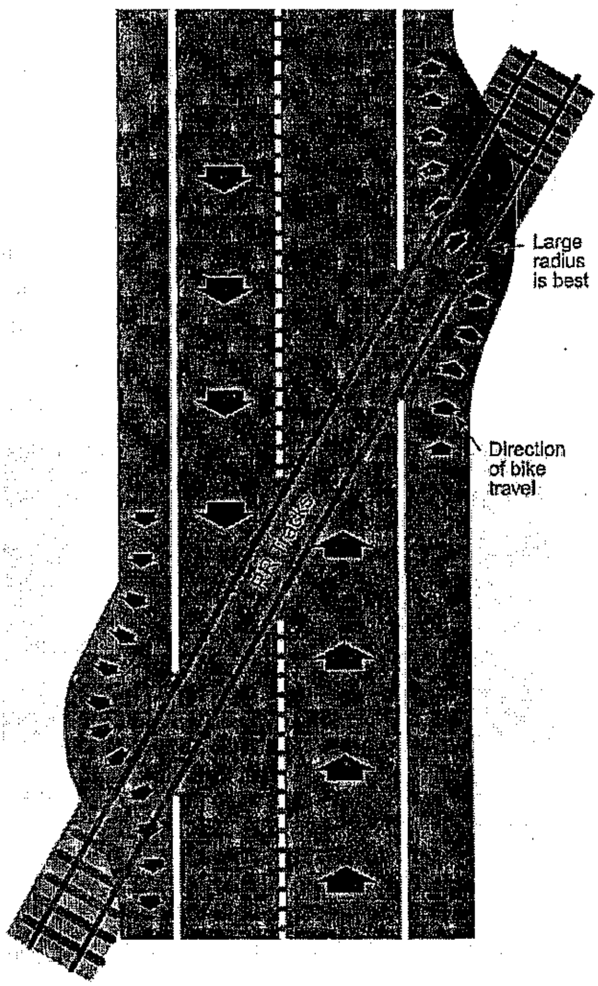
Source: Implementing Bicycle Improvement at the Local Level
USDOT, FHWA Report No. FHWA-RD-98-105

Figure 3.5. A possible warning sign for use at diagonal railroad crossings

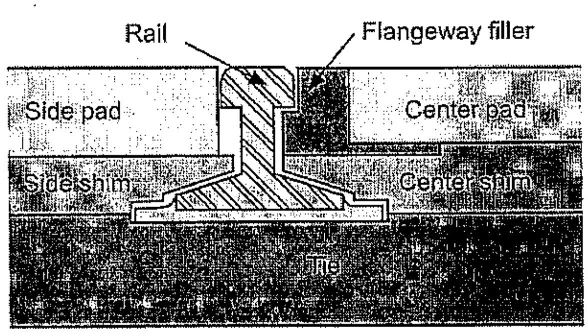
Information on commercial available flangeway fillers is one of many supplemental details included in North Carolina's new Planning and Design Guidelines. On low-speed, lightly traveled railroad tracks, flangeway filler can eliminate dangerous non-right angle crossings by filling the gap between the inside rail-bed and the rail, as illustrated in Figure 3.6. According to Chapter 8 of report No. FHWA-RD-98-105, it is important to note that flangeway fillers works only on very low speed rail lines.

Another measure that can significantly improve the "ride-ability" of rail-bicycle trails is the improvement of *rough railroad crossings.* Frequent maintenance, therefore, is essential to solving this problem. However, the best solution is to replace a defective crossing with either a non-slippery concrete crossing or one of the rubberized installations. The latter are not simply rubber pads placed over existing crossings. They typically involve replacement of the track-bed with a concrete slab and extensive construction work. While the resulting crossing may cost significantly more to install than the less expensive timber or asphalt crossings, they generally save money in long-term maintenance.

Drainage grates also can pose a serious problem for bicyclists. Many old designs can actually trap a bicyclist's wheel throwing the cyclist over the handlebars. The best approach is to replace these grates with "bicycle-safe" grates as shown in Figure 3.7. It should be noted that even "bicycle-safe" grates will still give a bicyclist a jolt if the wheel is caught the wrong-way by the grates. Placement of such grates as shown in Figure 3.8 is equally important. Grates should be installed level to the pavement and readjusted with future paving overlays.



Roadway flare allows wider angle crossing

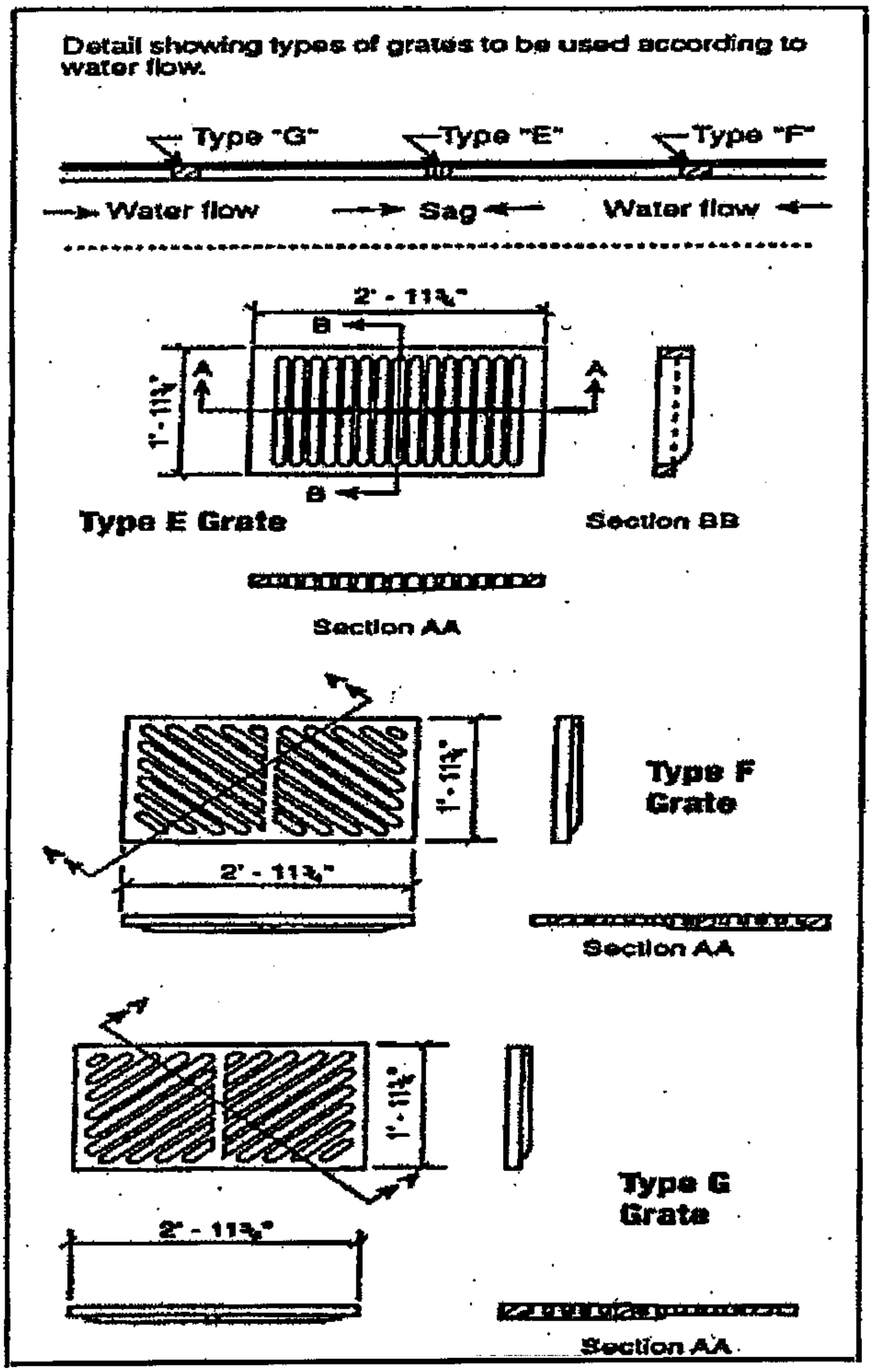


Flangeway filler strip applied to the inside flangeway to the rail

Source: Implementing Bicycle Improvement at the Local Level

USDOT, FHWA Report No. FHWA-RD-98-105

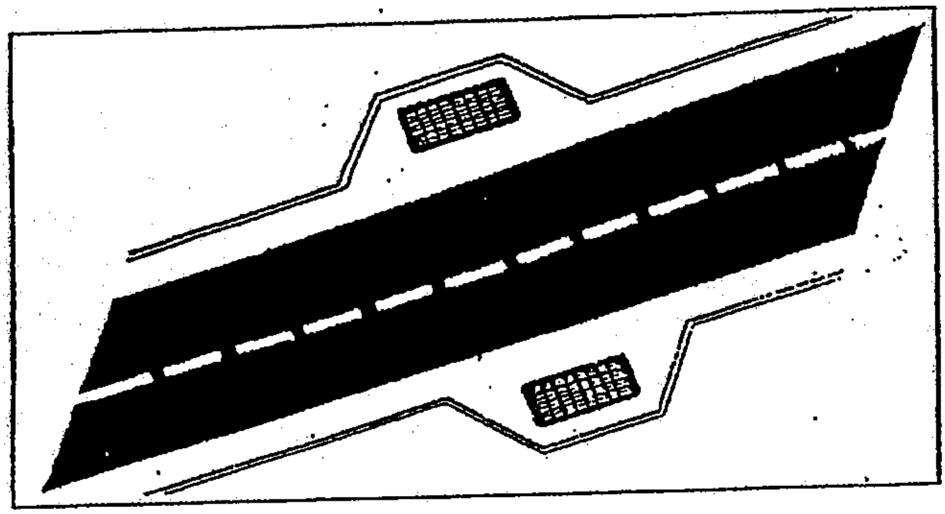
Figure 3.6. Flangeway filler can eliminate dangerous non-right angle crossings.



Source: Implementing bicycle improvements at the local level

USDOT, FHWA report no. FHWA-RD-98-105

Figure 3.7. Bicycle-safe drainage grates approved by NCDOT



Source: Implementing bicycle improvements at the local level

USDOT, FHWA report no. FHWA-RD-98_105

Figure 3.8. Bike compatible drainage grate placement

Strategies to improve hazardous railroad crossings for bicyclists

At-grade railroad crossings can pose a serious hazard for cyclists. A 1998 FHWA report (29) presents the factors that impact bicycle use, problem overviews, and implementation strategies to improve existing conditions for bicyclists. To eliminate hazardous railroad crossings for bicyclists, six subtasks were suggested as follows:

1. Identify all local at-grade railroad crossings
2. Determine which are hazardous
3. Prioritize those hazardous crossings identified
4. Determine which approaches will work with which crossings
5. Include a reasonable number of crossings as projects in the Transportation Improvement Plan (TIP)
6. Evaluate progress on a regular basis.

Depending on the problem identified and the solution chosen, the resources necessary for a particular crossing may vary from a few warning signs to a full concrete or rubberized crossing. The first option could probably be installed for less than $200, depending on departmental labor rates. The latter could easily cost $100,000, depending on the roadway width and other geometric and traffic considerations.

The following paragraphs present discussion of the six subtasks suggested to eliminate hazardous railroad crossings for bicyclists

1. Identify crossings

Using a current, accurate, and detailed local road map, highlight all instances where a roadway/trail crosses a railroad track or set of tracks. In addition, identify the responsible agencies or companies for all crossings shown on the map.

2. Determine hazards

Use the map described above to locate crossings that are either diagonal (45 degrees or less) or rough. If the map is sufficiently accurate, diagonal crossings may be measured and identified in the office. However, the roughness and flangeway opening of the crossing are best determined by riding across it on a bicycle.

3. Prioritize hazardous crossings

Set priorities on improving the hazardous railroad crossings identified in the previous step. There are four primary factors to consider when prioritizing hazardous railroad crossings:

1) public desires
2) the degree of hazard
3) the likely importance of the route, and
4) the potential for a solution.

Through public involvement procedures, identify those crossings that are of most concern to the bicycling public. This may be done through public meetings, surveys, or media efforts. However, these processes may fail to identify some critically important projects. This is particularly true if the public reached does not include groups like school children or casual riders.

Next, consider the actual degree of hazard, taking into account the angle of the crossing, its roughness, and flangeway opening, as well the combined effects of all three factors (if present).

In addition, consider whether the crossing is near a potential bicycle traffic generator (e.g., a school, neighborhood commercial area, or residential area). Further consider whether it is on either a popular bicycling route or is on the only route through a particular area.

Finally, consider the potential for a solution. Factors include how expensive the solution may be, the cooperativeness of the railroad, and whether the crossing is scheduled for improvement and whether there is sufficient public support, especially in the case of a potentially expensive project.

4. Determine approaches

With diagonal crossings, determine whether the track is a low-speed line, where a flangeway fill may work (29). If it is not, consider the potential for widening the paved roadway surface to give bicyclists room to cross at a wider angle. If neither of these is a possibility, consider warning signs and/ or pavement markings to warn bicyclists about the problem.

With rough crossings, determine the potential for a rubberized crossing installation across the entire roadway surface. If costs are too high and benefits for other road users are likely to be insignificant, look at the possibility of installing two rubberized crossing sections in the outside lane, bike lane, or paved shoulder of each side of the roadway. The key is to install the sections where bicyclists will be riding. If it is financially impossible to improve a hazardous crossing in the near future, the possibility of providing warning signs should be considered.

5. Select projects

On the basis of the priorities determined above and the type of work required, set a schedule for inclusion of the projects in the Transportation Improvement Program (TIP).

6. Evaluate results

On at least an annual basis, determine what progress has been made toward the goal of making crossings bicycle-safe. Consider the number of crossings improved, the extent to which the most critical have been dealt with, and whether new crossing problems have arisen.

In the short term, it is relatively easy to identify hazardous crossings and install bicycle-related warning signs or markings. Paving aprons for bicyclists to approach diagonal crossings at a wider angle will take longer, depending on factors like shoulder condition and available space. Replacing crossings with rubberized installations will take the longest time of all, depending on budgeting considerations, as well as the cooperation of the railroad involved.

Purpose of Traffic Signs

Traffic signs are devices placed along, beside, or above a highway, roadway, pathway, or other route to guide, warn, and regulate the flow of traffic, including motor vehicles, bicycles, pedestrians, and other travelers. Signs should only be placed only where warranted by facts and engineering studies for safety and proper regulation of traffic. However, the use of too many signs in a given location may reduce the effectiveness of all the signs at that location. In Illinois, more than 250 crashes occur annually at railroad crossings. Slightly over 1% of these crashes involve bicycles. Driver negligence or refusal to obey warning signs and signals may lead to such crashes. Effective January 1, 1996, violators who disobey railroad warning signs and signals face tougher penalties. In an effort to heighten awareness about the dangers of railroad crossings, legislation was passed in July 1995, which imposes a mandatory fine of $500 or 50 hours of community service. The new fines apply to pedestrians (Illinois Vehicle Code 5/11-1011) as well as motorists (IVC 5/11-1201).

Also added as paragraph (d) of Sec 5/11-1201, the law gives railroad crossbuck signs (without active warning signals) the same weight as a yield sign. This requires pedestrians and motorists to give trains the right of way. Any collision with a train is considered prima facia evidence of a driver's failure to yield the right of way.

4. FIELD DATA COLLECTION FOR EVALUATION OF EXPECTED ACCIDENT FREQUENCY FORMULAS

General

There are 9,063 public railroad crossings and 5,207 private crossings in Illinois. Most of the private crossings have passive devices. A small percentage of railroad crossing crashes happens at the private crossings. Data was collected only from public crossings that exist on main tracks. We did not include any private crossings in this study. Illinois has four main passenger rail routes and several freight routes. Two of the passenger routes run north-south: Chicago-Carbondale "Illini" and Chicago-St Louis "Statehouse". The other two are running east-west: Chicago- Fort Madison and Chicago- Burlington. It is more effective to examine rail-highway crossing safety along a corridor than at an isolated crossing. The research team in collaboration with the TRP selected three corridors for further study. The selected corridors are shown in Figure 4.1. Corridor 1 (Norfolk & Western) runs from west to east in central Illinois and includes the following counties: Pike, Scott, Morgan, Sangamon, Macon, Piatt, Champaign and Vermilion county. Corridor 2 (Union Pacific) runs from west to east in northern Illinois and includes the following counties: Whiteside, Ogle, Lee, Dekalb, Kane, Du Page and Cook county. Corridor 3 (Illinois Central) runs from south to north and includes: Union, Jackson, Perry, Marion, Effingham, Shelby, Cumberland, Coles, Champaign, Ford, Iroquois, Kankakee, Will and Cook county.

Selection criteria

The criteria for selecting the crossings included in this study were established by considering the following factors: type of warning devices used at crossing, traffic ADT, train volume, number of lanes, number of main tracks, number of other tracks, train speed, and location of crossing (urban vs. rural). For the sample to be representative of the entire population of the rail crossings, locations were selected so that the frequency distribution of those factors in the sample were similar to the frequency distribution for the entire population of the railroad crossings in Illinois. Approximately 80% of the selected locations were chosen from crossings with crash history and the remaining 20% were chosen from crossings with no crash history. It seems persuasive to select crossings based on the number of crashes. However, identifying high crash crossings based on the number of crashes fosters a bias toward urban areas and main roads where traffic volumes are high. To avoid this trap, roughly 1/3 of the crossings were selected from urban areas and the other 2/3 from suburban and rural areas.

The research team used the Crossing Inventory database maintained by Illinois Commerce Commission (ICC) to obtain inventory data for the railroad crossings to be surveyed. Not all of the crossings were potential candidates for field review because of

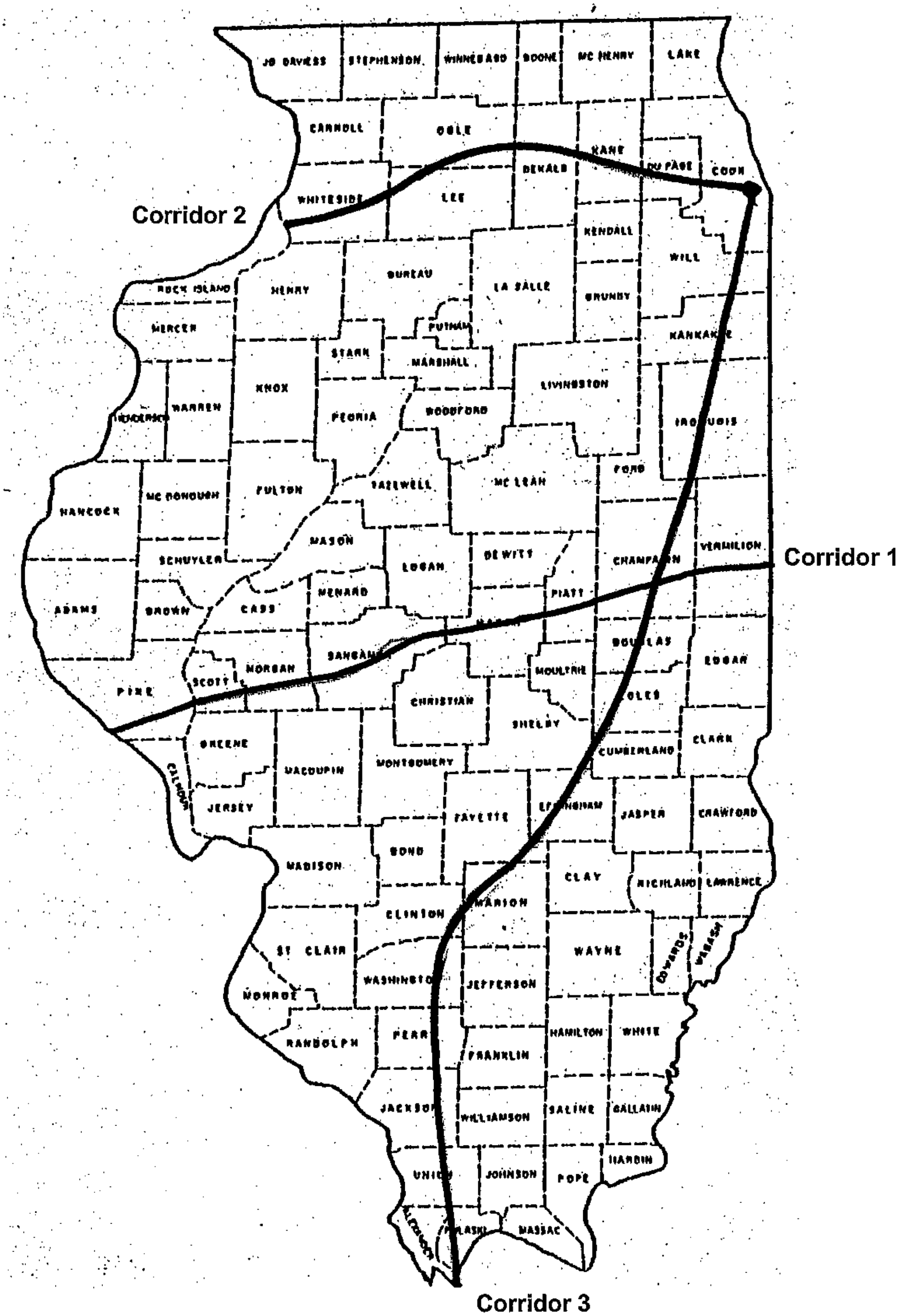


Figure 4.1. Schematic sketch for the three selected corridors

Table 4.1. Distribution of the 105 crossings visited by county and corridor.

Number of crossings visited	Crossing ID	County
Corridor 1		
2	479522Y, 479593V	Pike
4	479442F, 479443M, 479445B, 479447P	Scott
3	479380K, 479387H, 479403P	Morgan
11	479276R, 479283B, 479310V, 479311C, 479321H, 479322P, 479340M, 479354V, 479357R, 479368D, 479370E	Sangamon
4	479188F, 479191N, 479256E, 479258T	Macon
3	479162D, 479957T, 479960B	Piatt
8	479895X, 479898T, 479915G, 479916N, 479920D, 479927B, 479950V, 479951C	Champaign
6	479854T, 479862K, 479863S, 479886Y, 479876T, 479844M	Vermilion
41	**Total number of crossings visited on Corridor 1**	
Corridor 2		
3	175196F, 175209E, 175216P	Whiteside
1	175126R	Ogle
5	175159D, 175151Y, 175150S, 175149X, 175139S	Lee
4	175049T, 175043C, 175041N, 175024X	Dekalb
4	175003E, 175018U, 175021C, 175015Y	Kane
6	174973G, 174965P, 174953V, 174933J, 174924K, 174020S	Du Page
9	174284M, 174278J, 174273A, 174010L, 174009S, 174001M, 173998Y, 173996K, 173957U	Cook
32	**Total number of crossings visited on Corridor 2**	
Corridor 3		
3	299027M, 299033R, 299039G	Union
1	299009P	Jackson
3	295049Y, 295043H, 295028F	Perry
2	295002D, 295014X	Washington
3	294991K, 295310J, 295311R	Marion
2	289189M, 295261P	Effingham
2	289160P, 289163K	Cumberland
1	289167M	Shelby
2	289135G, 289144F	Coles
2	289051L, 289101M	Champaign
1	289032G	Ford
6	288965G, 288979P, 288986A, 288996F, 289015R, 288978H	Iroquois
2	288927X, 288944N	Kankakee
1	289680Y	Will
1	289650G	Cook
32	**Total number of crossings visited on Corridor 3**	

geographic location, lack of warning devices, or being in a private property. Data were collected from 105 highway-railroad grade crossings scattered over 27 counties and located on three corridors as shown in Table 4.1.

In the field investigation, the data collection team couldn't locate two of the selected crossings because of lacking specific location information in ICC Inventory file. Two other crossings were found upgraded to grade-separation and were excluded from the data collection process. Three of the crossings were found closed and three other crossings were located on minor tracks. Finally one of the selected crossings was found to be abandoned and another was found to have wrong ID. This brought the number of crossings to be eliminated from further analysis to twelve. Therefore the number of crossings left to be used in analysis was 93 crossings.

Distribution by warning devices

The distribution of the 93 crossings by corridor and field warning device type is shown in Table 4.2.

Table 4.2. Distribution of the 93 crossings between corridors and field warning devices

	No. of Crossings			
	Total	Crossbuck	Flash Lights	Gates
Corridor 1	36	13	8	15
Corridor 2	28	2	-	26
Corridor 3	29	10	-	19
Total	**93**	**25**	**8**	**60**
%	100	27	9	64

Nearly two-thirds of train crashes in Illinois occurs at crossings with active devices. Therefore, we selected nearly 2/3 of the sites to be visited with active warning device and 1/3 with passive device. Roughly 1/3 of the sample crossings were selected from each of the three pre-selected rail corridors with minor shift to meet the aforementioned criteria. This proportion covers a mix of rail crossing warning devices (passive and active).

Distribution by volume

The selected sites also represent a wide range of highway traffic volume and number of trains per day as shown in Table 4.3 and Table 4.4.

Table 4.3. Distribution of the 93 crossings by AADT

AADT	Frequency	*Cumulative %*
≤ 10	1	1.1
11- 100	24	26.9
101- 250	17	45.2
251- 1000	14	60.2
1001- 2501	14	75.3
2501- 5000	5	80.7
5001- 10000	8	89.3
10001- 15000	5	94.6
15001- 25000	4	98.9
25001- 50000	1	100.0
AADT > 50000	0	100.0

Table 4.4. Distribution of the 93 crossings by total train/day

total train/day	Frequency	*Cumulative %*
≤ 1	0	0.0
2- 5	0	0.0
6- 10	0	0.0
11- 20	16	17.2
21- 30	27	46.2
31- 50	25	73.1
51- 100	25	100.0
> 100	0	100.0

Distribution by crashes

Examining the FRA crash file revealed that the 93 crossings had 105 crashes over the 5-year period (1993-1997). Table 4.5 shows the distribution of the crashes by warning devices.

Table 4.5. Distribution of the crashes by the warning devices for the 93 selected locations

Warning Devices	No. of crossings	No. of crossings with crashes	No. of crossings without crashes	No. of crashes
Crossbuck	25	20	5	21
Flashing Lights	8	5	3	11
Gates	60	49	11	73
Total	**93**	**74**	**19**	105

Table 4.6 shows the distribution of the crashes by Corridor. The crossings with flashing lights on corridor 2 and 3 did not meet the selection criteria. Thus, crossings with flashing lights was selected from corridor 1.

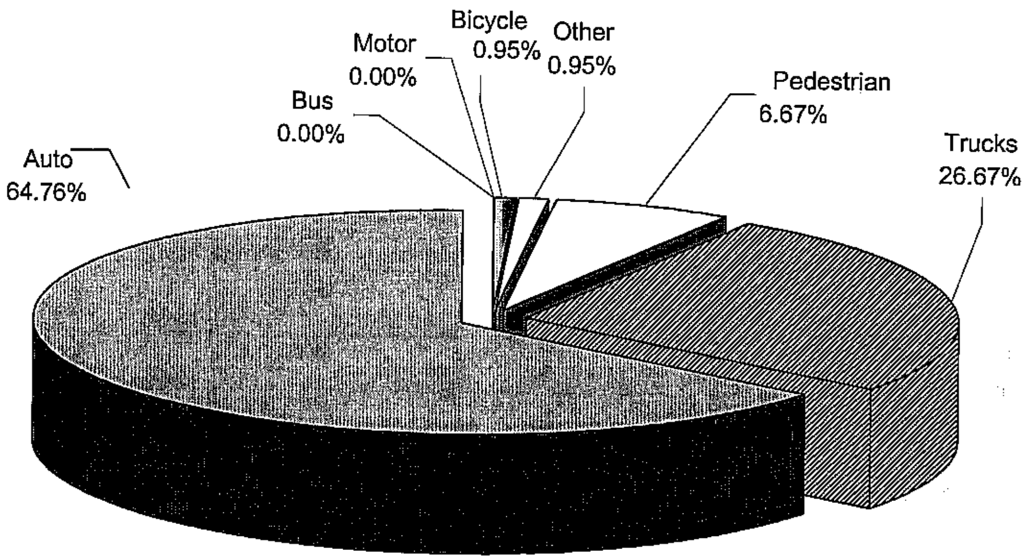
Table 4.6. Distribution of the crossings by Corridor

Warning Devices	Corridor 1		Corridor 2		Corridor 3	
	With crashes	Without crashes	With crashes	Without crashes	With crashes	Without crashes
Crossbucks	12	1	2	-	6	4
Flashing Lights	5	3	-	-	-	-
Gates	11	4	22	4	16	3
Total	**28**	**8**	**24**	**4**	**22**	**7**

Figure 4.1 represents the distribution of 5-year crashes by highway user for the 93 selected crossings. Crash data at the selected crossings shows that 64.8% of the crashes involved passenger cars whereas 26.7% involved trucks . These percentages are comparable to 62.3% and 27.7% when considering the proportion of crashes on all public crossings in Illinois as shown in Figure 5.4.

The previous discussion shows that the selected sample rationally represents the entire population of the railroad crossings in Illinois.

Distribution of 5-year accidents for the 93 selected crossings by Highway user
1/1/93 - 12/31/97



Distribution of number of crashes, fatalities and injuries by highway user for the 93 selected crossings
(1/1/93 ~ 12/31/97)

Highway User	No of Crashes	Percent	Fatalities	Percent	Injuries	Percent	PDO	Percent
Bus	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Motor	0	0.00%	0	0.00%	0	0.00%	0	0.00%
Bicyc	1	0.95%	0	0.00%	1	2.44%	0	0.00%
Other	1	0.95%	0	0.00%	0	0.00%	1	2.00%
Ped	7	6.67%	5	16.67%	2	4.88%	0	0.00%
Trucks	28	26.67%	5	16.67%	9	21.95%	16	32.00%
Auto	68	64.76%	20	66.67%	29	70.73%	33	66.00%
Total	105	100%	30	100%	41	100%	50	100%

Figure 4.2.Distribution of 5-year crashes by highway user for the 93 selected crossings.

Data collected

The Crossing Inventory file maintained by ICC is probably the most comprehensive database on Illinois rail-highway crossings; however, it does not contain the up-to-date information for all crossings. The inventory data contains several physical and operational characteristics of the crossings. More up-to-date information about key geometry and traffic variables were obtained and updated by the research team for the selected 93 crossings. Figure 4.3 shows the data items collected from each railroad crossing visited. Table 4.7 shows the discrepancies between the warning devices coded in the inventory file obtained from ICC, the warning devices coded in FRA files and the warning devices existing in field.

Table 4.7. Warning devices for the 93 visited crossings according to ICC, FRA and field databases.

Database	No. of Crossings			
	Crossbuck	Flashing Lights	Gates	Others
ICC	32	18	41	2
FRA	32	9	52	-
Field	25	8	60	-

The inventory requires active support of both railroads and state. As seen from Table 4.7, often changes take place without accompanying inventory updates. However, IDOT is currently making a diligent effort to update the inventory file. It is expected that this task will result in a more useful up-to-date database. The updated database will help understanding and formulating a strong relationship between crash history and other geometrics and traffic parameters for railroad crossing.

Comparison of the field observed warning devices and the devices recorded in ICC inventory file revealed that twenty of the 93 crossings have their warning devices upgraded as shown in Table 4.8. Those crossings cannot be used in further analysis because the time periods associated with the warning devices before and after upgrade are unknown. Therefore, only data from 73 crossings will be further examined to study the relationship between crashes and other geometric and traffic factors.

Table 4.8. Crossings with upgraded warning devices.

<table>
<tr><th>No of Crossings</th><th>Warning Devices in ICC database</th><th>Field Warning Devices</th></tr>
<tr><td>1</td><td>Stop Sign</td><td>Crossbucks</td></tr>
<tr><td>1</td><td>Bell</td><td rowspan="3">Gates</td></tr>
<tr><td>8</td><td>Crossbuck</td></tr>
<tr><td>10</td><td>Flash Lights</td></tr>
<tr><td>20</td><td colspan="2"></td></tr>
</table>

Collection of Sight Distance data

All 93 selected crossings were visited to obtain information about physical layout including sight distance. During the site visits traffic and geometric information obtained from ICC Inventory database were verified and updated.

Sight distance is one of the factors considered at railroad crossings with passive warning devices. According to AASHTO, there are two main scenarios that can occur at these crossings related to determining the sight distance. In the first scenario, the vehicle operator can observe the approaching train in a sight line that will safely allow the vehicle to either pass through the crossing or stop prior to encroachment in the crossing area prior to the train's arrival at the crossing. In the second scenario a vehicle has stopped at a railroad crossing and the next maneuver is to depart from the stopped position. It is necessary that the vehicle operator have a sight distance along the tracks that will permit sufficient time to accelerate the vehicle and clear the crossing prior to the arrival of a train even though the train might come into view as the vehicle is beginning its departure process.

Both of these scenarios are shown on Figure 4.4 and Figure 4.5. The equations shown next to each figure were used to create Table 4.9. The research team used Table 4.9 and Figure 4.6 to evaluate the sight distance for the four quadrants of each crossing visited. The sight distance data were coded as either "Obstructed" or "Not obstructed" based on whether the field available sight distance is less than the values in Table 4.9.

LOCATION AND CLASSIFICATION OF THE CROSSING			
Name of Observer		City or Nearest City	
Date and time		In/Near City	
Weather Conditions		Highway Type	
Crossing Number		Street or Road Name	
Corridor Number		Pedestrian Crossing	☐ At grade ☐ Separated
County			

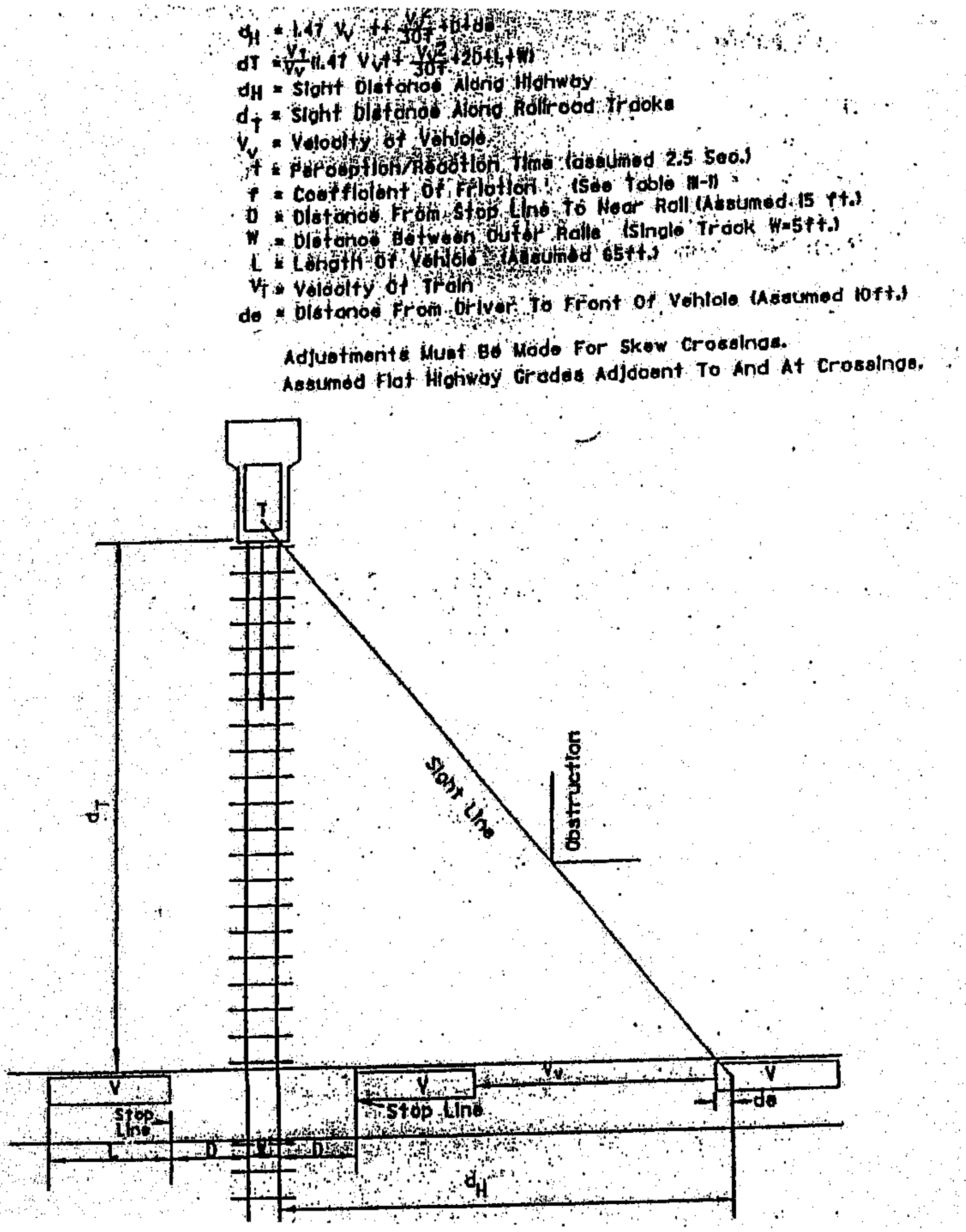
PHYSICAL LAYOUT OF THE CROSSING			
Number of tracks		Type of tracks	☐ Main ☐ Other
Type of Warning Devices	☐ Crossbucks ☐ Stop Sign ☐ Flashing lights ☐ Gates ☐ Other	Crossing Surface	☐ Paved ☐ Not paved
Type of highway pavement	☐ Asphalt ☐ Concrete ☐ Other (Specify)	Type of development	☐ Open Space ☐ Residential ☐ Commercial ☐ Other

______BOUND ROADWAY APPROACH			
Grade (%)	☐ 0% ☐ <3 % ☐ 3~6 % ☐ >6 %	Distance from stop line to nearest RR track	
# of traffic lanes in both directions		Pavement markings	☐ Stoplines ☐ RR Xing Symbols ☐ Other ☐ None
Shoulder width			

______BOUND ROADWAY APPROACH			
Grade (%)	☐ 0% ☐ <3 % ☐ 3~6 % ☐ >6 %	Distance from stop line to nearest RR track	
# of traffic lanes in both directions		Pavement markings	☐ Stoplines ☐ RR Xing Symbols ☐ Other ☐ None
Shoulder width			

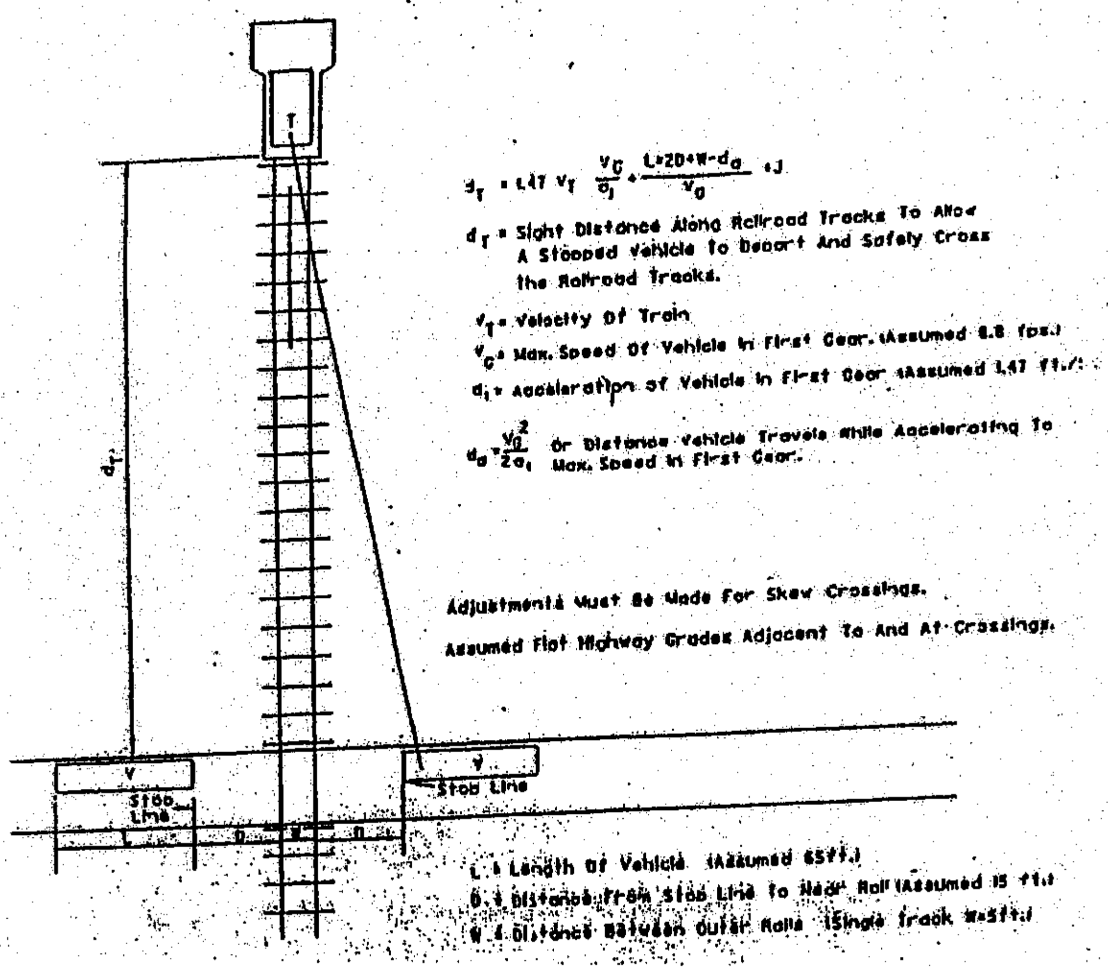
TRAFFIC DATA			
Highway speed (mph)		If speed is not posted, which speed do you use for Sight distance evaluation?	

Figure 4.3. Data Collection Worksheet



Source: American Association of State Highway and Transportation Officials. A policy on geometric design of highways and streets, 1990.

Figure 4.4. First Scenario: moving vehicle to safely cross or stop at railroad crossing.



Source: American Association of State Highway and Transportation Officials. A policy on geometric design of highways and streets, 1990.

Figure 4.5. Departure of vehicle from stopped position to cross single railroad track.

Crossing Number	
Show the North Arrow	
Write down the intersection angle	

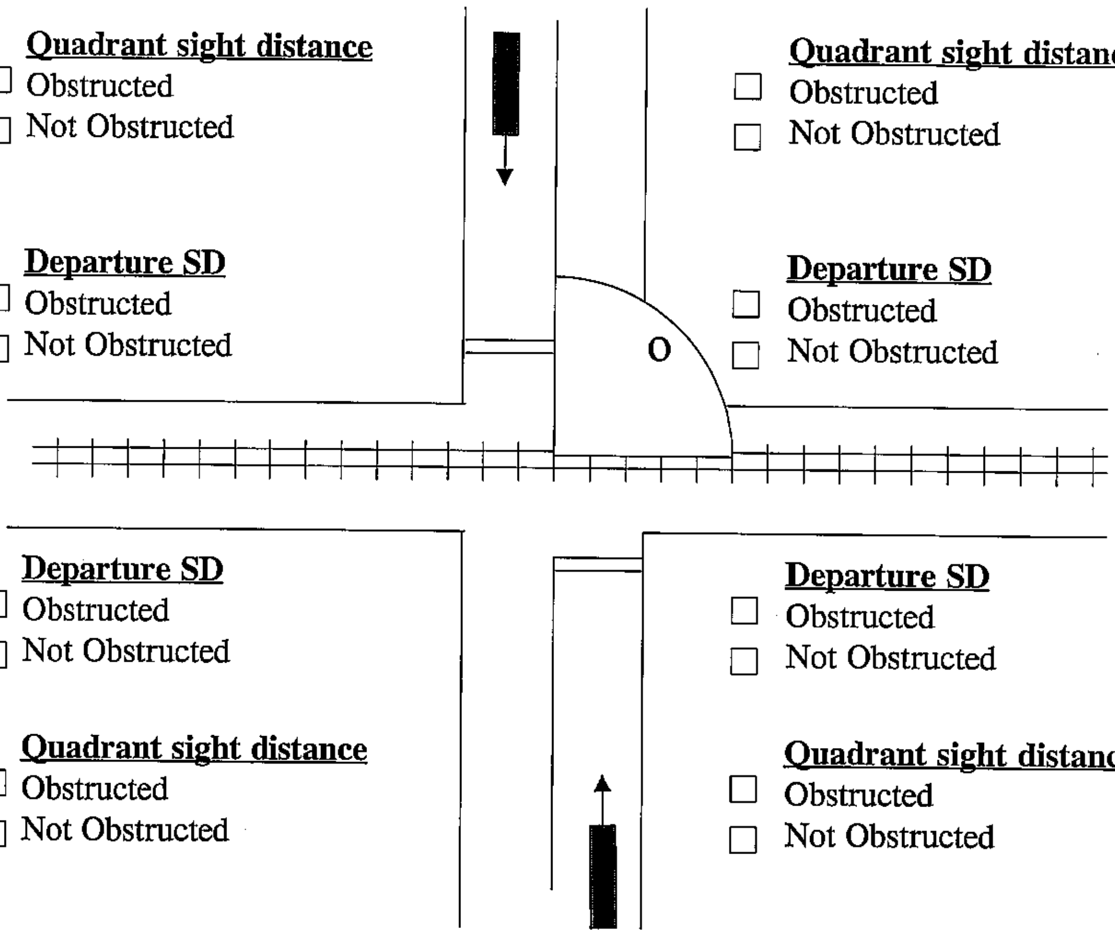
Please fill the appropriate boxes

Quadrant sight distance
☐ Obstructed
☐ Not Obstructed

Quadrant sight distance
☐ Obstructed
☐ Not Obstructed

Departure SD
☐ Obstructed
☐ Not Obstructed

Departure SD
☐ Obstructed
☐ Not Obstructed



Departure SD
☐ Obstructed
☐ Not Obstructed

Departure SD
☐ Obstructed
☐ Not Obstructed

Quadrant sight distance
☐ Obstructed
☐ Not Obstructed

Quadrant sight distance
☐ Obstructed
☐ Not Obstructed

Comments:

Figure 4.6. Sight Distance Evaluation Sheet.

Table 4.9. Required design sight distance for combination of highway and train vehicle speeds.

Train Speed mph	Departure from stop	Moving Vehicle												
	Vehicle Speed (mph)													
	0	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
	Distance Along Railroad from Crossing, (yard)													
10	80	48	39	34	33	33	33	34	36	37	39	41	42	45
15	120	73	58	52	49	49	50	52	54	56	58	61	63	67
20	160	97	77	69	66	66	66	69	72	75	77	82	85	90
25	200	121	97	86	82	82	83	86	89	94	97	102	106	112
30	240	145	116	103	99	99	100	103	107	112	116	122	127	134
35	280	169	135	121	115	115	116	121	125	131	135	143	148	157
40	320	193	155	138	132	132	133	138	143	150	155	163	169	179
45	361	218	174	155	148	148	149	155	161	168	174	184	190	202
50	401	242	193	172	164	164	166	172	179	187	193	204	211	224
55	441	266	213	190	181	181	183	190	197	206	213	224	233	246
60	481	290	232	207	197	197	199	207	215	225	232	245	254	269
65	521	314	251	224	214	214	216	224	233	243	251	265	275	291
70	561	339	270	241	230	230	232	241	251	262	271	286	296	314
75	601	363	290	259	247	247	249	259	268	281	290	306	317	336
80	641	387	309	276	263	263	266	276	286	299	309	326	338	358
85	681	411	328	293	280	280	282	293	304	318	329	347	359	381
90	721	435	348	310	296	296	299	310	322	337	348	367	381	403
		Distance Along Highway from Crossing, (yard)												
		23	33	44	57	74	91	113	136	162	188	220	250	289

Relationship between crashes and contributing factors

Data from ICC Crossing Inventory File, the FRA Accident/Incident Reporting System and field observations were combined and used to explore the relationship between accident frequency and contributing factors. Five years of data were used in this evaluation. The inventory file compiled for the 73 crossings was compared to the accident file. This comparison revealed that three of the 73 crossings had their warning devices upgraded sometime between 1993 and 1997. Table 4.10 shows the discrepancies between the 93-97 accident file and the inventory file.

Table 4.10. Discrepancies between the 93-97 accident file and inventory data

Serial No	Crossing ID	Warning Devices from		Warning Devices in 93-97 Accident File	
		Field	ICC Inventory	Device	Date of Latest Accident
1	175015Y	Gates	Gates	Crossbucks	07/03/93
2	299027M	Gates	Gates	Crossbucks	8/16/93
3	479258T	Gates	Gates	Crossbucks	03/29/94

Once again, because of lack of information about the exact date the devices were upgraded, those three crossings have to be excluded. Thus, 70 crossings remain to be used in the statistical analysis.

Step-wise regression analyses were conducted to examine the relationship between accident frequency and contributing factors. The number of accidents in five years (AC9397) was used as the dependent variable (response) and the following variables were introduced as possible predictors: average daily traffic (ADT), number of lanes (NOL), number of main tracks (NMT), number of day time train (NDTT), number of nighttime trains (NNTT), number of day switch train (NDST), number of night switch train (NNST), number of total train (NTT), maximum timetable speed (MTS), sight distance (SD), and the multiplicative terms (ADT×NTT), (ADT×NDTT), and (NOL×NMT). Table 4.11 shows the best model using one, two, three, four, five or six variables.

As shown, the product of average daily traffic and number of daytime train yields the strongest one-variable model with R^2 = 31.2. However, a model was sought for which

- Error Mean Square (MSE) is at the minimum or so close to the minimum that adding more variables is not worthwhile

- C_p value is near the number of parameters, p, (B_0, B_1, .. , B_n). This indicates that the bias of the regression model is small. The statistic C_p is determined by the following equation

$$C_p = \frac{RSS}{\hat{\sigma}^2} + 2p - n$$

n = number of observations
p = number of parameters
RSS = residual sum of squares = $\sum \hat{e}_i^2$
$\hat{\sigma}$ = standard error of regression

- R^2 does not increase significantly by adding more variables.

Examining Table 4.11 reveals that the model based on five variables is the best because C_p = 5.6 is very close to the number of parameters which is 6 in this case. The square root of MSE for that model is 0.732 is the second lowest value in the table. The coefficient of determination for that model is 56.8%. Thus, the regression equation is

AC9397 = -0.491+ 0.000202 ADT+ 0.0683 NNTT – 0.000016 ADT(NTT) + 0.000023 ADT(NDTT) - 0.132 NOL(NMT)

Table 4.11. Best Subsets Regression.
Response is AC9397

Var	R^2	Adj R^2	C_p	S	ADT	NOL	NMT	NDTT	NNTT	NDST	NNST	NTT	MTS	SD	ADT×NTT	ADT×NDTT	NOL×NMT
1	31.2	30.2	35.2	0.896												X	
1	30.2	29.2	36.6	0.903				X									
2	39.0	37.1	25.8	0.851				X								X	
2	38.1	36.2	27.1	0.857	X			X									
3	43.7	41.2	20.8	0.823				X							X	X	
3	43.0	40.4	21.9	0.828								X			X	X	
4	52.6	49.7	9.8	0.762	X				X						X	X	
4	51.3	48.3	11.6	0.771	X							X			X	X	
5	56.8	53.4	5.6	0.733	X				X						X	X	X
5	55.1	51.6	8.1	0.747	X							X			X	X	X
6	58.1	54.2	5.6	0.727	X				X				X		X	X	X
6	57.1	53.0	7.2	0.736	X		X		X						X	X	X

Table 4.12. Summary of the regression of AC9397 on ADT NNTT ADT(NTT) ADT(NDTT) NOL(NMT).

Predictor	Coef	SD	t	p-value
Constant	-0.491	0.2484	-1.98	0.053
ADT	0.000202	0.00004436	4.56	0.000
NNTT	0.0683	0.01475	4.63	0.000
ADT(NTT)	– 0.000016	0.00000284	-5.49	0.000
ADT(NDTT)	0.000023	0.00000409	5.72	0.000
NOL(NMT)	- 0.132	0.05276	-2.50	0.015

S = 0.733 R-Sq = 56.8% R-Sq(adj) = 53.4%

Considering 95% confidence interval, p-value < 0.05 indicates that there is significant evidence that the coefficients (B_o, B_1, ..B_n) of the independent variables are not zero. In Table 4.12, The p-value of 0.053 indicates that the evidence for the coefficient, B_0, not being zero appears insufficient. That is to say, the constant adds little to the prediction and we may fit the model without intercept. All other coefficients are significantly different from zero. This indicates that all variables in the model appear to be significant predictors.

Table 4.13. Analysis of Variance.

Source	DF	SS	MS	F	P
Regression	5	45.1315	9.0263	16.82	0.000
Residual Error	64	34.3542	0.5368		
Total	69	79.4857			

Examining Analysis of Variance in Table 4.13 support the previous conclusion. The p-value from the ANOVA table tells us to reject the null hypothesis H_0: $B_1 = B_2 = .. = B_n = 0$ and accept the alternative hypothesis H1: not all B equal zero. In other words, there is a regression relation between the response AC9397 and the set of predictors ADT, NNTT, ADT(NTT), ADT(NDTT)and NOL(NMT).

It is worth noting that the sight distance does not appear as a predictor in any model. This by itself does not suggest that the sight distance is a trivial factor. Rather, it tells us that the sight distance can not be used to mathematically predict the number of future accident in a railroad crossing.

5. ACCIDENT CHARACTERISTICS AT RAILROAD-HIGHWAY GRADE-CROSSING IN ILLINOIS

The Grade Crossing Inventory File and the FRA Accident Data File for the period of January 1, 1988, through December 31, 1997, were obtained from Illinois Commerce Commission and Illinois Department of Transportation. The Inventory File contained data for 9063 public grade crossings in Illinois. The Accident File contained record for 2776 crashes that occurred in Illinois over a ten-year period (1988-1997). The Inventory File was then merged with the Accident File using the crossing identification number. The merged file was used to find the general trends and effects of selected physical and operational parameters on train-vehicle collisions at rail-highway grade crossings. The data items contained in the Inventory and Accident File are listed below.

Data Item in Grade-Crossing Inventory File

For highway-railroad grade crossings in Illinois (9063 records) the following parameters were reported in the ICC inventory file

- Crossing Number
- Main AAR (Company name operating the railroad line such as ALS, CTA, etc.)
- Line (Name of the line)
- Milepost
- Branch
- County Name
- In/Near the City
- City Name
- Street Name
- Highway (Highway System e.g. , Federal-Aid Primary)
- Warning Device (Warning device type such as bells, gates, etc.)
- AADT (Average daily traffic)
- Number of Traffic Lanes
- Road Classification (Arterial, collector, local – urban, rural)
- Number of Main Tracks
- Number of Other Tracks
- Number of Day Thru Trains
- Number of Nite Thru Trains
- Number of Day Switch Trains
- Number of Nite Switch Trains
- Train Total (Total number of trains per day)
- Maximum Timetable Speed

Data Item in Accident File

The Accident File contains records of 2776 crashes that occurred in ten years (1988-1997). Two files were created that have the crash data for each five years separately. There were 1592 crash records for 1988-1992 and 1184 crash records for 1993-1997. The Accident File contained the following parameters:

Crossing Number
Date (From 1/5/88 to 12/26/97)
Time
Main AAR (Company name operating the railroad line such as ALS, CTA, etc.)
Line (Name of the line where the crash occur)
Milepost
County Name
City Name
Street / Highway
Fatalities (Number of deaths)
Injuries (Number of people injured)
Equipment Involved (Freight, passenger, switch trains or other)
Equipment Owner
Highway User (Auto, truck, pedestrian, bicycle, motor, bus, other)
Crash Type (Train-vehicle, vehicle-train, pedestrian)
Weather (Clear, cloudy, rainy, snowy, foggy)
Warning Device (Warning device type such as bells, gates, etc.).

General Trend for Crashes at Rail-Highway Grade Crossings

The national trend for rail-highway grade crossing crashes has been decreasing in the last 10 years as shown in Figure 5.1. The trend in Illinois is similar to the national trend as shown in Figure 5.2. Since 1988, there has been roughly 60%, 55% and 50% reductions in the number of fatal, injury and PDO crashes in IL.

Figure 5.3 shows distribution of ten-year crashes by highway user. In 65% of crashes an automobile was involved. In 25% of crashes a truck was involved. Pedestrian and bicycle were involved in 6% of crashes.

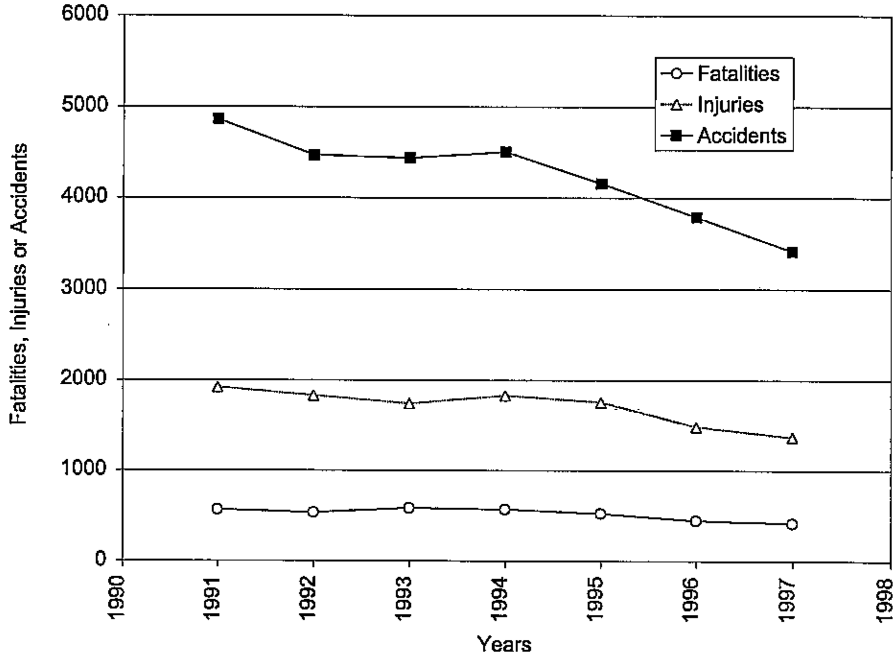


Figure 5.1. National Rail-Highway Grade Crossings Fatalities, Injuries and Accidents in the 1990s.

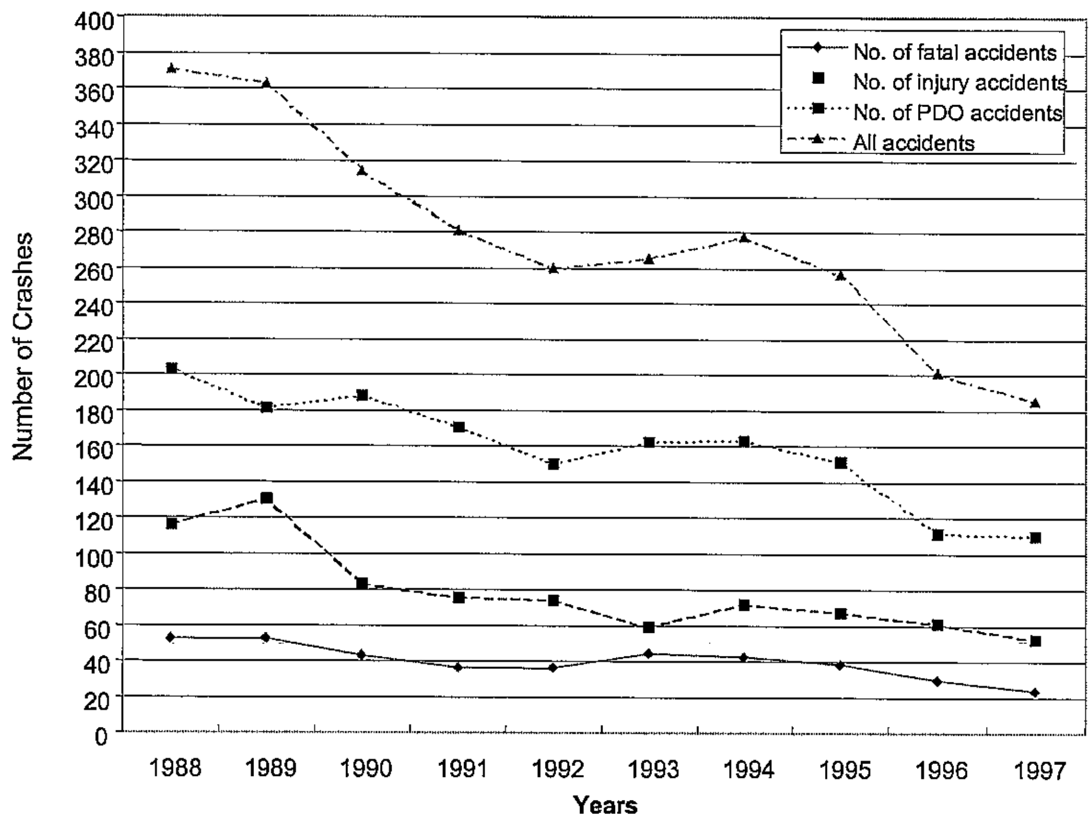
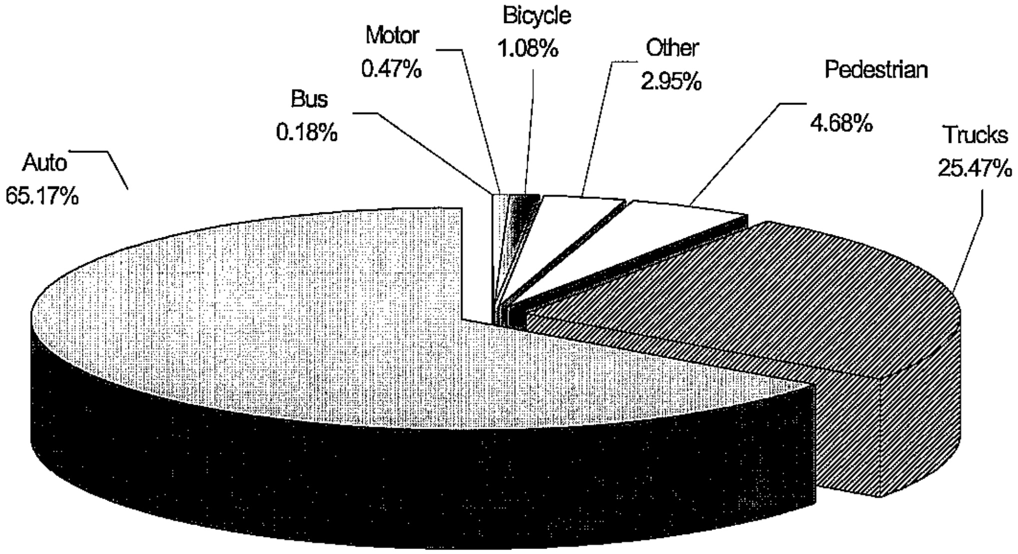


Figure 5.2. Number of Accidents per Type in Illinois-1988 to1997.

Distribution of 10-year accidents by Highway user
1/1/88 - 12/31/97



Distribution of number of accidents, fatalities and injuries by highway user
1/1/88 - 12/31/97

Highway User	No of Accidents	Percent	Fatalities	Percent	Injuries	Percent	PDO	Percent
Bus	5	0.18%	7	1.48%	43	3.73%	3	0.19%
Motor	13	0.47%	4	0.85%	6	0.52%	3	0.19%
Bicyc	30	1.08%	18	3.81%	8	0.69%	5	0.31%
Other	82	2.95%	8	1.69%	35	3.03%	49	3.08%
Ped	130	4.68%	83	17.55%	45	3.90%	7	0.44%
Trucks	707	25.47%	84	17.76%	252	21.84%	440	27.64%
Auto	1809	65.17%	269	56.87%	765	66.29%	1085	68.15%
Total	2776	100%	473	100%	1154	100%	1592	100%

Figure 5.3. Distribution of ten-year crashes by highway user.

Distribution by Crash Types

To find general trends only the most recent data (1993-1997) was used. Table 5.1 presents data for rail-highway crossing crashes in Illinois from 1993 to 1997. The table reveals a decreasing trend in the number of fatalities, injuries and accidents.

Table 5.1: Highway-Rail Crossing Crash Statistics (1993-1997).

Year	1993	1994	1995	1996	1997	Total
Fatalities	49	47	49	33	26	204
Injuries	91	97	119	81	73	461
Accidents	265	277	256	201	185	1184

Between 1993 and 1998, there were 1184 crashes at rail-highway crossings in Illinois. These crashes claimed 204 lives and resulted in additional 461 injuries.

Table 5.2: Number and severity of crashes for 1993 to 1997.

Type of crashes	No. of crashes	%	No of Fatalities	No of Injuries
Fatal	176	15	204	62
Injury	311	26	-	399
PDO	697	59	-	-
Total	1184	100	204	461

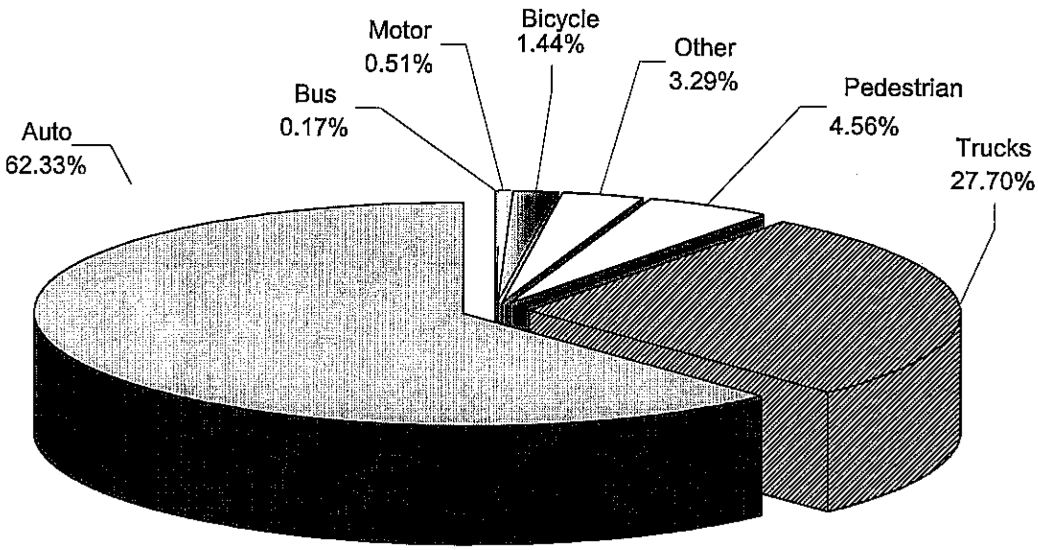
Crash Distribution by Warning Devices

There are 9,063 highway-rail grade crossings in Illinois. Table 5.3 shows percentage of crossings and crashes by warning device between 1993-97. Approximately, 40% of the crossings have crossbucks, 25% have gates and 29% have flashing lights. About 4.6% have no devices. The remaining 1.4% have signal, stop signs, bell or wigwag. The greatest number of crashes occurred at crossings with gates followed by crossbucks and flashing lights. While 25% of public grade crossing in Illinois are protected by gates, these crossings account for about 40% of crashes. This disproportion may be attributed to the higher exposure level (higher train and vehicle volume) that exists at such crossings.

Crash Distribution by Highway User

The crash data was also tabulated by the highway user and type of collision. Table 5.4 shows the number of crashes between 1993 and 1997 grouped by crash type and highway user. Crashes were classified under three categories: vehicle hits train, train hits vehicle and pedestrian. Approximately 69% of crashes took place when a train hit a vehicle, 26% took place when a vehicle struck a train, and 5% took place when a pedestrian crossed a set of tracks to beat a train. In 62% of crashes an automobile was involved. In 28% of crashes a truck was involved. Pedestrians and bicycles were involved in 6% of crashes.

Distribution of 5-year accidents by Highway user
1/1/93 - 12/31/97



Distribution of number of accidents, fatalities and injuries by highway user
1/1/93 - 12/31/97.

Highway User	No of Accidents	Percent	Fatalities	Percent	Injuries	Percent	PDO	Percent
Bus	2	0.17%	7	3.43%	29	6.29%	1	0.14%
Motor	6	0.51%	2	0.98%	2	0.43%	2	0.29%
Bicyc	17	1.44%	9	4.41%	4	0.87%	4	0.57%
Other	39	3.29%	4	1.96%	15	3.25%	25	3.59%
Ped	54	4.56%	33	16.18%	18	3.90%	4	0.57%
Trucks	328	27.70%	40	19.61%	110	23.86%	206	29.56%
Auto	738	62.33%	109	53.43%	283	61.39%	455	65.28%
Total	1184	100%	204	100%	461	100%	697	100%

Figure 5.4. Distribution of five-year crashes by highway user.

Table 5.3. Crossings and Crashes at Highway-Rail Crossings by Warning Device - 1993 to 1997.

Warning Device	All Crossings		Crossings with crashes		Crashes	
	Number	%	Number	%	Number	%
Crossbucks	3646	40.23	264	27.97	358	30.24
Gates	1891	20.87	273	28.92	320	27.03
Flash.Lites	2162	23.86	211	22.35	221	18.67
Cant&Gates	381	4.20	107	11.33	159	13.43
Cantilevers FLS	434	4.79	74	7.84	107	9.04
Stop Signs	68	0.75	3	0.32	7	0.59
No devices	418	4.61	5	0.53	4	0.34
Hwy Signals	2	0.02	1	0.11	4	0.34
Bells	40	0.44	5	0.53	3	0.25
Wigwags	21	0.23	1	0.11	1	0.08
Total	9063	100	944	100	1184	100

Table 5.4. Number of crashes grouped by crash type and highway user - 1993 to 1997.

Highway User	Crash Type	No. of crashes	% of crashes	No. of Fatalities	No. of Injuries
Auto	Trn-Veh	515	43	90	177
	Veh-Trn	224	19	19	108
Truck	Trn-Veh	261	22	37	75
	Veh-Trn	67	6	3	35
Ped	Ped	53	4	33	16
Other	Trn-Veh	31	3	4	8
	Veh-Trn	8	1	0	7
Bicycle	Ped	14	1	8	3
	Trn-Veh	3	0	1	1
Motorcycle	Trn-Veh	6	1	2	2
Bus	Trn-Veh	2	0	7	29
Total		1184	100	204	461

Crash Distribution by AADT

The occurrence of a crash depends on the probability of having a vehicle and a train at a crossing at the same time. This probability is directly related to the vehicle and train volumes. Data was stratified according to the traffic volume ranges given in Table 5.5. Roughly 14% of crossings had AADT greater than 5,000 veh/day, but 36% of crashes took place at these crossings. On the other hand, 27% of crossings in Illinois had AADT of 100 veh/day or less and 13% of crashes took place at these crossings. This suggests that the AADT is an important factor that should be considered in crash prediction procedure.

Table 5.5: Frequency of Crashes by AADT - (1993 - 1997).

AADT veh/day	All Crossings		Crossings with crash		Crashes	
	Number	%	Number	%	Number	%
0-10	177	1.95	5	0.53	5	0.42
11-100	2231	24.62	143	15.15	152	12.84
101-250	1404	15.49	108	11.44	133	11.23
251-1000	2215	24.44	201	21.29	237	20.02
1001-2500	1058	11.67	123	13.03	150	12.67
2501-5000	675	7.45	72	7.63	82	6.93
5001-10000	602	6.64	106	11.23	149	12.58
10001-15000	317	3.50	71	7.52	101	8.53
15001-25000	265	2.92	80	8.47	119	10.05
25001-50000	117	1.29	34	3.60	53	4.48
> 50000	2	0.02	1	0.11	3	0.25
Total	9063	100	944	100	1184	100

Crash Distribution by Number of Total Trains (NTT)

The data was also grouped by train volume as shown in Table 5.6. As shown, 41% of crossings had no more than 5 trains/day and 18% of crashes happened at these crossings. On the other hand, only 11% of crossings had more than 30 trains/day and they accounted for 33% of crashes. This gives a clear indication that the train volume also plays an important role in any crash prediction.

Table 5.6. Frequency of crashes by Train Total Volume - 1993 to 1997.

Train Total train/day	All Crossings		Crossings with crash		Crashes	
	Number	%	Number	%	Number	%
0-1	1260	13.90	34	3.60	36	3.04
2-5	2440	26.92	147	15.57	178	15.03
6-10	1627	17.95	150	15.89	166	14.02
11-20	1778	19.62	225	23.83	275	23.23
21-30	919	10.14	123	13.03	146	12.33
31-50	572	6.31	109	11.55	150	12.67
51-100	396	4.37	136	14.41	202	17.06
101-190	71	0.78	20	2.12	31	2.62
Total	9063	100	944	100	1184	100

Frequency of Crashes by Weather Conditions

About 62% of crashes happened in clear weather and 22% in cloudy condition as shown in Table 5.7. The adverse weather conditions (rain, snow, fog) account for 17% of crashes.

Table 5.7. Frequency of Crashes by weather conditions (1993-1997).

Weather	No. of crashes	%
Clear	734	62
Cloudy	257	22
Rain	91	8
Snow	67	6
Fog	35	3
Total	1184	100

Frequency of Crashes by Equipment Owner

Analysis of the data by equipment owner shows that 35% of the crashes involved Union Pacific (UP), Burlington Northern (BN), and (CNW) as shown in Table 5.8. The other 75% is distributed among the other 33 companies .

Table 5.8. Crashes by equipment owner - 1993 to 1997.

Equipment Owner	No. of crashes	%
UP	151	12.8
BN	134	11.3
CNW	122	10.3
NIRC	92	7.8
NW	81	6.8
ICG	66	5.6
ATK	50	4.2
NS	47	4.0
CSX	46	3.9
SOO	44	3.7
SOU	34	2.9
IC	31	2.6
CR	28	2.4
CC	26	2.2
BNSF	25	2.1
ATSF	24	2.0
All other	183	15.4
Total	1184	100.0

Frequency of Crashes by Type of Trains

The data showed that 66% of railroad-highway crossings crashes involved freight trains, 17% involved passenger trains and 8% involved switching trains as shown in Figure 5.5. The remaining 9% was other category that includes commuter train, work train, single car, cut of cars and light locomotive.

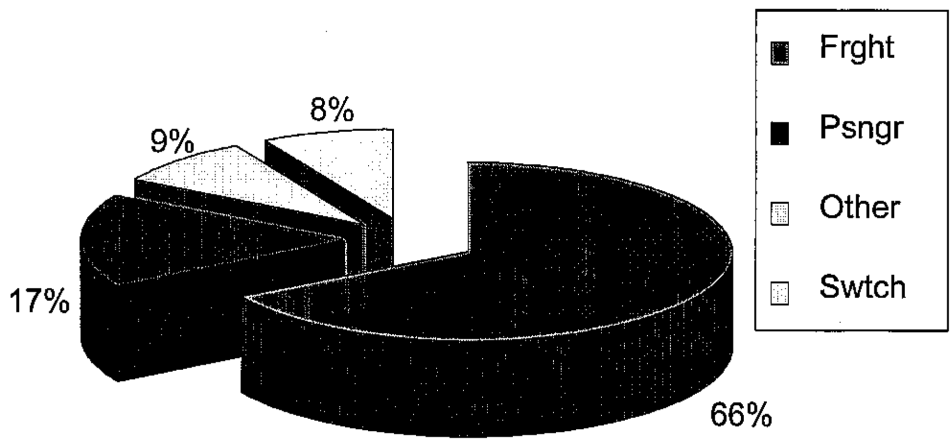


Figure 5.5. Frequency of Crashes by Equipment Involved (1993-1997).

6. EVALUATION AND ANALYSIS OF IDOT EAF FORMULA AND ALTERNATE FORMULAS

In developing a procedure for prioritizing the safety improvements to rail-highway grade crossings, the research team carried out a comprehensive review of published reports and articles on hazard index formula, priority ranking techniques, and crash prediction equations. The team also reviewed the expected accident frequency and hazard index formulas used by other state DOTs for prioritizing rail-highway crossing safety improvements to select procedures that may be appropriate in Illinois conditions. Some formulas compute hazard indices directly from the data elements contained in DOT Crossing Inventory File. In other formulas, more data such as sight distance and average daily school bus traffic are needed. The latter type was excluded from further analysis because the required data is not available in Illinois. As a result, four formulas were selected as potential candidates for further evaluation.

This chapter describes data reduction and data analysis, evaluation of IDOT EAF formula, and presents a discussion of the capability of the selected formulas in determining the crossings with the greatest need for improvement. The differences are highlighted especially for those formulas that were considered potential candidates for adoption in Illinois. A brief discussion of the strengths and weaknesses of the potential formulas are also presented.

To evaluate the validity of IDOT EAF formula as well as other alternate formulas, the observed crash data were compared to the results from the formulas. Scatter plot and regression analysis of number of crashes predicted versus number of crash observed for the rail-highway grade crossings are presented.

Data Reduction

Two data sets were used for evaluation of IDOT EAF formula as well as other alternate formulas. The first set was the US DOT Rail-Highway Crossing Inventory file. The second set was the FRA ten-year (1988-1997) accident file. Nationally, Illinois is second only to Texas in the total number of railroad crossings. Illinois Rail-Highway Crossing Inventory file has entries for 9,063 public highway-rail crossings. The research team reduced the inventory data using the following steps:

1. Examining the inventory file revealed that only two isolated observations have a recorded number of day switch train (NDST) of 92. These two observations are outliers and do not seem to belong to the remainder of the data set because the highest NDST recorded was 50 and were therefore deleted from the database.

2. Similarly, 20 isolated observations were recorded with a number of nighttime trains (NNTT) of 99. These 20 observations are outliers because the highest NNTT recorded was 50. These observations were deleted from the database.

3. Sixteen crossings have number of daytime trains (NDTT) of 99. It appears that the number 99 was recorded whenever there is a lack of real data. Therefore, those observations were deleted.

4. Forty-five crossings with recorded Annual Average Daily Traffic (AADT) = 0 were deleted from the database. An AADT of zero indicates either crossing has been closed or converted to interchange.

5. Seven crossings that have number of lanes (NOL) = 0 were deleted from the database. These crossings may have been closed or converted to interchange.

6. Thirty-eight crossings with NOL > 4 were deleted. Such crossings are not widely encountered and prediction of crashes for these crossing is relatively complex.

7. Any crossing that doesn't have at least one main track was deleted. As a result 999 crossings with NMT =0 were excluded.

8. Five additional crossings with NMT > 4 were excluded. Such wide crossings need special treatment beyond the scope of this study.

9. The remaining records were examined and 543 crossings were found to have number of total train (NTT) = 0. This suggests that these crossings have train traffic that is less than one train per day or they are abandoned. The crossings will not be used in any further analysis.

10. Currently, the allowable train maximum timetable speed in Illinois is 80 mph. Ninety-nine records with maximum timetable speed (MTS) of 90 mph or greater were therefore deleted.

11. Twenty-eight crossings with MTS ≤ 5 mph were deleted.

12. Finally, 125 crossings that have number of other track (NOOT) > 2 were excluded.

This completes the first stage of the data cleaning. Table 6.1 summarizes these steps.

The research team obtained two files from Illinois Commerce Commission (ICC) containing warning device upgrades completed from 1/1/1993 through 12/31/1997. One file contains upgrades by Commission Order and the other is for upgrades by Commission X-Resolution. This data does not tell what devices were in existence prior to the upgrade. In addition, the research team obtained a file containing additional crossings where upgrades were ordered/authorized by the Commission during the time period 1/1/93 to 12/31/97, but no reports have been received from the railroads concerning completion of the projects.

Table 6.1. Summary of first stage of data cleaning.

Total No of Xings reported in ICC Inventory file	**9063**
Criteria for Crossings deleted	**No deleted**
(NDST = 92)	2
(NNTT = 99)	20
(NDTT = 99)	16
(ADT = 0)	45
(NOL = 0)	7
(NOL > 4)	38
(NMT = 0)	999
(NMT > 4)	5
(NTT = 0)	543
(MTS = 90)	99
(MTS ≤ 5)	28
(NOOT > 2)	125
No. of Crossings with valid observations	**7136**

Upgrading the warning devices may lead to a reduction in the number of crashes. Therefore, to objectively analyze the relation between crash history and other geometric and traffic factors, the warning device in the data used has to remain unchanged. Based on that, 272 crossings were deleted from the reduced inventory file because upgrades were completed/ordered by ICC during the time period 1/1/93 to 12/31/97.

The reduced inventory file was then compared to the file created for the 105 crossings visited. To avoid using the same crossings twice- once during the preliminary analysis presented in an earlier chapter and another time in the analysis presented in this chapter- 88 of the visited crossings that remained in the reduced inventory file were deleted.

Finally, the research team compared the inventory file to the ten-year (1988-1997) accident file. Comparison revealed that 175 crossings were found to have unmatched warning devices which indicates a possibility of upgrading or miscoding. Therefore, these crossings also were excluded. By this we completed the second stage of the data reduction. This brought the number of crossings to be used for further analysis to 7,136 - 272 - 88 - 175 = 6,601.

Tables 6.2, 6.3 and 6.4 present five and ten year crash statistics by warning devices.

Table 6.2. Crash Statistics (88-92).

Warning Devices	No. of crossings	No. of Crossings w crashes	% of Xings with crashes	No. of Crashes	No. of Crossings w/o crashes
Xbucks	2700	192	7.11%	209	2508
FL	1976	261	13.21%	338	1715
Gates	1749	357	20.41%	546	1392
Others[1]	93	8	8.60%	10	85
NWD	83	2	2.41%	2	81
Total	**6601**	**820**	**12.42%**	**1105**	**5781**

Table 6.3. Crash Statistics (93-97).

Warning Devices	No. of crossings	No. of Crossings w crashes	% of Xings with crashes	No. of Crashes	No. of Crossings w/o crashes
Xbucks	2700	190	7.04%	211	2510
FL	1976	201	10.17%	237	1775
Gates	1749	260	14.87%	338	1489
Others[1]	93	4	4.30%	4	89
NWD	83	1	1.20%	1	82
Total	**6601**	**656**	**9.94%**	**791**	**5945**

Table 6.4. Crash Statistics (88-97).

Warning Devices	No. of crossings	No. of Crossings w crashes	% of Xings with crashes	No. of Crashes	No. of Crossings w/o crashes
Xbucks	2700	359	13.30%	420	2341
FL	1976	387	19.59%	575	1589
Gates	1749	499	28.53%	884	1250
Others[1]	93	11	11.83%	14	82
NWD	83	3	3.61%	3	80
Total	**6601**	**1259**	**19.07%**	**1896**	**5342**

[1]Others include Bells, Stop Signs, Wigwags and Unknown

Data Analysis

The research team conducted a comprehensive statistical analysis of the variables that may contribute to crash occurrence at railroad crossings in Illinois. Crash statistics were presented in two broad categories:

- Population-based rates
- Traffic-based rates.

Population-based rates

The 1993 number of registered vehicles and number of licensed drivers listed by each county in Illinois were obtained from the office of Secretary of State. In addition, the 1993 population of Illinois Counties was downloaded from the US Census web site. 1993 was chosen as the midpoint between 1988 and 1997. Population-based rates were computed based on the reduced data of 6,601 railroad crossings as shown in Table 6.5.

Table 6.5. Population-based rates crash statistics for Illinois Counties over ten years (88-97).

1	2	3	4	5	6	7	8	9	10	11	12	13
Rank	County Name	Area (Sq mile)	Population (July 1993)	1993 Licensed Drivers	1993 Registered Vehicles	No of crossings with crashes	No of crossings	No of crashes recorded during 10	Average no of crashes per year	(11)=(4)/(8) Pop/Xing	(12)=(5)/(8) Drivers/Xing	(13)=(6)/(8) RegVeh/Xing
1	COOK	945.7	5,172,924	3,053,660	3,127,585	270	654	533	53.3	7,910	4,669	4,782
2	DU PAGE	334.4	828,084	598,233	717,546	48	98	101	10.1	8,450	6,104	7,322
3	ST CLAIR	663.9	265,391	166,631	211,499	46	127	83	8.3	2,090	1,312	1,665
4	MADISON	725.1	254,579	178,570	233,767	41	172	68	6.8	1,480	1,038	1,359
5	LAKE	447.8	549,743	370,879	437,540	40	113	64	6.4	4,865	3,282	3,872
6	MACON	580.6	117,262	83,275	114,647	30	119	51	5.1	985	700	963
7	WINNEBAGO	513.8	261,584	182,203	233,893	28	78	46	4.6	3,354	2,336	2,999
8	KANE	520.7	341,613	224,386	285,836	28	87	41	4.1	3,927	2,579	3,285
9	WILL	837.3	386,379	252,486	308,742	28	124	39	3.9	3,116	2,036	2,490
10	CHAMPAIGN	997.2	169,862	109,852	133,855	28	144	34	3.4	1,180	763	930
11	SANGAMON	868.3	187,732	129,778	179,867	21	162	31	3.1	1,159	801	1,110
12	FRANKLIN	412.1	40,307	29,172	39,566	22	74	30	3	545	394	535
13	MCHENRY	604.1	207,749	146,489	190,755	23	66	29	2.9	3,148	2,220	2,890
14	PEORIA	619.6	183,310	125,625	168,575	19	88	28	2.8	2,083	1,428	1,916
15	MCLEAN	1183.6	135,056	87,844	119,218	23	175	27	2.7	772	502	681
16	TAZEWELL	648.9	125,558	90,109	123,622	21	96	27	2.7	1,308	939	1,288

17	IROQUOIS	1116.5	31,348	22,313	32,978	19	188	24	2.4	167	119	175
18	KANKAKEE	677.5	100,205	66,699	88,127	19	96	24	2.4	1,044	695	918
19	MONTGOMERY	703.8	30,651	20,887	30,562	17	83	23	2.3	369	252	368
20	OGLE	758.9	48,103	33,753	46,550	20	81	23	2.3	594	417	575
21	KNOX	716.3	56,471	38,624	51,500	18	106	22	2.2	533	364	486
22	GRUNDY	420.1	34,253	24,502	33,716	13	61	21	2.1	562	402	553
23	MCDONOUGH	589.3	34,453	20,768	27,921	14	85	21	2.1	405	244	328
24	HENRY	823.3	51,149	37,027	53,012	17	76	20	2	673	487	698
25	JEFFERSON	571.1	37,252	25,689	34,962	13	131	20	2	284	196	267
26	LA SALLE	1135.0	108,659	76,182	103,849	17	168	20	2	647	453	618
27	VERMILION	899.1	87,594	60,175	80,071	16	137	20	2	639	439	584
28	EFFINGHAM	478.7	32,275	22,737	33,949	17	69	19	1.9	468	330	492
29	MORGAN	568.8	36,368	24,347	34,794	12	71	18	1.8	512	343	490
30	DE KALB	634.2	79,611	49,135	64,842	14	88	17	1.7	905	558	737
31	LIVINGSTON	1043.8	39,891	26,157	36,627	13	101	16	1.6	395	259	363
32	CLINTON	474.3	34,772	22,583	31,545	10	61	15	1.5	570	370	517
33	BUREAU	868.6	35,972	25,773	36,230	12	89	14	1.4	404	290	407
34	FULTON	865.7	38,432	26,725	37,021	13	114	14	1.4	337	234	325
35	JACKSON	588.1	61,187	39,344	46,900	10	43	12	1.2	1,423	915	1,091
36	MACOUPIN	863.7	48,157	33,912	48,826	11	80	12	1.2	602	424	610
37	PERRY	441.0	21,349	14,925	20,316	11	70	12	1.2	305	213	290
38	WILLIAMSON	424.2	59,124	40,845	55,760	8	76	12	1.2	778	537	734
39	BOND	380.2	15,280	10,774	15,209	9	55	11	1.1	278	196	277
40	MARION	572.3	41,775	29,521	41,817	9	87	11	1.1	480	339	481
41	MOULTRIE	335.6	13,960	9,282	14,837	7	56	11	1.1	249	166	265
42	RANDOLPH	578.4	34,132	22,248	32,082	9	77	11	1.1	443	289	417
43	WARREN	542.6	19,179	13,334	19,791	8	43	11	1.1	446	310	460
44	ADAMS	856.7	66,876	46,076	65,698	9	36	10	1	1,858	1,280	1,825
45	CARROLL	444.2	16,648	12,620	18,498	9	38	10	1	438	332	487
46	CHRISTIAN	709.1	34,520	24,772	36,173	9	58	9	0.9	595	427	624
47	WAYNE	713.9	17,018	12,431	18,505	9	34	9	0.9	501	366	544
48	ROCK ISLAND	426.8	150,157	105,068	136,510	6	92	8	0.8	1,632	1,142	1,484
49	WHITESIDE	684.8	60,231	42,964	60,432	6	46	8	0.8	1,309	934	1,314
50	FAYETTE	716.5	20,938	13,910	20,456	7	49	7	0.7	427	284	417
51	FORD	485.9	13,932	10,211	14,758	7	76	7	0.7	183	134	194
52	KENDALL	320.7	42,282	29,948	38,460	5	30	7	0.7	1,409	998	1,282
53	LOGAN	618.2	31,026	20,009	27,769	6	87	7	0.7	357	230	319
54	DOUGLAS	416.9	19,538	13,049	18,774	4	55	6	0.6	355	237	341
55	LEE	725.4	35,244	23,656	34,141	5	27	6	0.6	1,305	876	1,264
56	PIATT	440.0	15,994	11,784	16,771	5	83	6	0.6	193	142	202
57	CASS	376.0	13,251	9,462	13,886	3	8	5	0.5	1,656	1,183	1,736
58	CRAWFORD	443.6	20,752	14,555	21,450	5	34	5	0.5	610	428	631
59	EDGAR	623.6	19,581	14,089	20,442	5	67	5	0.5	292	210	305
60	EDWARDS	222.4	7,284	5,251	7,687	2	39	5	0.5	187	135	197
61	JERSEY	369.2	21,110	14,385	20,411	4	19	5	0.5	1,111	757	1,074

62	MARSHALL	386.1	12,764	9,279	13,122	5	23	5	0.5	555	403	571
63	RICHLAND	360.2	16,628	11,890	17,468	5	28	5	0.5	594	425	624
64	CLARK	501.5	16,126	11,853	18,466	4	32	4	0.4	504	370	577
65	SHELBY	758.6	22,341	16,002	24,586	4	53	4	0.4	422	302	464
66	STEPHENSON	564.3	48,694	34,340	47,782	3	22	4	0.4	2,213	1,561	2,172
67	UNION	416.2	17,928	12,285	17,360	4	25	4	0.4	717	491	694
68	WABASH	223.5	13,022	9,609	13,464	4	22	4	0.4	592	437	612
69	CLAY	469.3	14,380	10,105	15,228	3	26	3	0.3	553	389	586
70	CUMBERLAND	346.0	10,917	7,327	11,168	3	30	3	0.3	364	244	372
71	DE WITT	397.6	16,728	12,112	19,898	3	60	3	0.3	279	202	332
72	HANCOCK	794.7	21,600	15,844	23,175	3	54	3	0.3	400	293	429
73	HENDERSON	378.8	8,335	5,962	9,056	2	19	3	0.3	439	314	477
74	JO DAVIESS	601.2	22,020	16,377	22,795	3	19	3	0.3	1,159	862	1,200
75	JOHNSON	346.0	11,659	6,936	10,214	3	15	3	0.3	777	462	681
76	MASON	539.0	16,681	11,736	17,433	3	33	3	0.3	505	356	528
77	MASSAC	239.1	15,120	10,745	14,978	3	13	3	0.3	1,163	827	1,152
78	MONROE	388.3	23,919	17,700	24,908	3	25	3	0.3	957	708	996
79	PIKE	830.3	17,454	12,537	19,932	3	37	3	0.3	472	339	539
80	PULASKI	200.8	7,365	4,875	6,594	1	12	3	0.3	614	406	550
81	WOODFORD	528.0	33,668	23,151	31,103	3	25	3	0.3	1,347	926	1,244
82	COLES	508.3	51,443	32,043	44,986	2	55	2	0.2	935	583	818
83	GREENE	543.1	15,309	10,347	15,117	2	32	2	0.2	478	323	472
84	HAMILTON	435.2	8,470	5,807	8,738	2	27	2	0.2	314	215	324
85	JASPER	494.4	10,623	7,459	11,632	2	43	2	0.2	247	173	271
86	SALINE	383.3	26,713	18,715	25,738	2	19	2	0.2	1,406	985	1,355
87	WHITE	494.9	16,020	12,291	18,259	2	62	2	0.2	258	198	295
88	BOONE	281.4	33,559	23,579	31,525	1	10	1	0.1	3,356	2,358	3,153
89	MENARD	314.3	11,658	8,234	11,917	1	11	1	0.1	1,060	749	1,083
90	PUTNAM	159.8	5,730	4,198	6,236	1	21	1	0.1	273	200	297
91	STARK	287.9	6,414	4,649	7,072	1	6	1	0.1	1,069	775	1,179
92	ALEXANDER	236.4	10,442	6,445	8,506	0	4	0	0	2,611	1,611	2,127
93	LAWRENCE	372.0	15,852	11,526	17,213	0	17	0	0	932	678	1,013
94	SCHUYLER	437.4	7,603	5,357	8,164	0	2	0	0	3,802	2,679	4,082
95	SCOTT	251.0	5,595	3,973	6,684	0	9	0	0	622	441	743
96	WASHINGTON	562.7	14,958	10,724	16,016	0	63	0	0	237	170	254
	Total	53,600	11,672,855	7,517,705	8,987,661	1,259	6,601	1,896	190	**	**	**
	MIN	160	5,595	3,973	6,236	0	2	0	0	167	119	175
	MAX	1,184	5,172,924	3,053,660	3,127,585	270	654	533	53	8,450	6,104	7,322
	AVG	558	121,592	78,309	93,621	13	69	20	2	1,120	766	1,022

The relationships between average number of crashes per year and number of population, licensed drivers and registered vehicles were investigated using the least squares fit for a linear, Polynomial, Logarithmic, Exponential and Power functions. The results showed that these relations are best described by a polynomial function. The relationship between crash rates and population was the strongest (R^2= 54%) among the other two relationships as shown in Figure 6.1, 6.2 and 6.3. The general trend is that the crash rate increases as the population per crossing increases. The crash rates increases rapidly once the population per crossing exceeded 4,000. This relationship can be used to estimate the average number of crashes that will take place in a county per year, given the number of railroad crossings and the population in that county.

The population-based crash rates do not directly reflect the traffic volumes using the crossings. Therefore, traffic-based rates were used to overcome this deficiency.

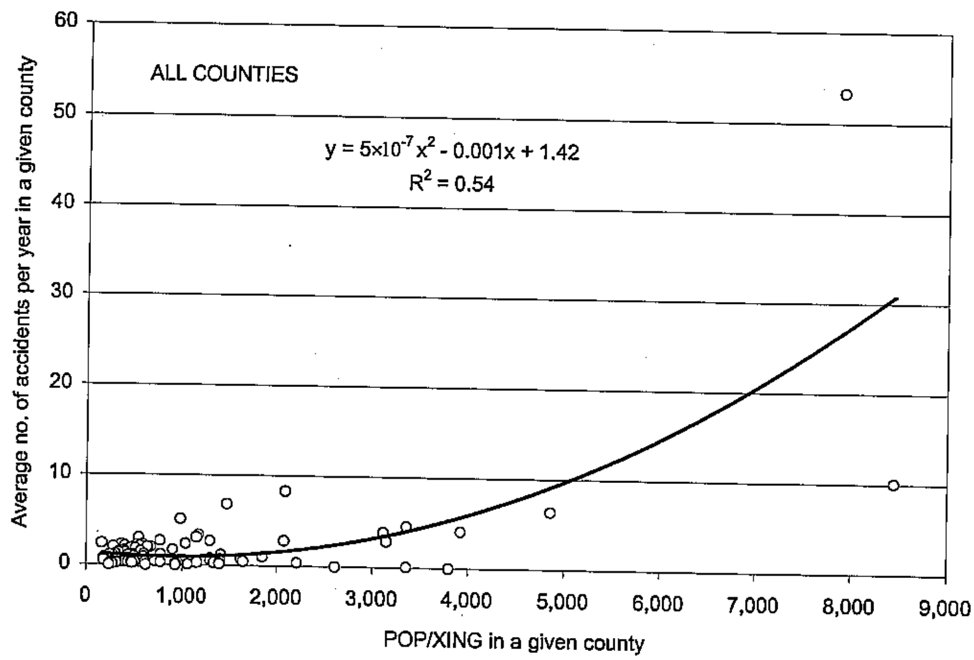


Figure 6.1. Relation between average number of crashes per year and average number of population per railroad grade crossing in a given county.

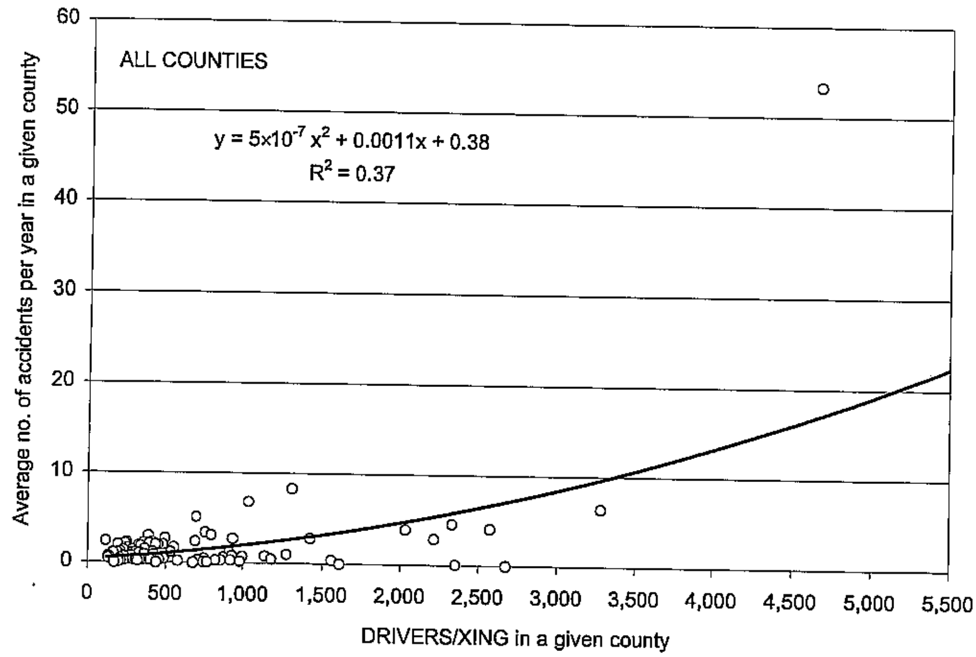


Figure 6.2. Relation between average number of crashes per year and average number of licensed drivers per railroad grade crossing in a given county.

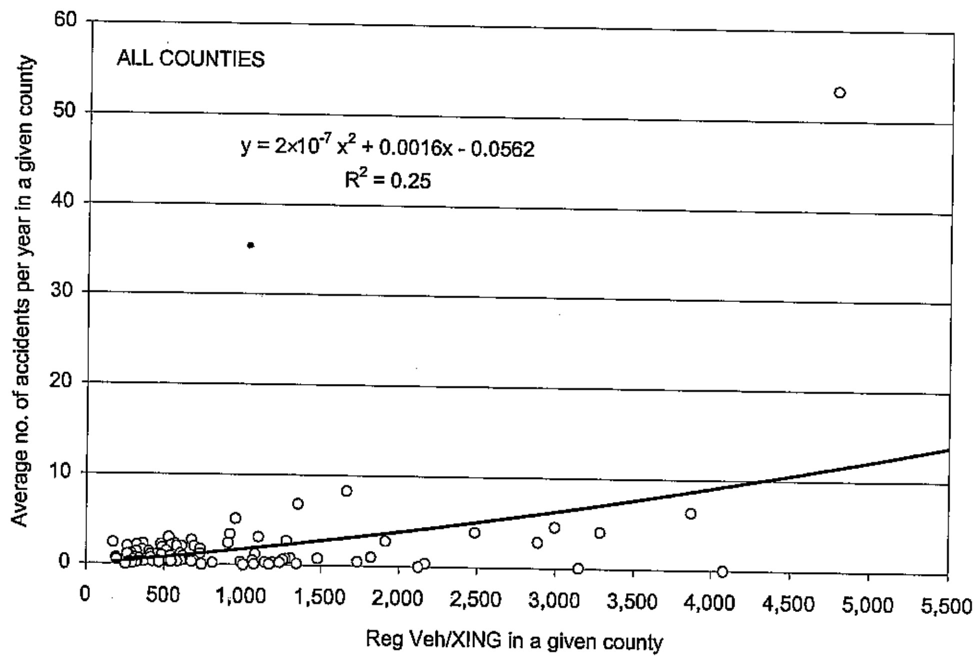


Figure 6.3. Relation between average number of crashes per year and average number of registered vehicles per railroad grade crossing in a given county.

Traffic-based rates

Traffic-based rates include variables such as average daily traffic. The relationships between average number of crashes per year and other traffic parameters were investigated using linear and nonlinear regression analysis as described in the following sections. Traffic-based rates method was used to evaluate IDOT EAF formula and other alternatives. Some of the alternative formulas considered in this study do not have special treatment for crossings with no warning devices, bell, wigwag and stop sign. Therefore, we decided to exclude such crossings from further analysis. In addition, examination of the relationships between number of crashes and ADT as well as NTT identified two outliers gated locations that do not seem to belong to the rest of the data set. Thus 178 extra crossings were eliminated from our database. This completed the data cleaning. The data set used in evaluation of IDOT and other DOTs formulas contains 6,423 crossings.

Evaluation of IDOT Expected Accident Frequency (EAF) Formula

Although crashes at railroad crossings account for a small percentage of all motor vehicle crashes, the number of people killed and injured in each crash is high. Installations of flashing lights and gates at railroad crossings have been shown to reduce the numbers of crashes noticeably. However, the installation and maintenance cost of this type of protection is high. The Illinois Department of Transportation currently uses an Expected Accident Frequency (EAF) formula as one parameter in prioritizing the need for a higher level of warning device at rail-highway crossings. The EAF formula was developed in late sixties using data collected from a number of state highway agencies and universities to develop a prediction model for the number of crashes per year at a given location. The resulting formula is:

$$EAF = A \times B \times T$$

where:

A = Vehicular traffic factor based on 10 year ADT
B = factor based on existing warning device
T = current train volume per day

Factor 'A' can be determined from Table 6.6.

Table 6.6. Vehicular traffic factor.

ADT	'A' Factor
250	0.000347
500	0.000694
1000	0.001377
2000	0.002627
3000	0.003981
4000	0.005208
5000	0.006516
6000	0.00772
7000	0.009005
8000	0.010278
9000	0.011435
10000	0.012674
12000	0.015012
14000	0.017315
16000	0.019549
18000	0.021736
20000	0.023877
25000	0.029051
30000	0.034757

To determine factor ‘A’ for intermediate values of ADT, the research team conducted a regression analysis that led to the following equation:

$$A = 1.35135 \times 10^{-6} \times \left(2 \times 10^{-10} \times ADT^3 - 10^{-5} \times ADT^2 + ADT - 67\right)$$

The protection factor ‘B’ can be determined from Table 6.7 according to the existing warning device and type of area (Urban vs. Rural)

Table 6.7. The protection factor ‘B’.

Warning Device	'B' Factor
Crossbucks, highway volume less than 500 per day	3.89
Crossbucks, Urban	3.06
Crossbucks, Rural	3.03
Flashing Lights, Urban	0.32
Flashing Lights, Rural	0.93
Gates, Urban	0.32
Gates, Rural	0.19

Typically, IDOT considers 2 crashes per 100 years, i.e.; EAF of 0.02 indicative of the need for a possible upgrade in warning device.

To evaluate the validity and reliability of the currently used EAF formula for prioritizing rail safety improvements, inventory data for 6423 crossings and five-year (1993-1997) crash data were used. The EAF formula was used to compute the expected number of crashes at each crossing. The results were analyzed using three different approaches.

1. Comparison of percentage of crossings with crash flagged out by EAF formula and percentage of crash captured.

2. Regression analysis of observed versus predicted number of crashes over five years.

3. Comparative analysis of the selected crash prediction/hazard formulas used in other jurisdictions.

Using these three approaches the effectiveness of the current EAF formula in finding high crash locations was assessed as described in the following text.

Percentage of Crossings with Crash and Percentage of Crash Captured

The EAF formula was used to compute the expected number of crashes at each of the 6,423 crossings. The results were sorted by the highest predicted number of crashes.

Thus, the crossing with the highest predicted number of crashes came at the top of the list, whereas the crossing with the least predicted number of crashes came at the bottom of the list. The research team looked at the top 25, 50, 75, 100 and 200 locations. As shown in Table 6.8-A, in the 200 locations with the highest EAF values, only 84 locations had crash history. In other words, 58% of the top 200 locations identified by the EAF formula did not have crash history. This is despite the fact that the database used has over 650 crossings with crash history.

On the other hand, the 6423 crossings were sorted by observed number of crashes so that the crossing with the highest recorded number of crashes came on the top of the list. The top 200 locations were found to have 332 crashes during a five-year period (1993-1997). However, the top 200 locations suggested by IDOT EAF formula were found to have 131 crashes during the same time frame. Thus, the EAF formula was successful in capturing only 131/332 = 39% of the number of crashes recorded for the top 200 hazardous locations in a five-year period. Similar statistics were computed for top 100, 75, 50 and 25 locations as shown in Table 6.8-A.

In addition, the research team divided the 6423 crossings by warning devices. Thus, three separate files were created. The first file contains inventory and crash data for 2700 crossings with Crossbucks. The second file contains inventory and crash data for 1976 crossings with Flashing lights. The third file contains inventory and crash data for 1747 crossings with Gates.

Considering the top 100 locations with crossbucks identified by the EAF formula, only 17% of the locations were found to have crash history. This percentage was 25% and 54% for crossings with flashing lights and gates respectively. The EAF formula was successful in capturing only 19%, 23% and 50% of the number of crashes recorded for the top 100 hazardous locations with crossbucks, flashing lights and gates respectively, as shown in Tables 6.8-B, 6.8-C, and 6.8-D. Similar values are presented in these tables for top 75, 50, and 25 locations.

Table 6.8-A. Evaluation of EAF Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest EAF	% of crossings w/acc captured by EAF	Total No of acc in top N locations w/acc	No of acc in top N locations with highest EAF	% of acc captured by EAF
200	84	42%	332	131	39%
100	51	51%	232	81	35%
75	42	56%	188	68	36%
50	31	62%	138	54	39%
25	16	64%	88	21	24%

Table 6.8-B. Evaluation of IDOT model using Crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest EAF	% of crossings w/acc captured by EAF	Total No of acc in top N locations w/acc	No of acc in top N locations with highest EAF	% of acc captured by EAF
100	17	17%	121	23	19%
75	14	19%	96	19	20%
50	11	22%	71	14	20%
25	4	16%	46	4	9%

Table 6.8 -C. Evaluation of IDOT model using Crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest EAF	% of crossings w/acc captured by EAF	Total No of acc in top N locations w/acc	No of acc in top N locations with highest EAF	% of acc captured by EAF
100	25	25%	136	31	23%
75	18	24%	111	21	19%
50	14	28%	86	16	19%
25	7	28%	58	8	14%

Table 6.8-D. Evaluation of IDOT model using Crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest EAF	% of crossings w/acc captured by EAF	Total No of acc in top N locations w/acc	No of acc in top N locations with highest EAF	% of acc captured by EAF
100	54	54%	175	87	50%
75	43	57%	150	69	46%
50	33	66%	125	57	46%
25	17	68%	78	23	29%

Regression Analysis of Observed Versus Predicted Number of Crashes

To further examine the validity of IDOT EAF formula, the actual number of crashes over five-year (1993-1997) at each of the 6423 crossings were plotted against number of crashes computed by IDOT EAF formula. Had the number of actual crashes perfectly matched the number of computed crashes for all crossings, the relationship is a regression line with slope equal to one, intercept equal to zero and coefficient of determination (R^2) equal to one. The formula that generates a regression line with slope close to 1, intercept close to zero and high R^2 value would be considered ideal in identifying a high priority location for safety improvement. Figures 6.4-A to 6.4-D reveal that IDOT EAF formula does not satisfy any of the aforementioned statistical tests. The formula seems to work relatively better in identifying gated locations with high crash rate. As shown in Figure 6.4-B, the formula falls short in identifying hazardous crossings marked with crossbucks.

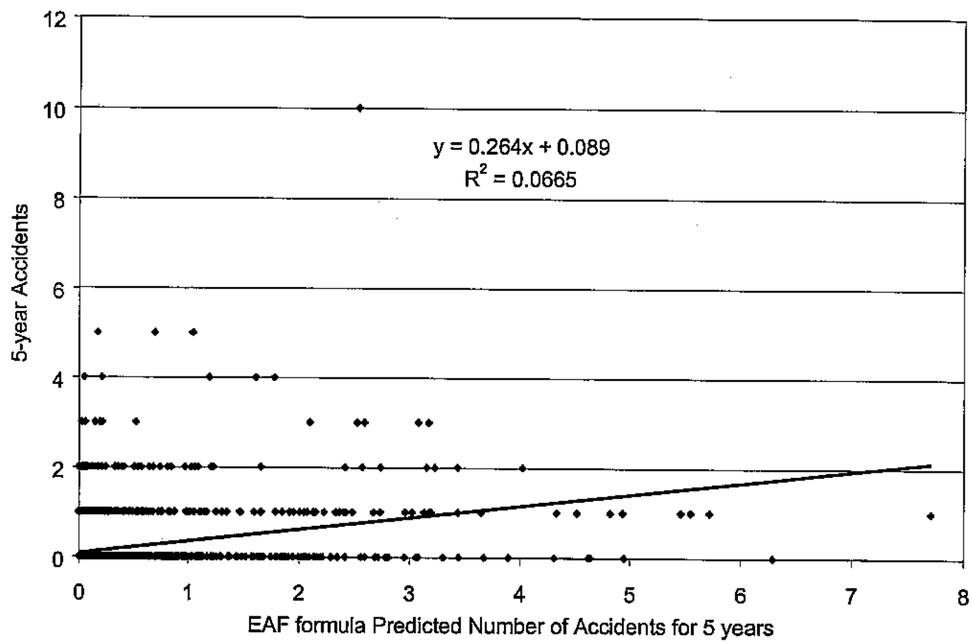


Figure 6.4-A. Relation between IDOT EAF and number of crashes recorded for 6,423 locations.

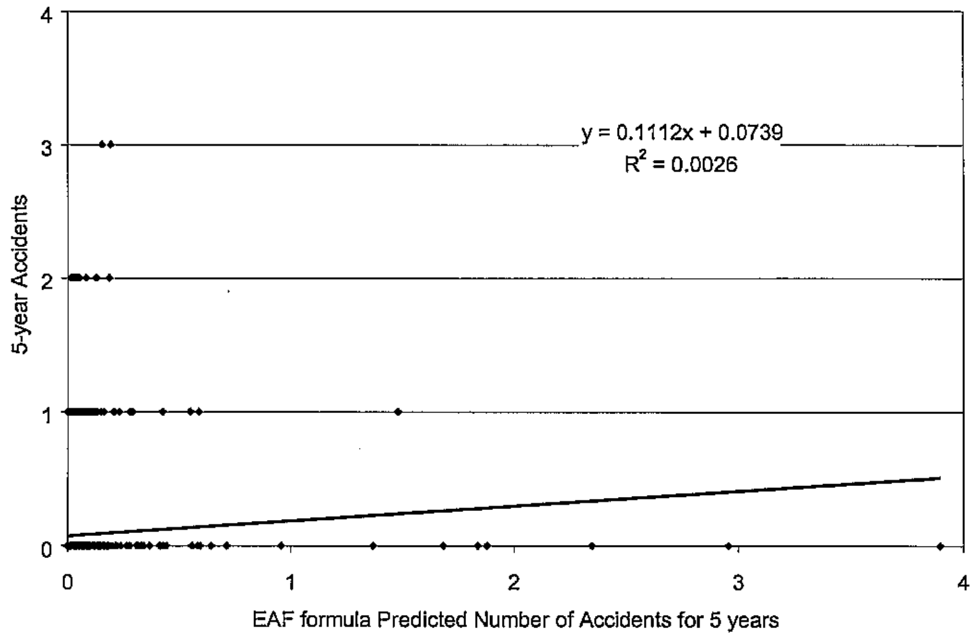


Figure 6.4-B. Relation between IDOT EAF and number of crashes recorded for 2,700 crossings marked with crossbucks.

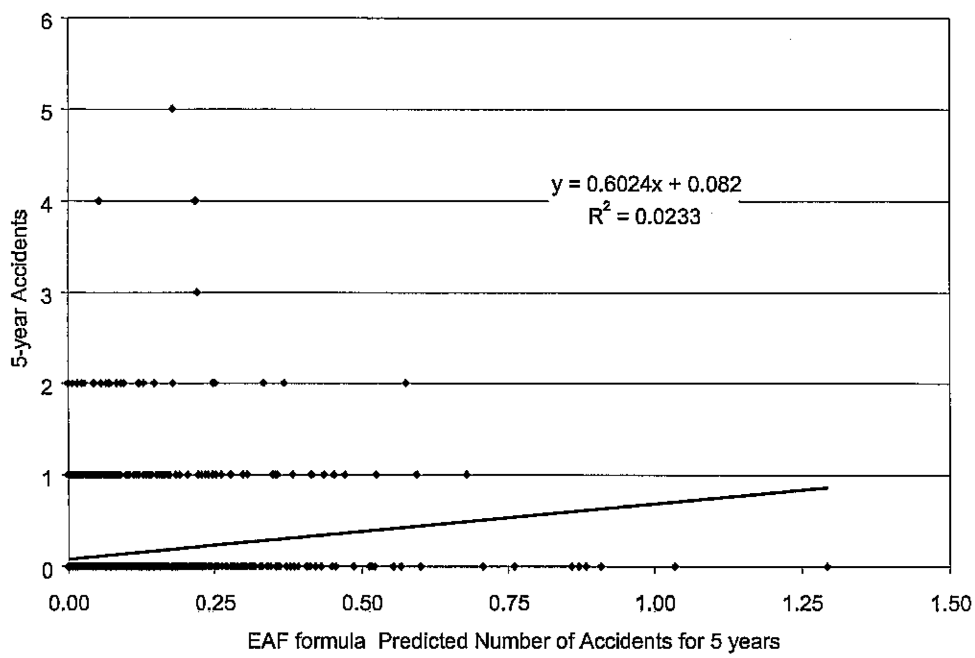


Figure 6.4-C. Relation between IDOT EAF and number of crashes recorded for 1,976 crossings marked by flashing lights.

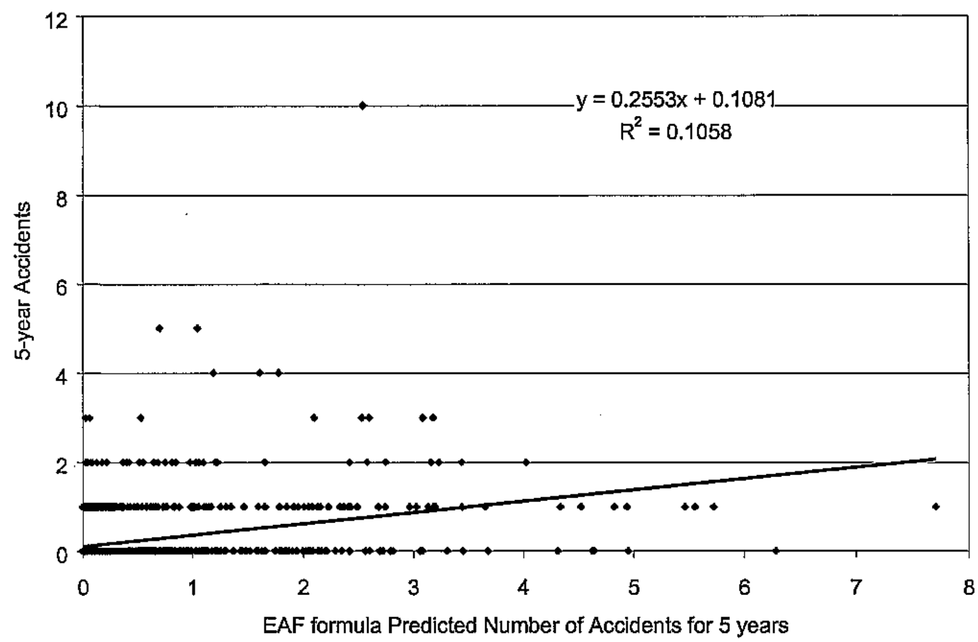


Figure 6.4-D. Relation between IDOT EAF and number of crashes recorded for 1,747 crossings marked with gates.

Comparative Analysis with Selected EAF Formulas Used in Other Jurisdictions

The suitability of the potential formulas and warrants for Illinois conditions was carefully examined. First, the research team established criteria for selecting potential hazard index formulas. The criteria considered are availability of data needed, ease of use, accuracy of outcome, the amount of input data required, and applicability to all types of land use.

Based on these criteria, four potential hazard index formulas were identified for further evaluation for Illinois conditions. These formulas are: Connecticut Hazard Index Formula, New Hampshire Index Formula used by Michigan, California Hazard Index Formula and USDOT Accident Prediction Model. The capabilities of these formulas in identifying the crossings with the greatest need for improvement were assessed using the approaches described above.

Connecticut Hazard Index Formula

Connecticut DOT prioritizes railroad grade crossings for safety improvement by ranking the crossings according to the Hazard Index calculated from the following formula (an adaptation of the New Hampshire Index):

$$HI = \frac{(T+1)\times(A+1)\times AADT \times PF}{100}$$

Where:

T = Train movements per day
A = Number of vehicle/train crashes in last 5 years
AADT = Annual Average Daily traffic
PF = Protection Factor from Table 6.9.

Table 6.9. Protection Factor for Connecticut Hazard Index Formula

PF	Devices
1.25	Passive Warning devices
0.25	Railroad Flashing lights
0.01	Gates with railroad Flashing Lights

It is worth noting that the above formula does not compute number of crashes. Rather, the formula produces an index as a surrogate for the number of crashes. The highest priority is assigned to the crossing with the highest calculated index.

In addition to the variables used as input in IDOT EAF formula, Connecticut formula also uses the crash history. Therefore, we used a five-year (1988-1992)-crash history as input to compute the hazard index corresponding to the crash record (1993-1997). The capability of the formula to identify the crossings with the greatest need for improvement was assessed using the three approaches used to evaluate IDOT EAF formula. The results are presented in Table 6.10-A to 6.10-D and Figures 6.5-A to 6.5-D.

As shown in Table 6.10-A, among the top 200 locations suggested by CHI formula only 74 locations were found to have crash history. On the other hand, among the top 200 locations suggested IDOT EAF, 84 locations were found to have crash history. In addition, the 74 crossings suggested by CHI formula had 108 crashes, whereas the 84 locations suggested by IDOT EAF formula had 131crashes. Thus, on average IDOT formula picked locations with higher crash rate (131/84=1.56 crashes/crossings versus 108/74=1.46 crashes/crossings). This does not suggest that IDOT EAF formula outperform CHI formula. This is because among the top 25 locations marked with crossbucks suggested by IDOT formula, only 4 crossings were found to have crash history. In contrast, among the top 25 locations marked with crossbucks suggested by CHI formula, 7 crossings were found to have crash history.

Figures 6.5-A to 6.5-D reveal that correlation between observed and predicted number of crashes is weak. CHI formula identifies gated locations with high crash rate relatively better than IDOT EAF formula does (R^2= 18.9% vs 10.6%).

Table 6.10-A. Evaluation of CHI Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CHI	% of crossings w/acc captured by CHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CHI	% of acc captured by CHI
200	74	37%	332	108	33%
100	40	40%	232	63	27%
75	29	39%	188	50	27%
50	18	36%	138	36	26%
25	8	32%	88	18	20%

Table 6.10-B. Evaluation of Connecticut formula using crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CHI	% of crossings w/acc captured by CHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CHI	% of acc captured by CHI
100	18	18%	121	23	19%
75	12	16%	96	15	16%
50	10	20%	71	13	18%
25	7	28%	46	7	15%

Table 6.10-C. Evaluation of Connecticut model using crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CHI	% of crossings w/acc captured by CHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CHI	% of acc captured by CHI
100	29	29%	136	37	27%
75	22	29%	111	29	26%
50	15	30%	86	20	23%
25	7	28%	58	8	14%

Table 6.10 -D. Evaluation of Connecticut model using crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CHI	% of crossings w/acc captured by CHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CHI	% of acc captured by CHI
100	59	59%	175	100	57%
75	44	59%	150	74	49%
50	31	62%	125	54	43%
25	19	76%	78	36	46%

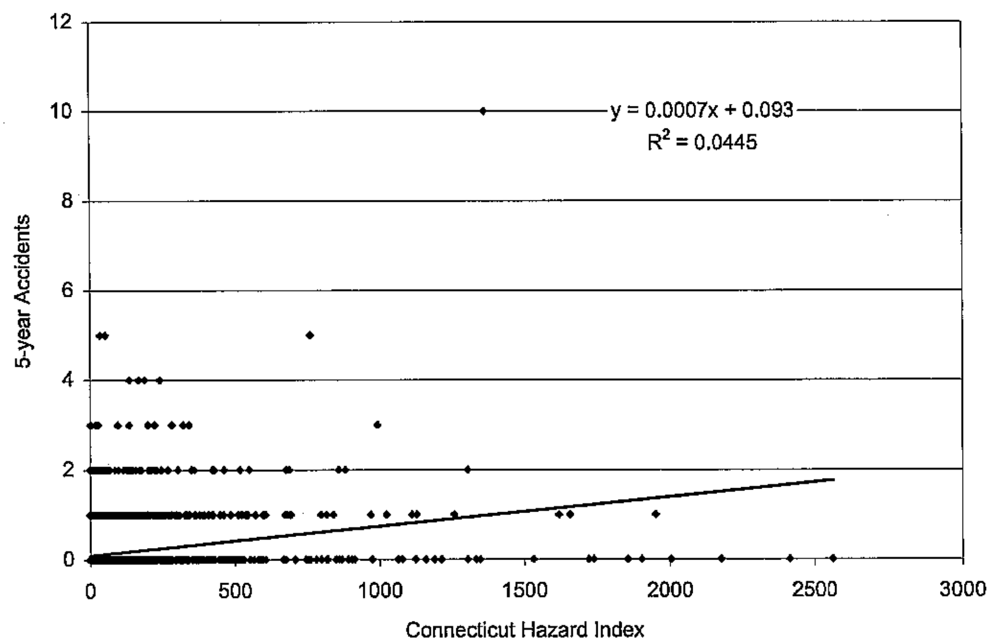


Figure 6.5-A Relation between Connecticut HI and number of crashes (1993-1997) for 6,423 locations.

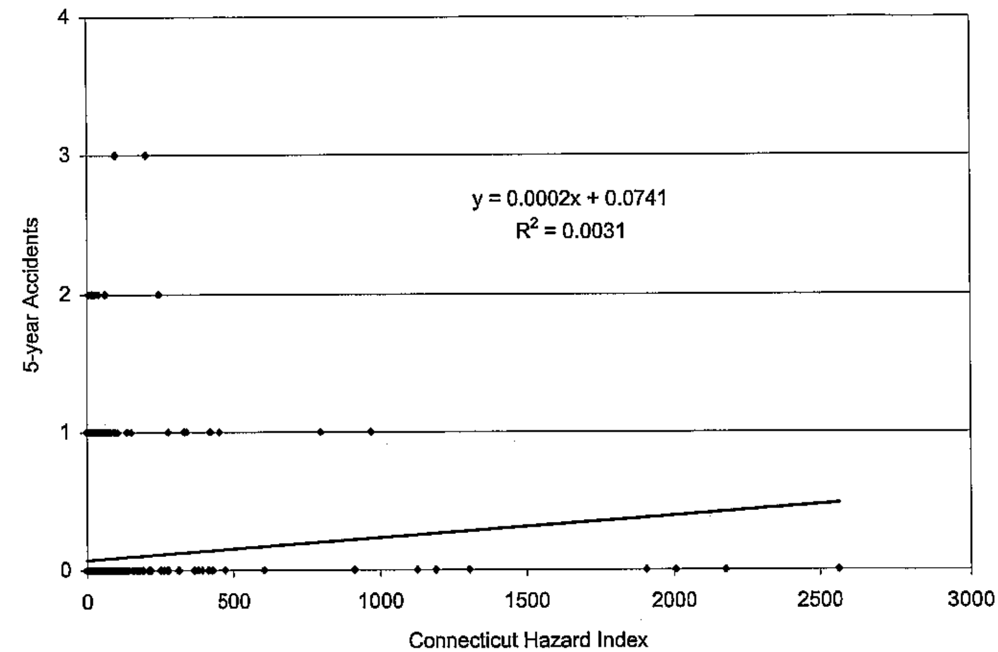


Figure 6.5-B. Relation between Connecticut HI and number of crashes (1993-1997) for crossings marked with crossbucks.

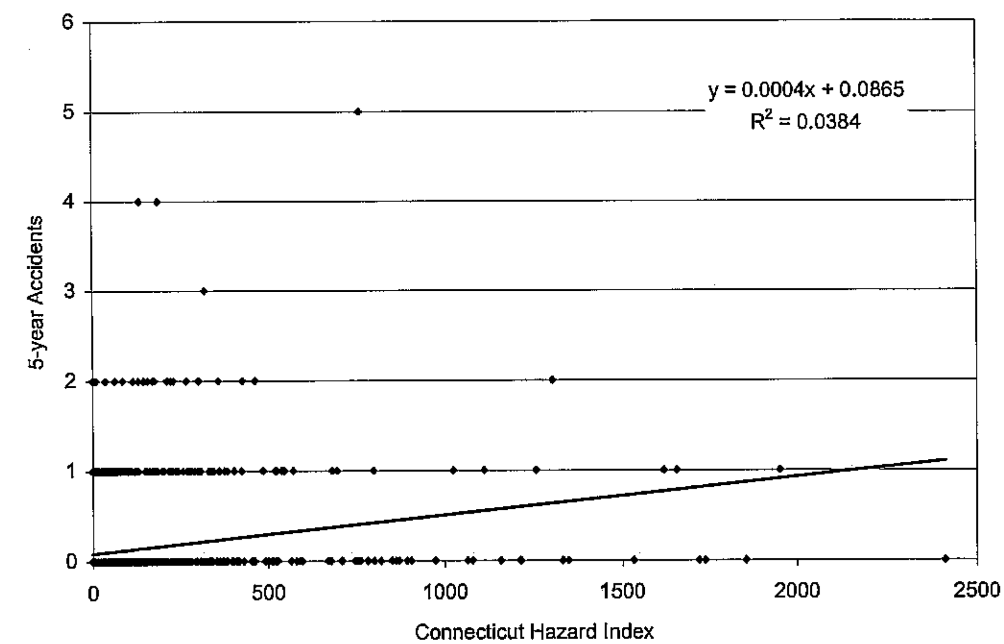


Figure 6.5-C. Relation between Connecticut HI and number of crashes (1993-1997) for crossings marked with flashing lights.

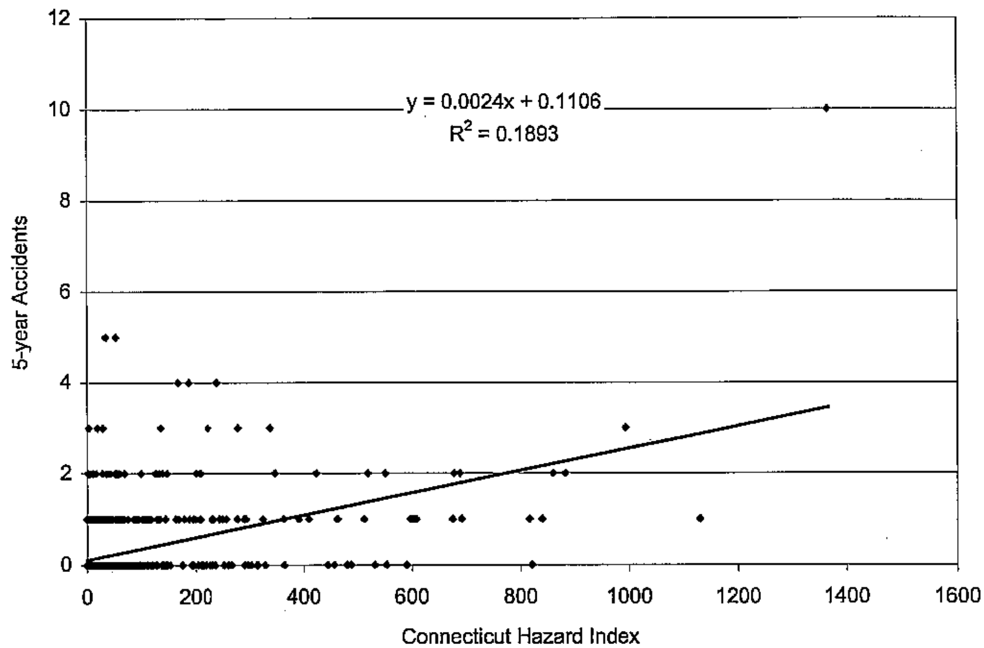


Figure 6.5-D. Relation between Connecticut HI and number of crashes (1993-1997) for crossings marked with gates.

New Hampshire Index Formula used by Michigan

Michigan DOT uses the New Hampshire Index Formula. The index is computed as follows:

$$HI = V \times T \times PF$$

Where:

V = AADT, Annual average daily traffic

T = Average daily train traffic

PF = Protection Factor and can be determined from Table 6.11.

Table 6.11. Protection Factor for Michigan New Hampshire Index Formula

PF	Devices
1.00	Reflectorized Crossbuck with or without a Yield Sign
0.30	Flashing-Light Signals
0.27	Flashing-Light Signals with cantilever Arms
0.24	Flashing-Light Signals with cantilever Arms and traffic Signal Interconnect
0.11	Flashing-Light Signals with Half-Roadway Gates
0.08	Flashing-Light Signals with Cantilever Arms and Half-roadway Gates
0.05	Flashing-Light Signals with Cantilever Arms, Half-Roadway Gates, and Traffic Signal Interconnection
The addition of warranted motion sensor or predictor circuitry further reduces the protection factor by 0.02	

This formula also computes a hazard index as a surrogate for the number of crashes. The highest priority is assigned to the crossing with the highest calculated index. The formula uses the same input used by IDOT EAF formula. Table 6.12-A to 6.12-D and Figures 6.6-A to 6.6-D were prepared to evaluate the reliability of the formula and to compare Michigan NHI to IDOT EAF formula.

As shown in Table 6.12-A, among the top 200 locations suggested by Michigan NHI formula only 80 locations were found to have crash history. Those crossings had 127 crashes. Thus, Michigan NHI formula is more or less comparable to IDOT EAF formula. Among the top 75 locations suggested by NHI formula, only 37 crossings were found to have crash history. In contrast, among the top 75 locations suggested by IDOT EAF formula, 42 crossings were found to have crash history. The average number of crashes per crossings identified by Michigan NHI was 54/37 = 1.46. On the other hand, the average number of crashes per crossings identified by IDOT EAF formula was 68/42= 1.62. This trend is reversed when the top 75 locations marked with flashing lights were considered. In this case, the average number of crashes per crossings identified by Michigan NHI was 24/18= 1.33 whereas the rate identified by IDOT EAF was 21/18 =1.17.

Figures 6.6-A to 6.6-D show that there is not much difference between the capability of the Michigan NHI and IDOT EAF formulas in identifying the crossings with the highest crash history. The coefficients of determination (R^2) for the regression lines between Michigan NHI predicted and observed number of crashes were 0.2, 2.2, 9.5 and 6.3% for crossings marked with crossbucks, flashing lights, gates, and all crossings combined, respectively. The corresponding R^2 value when using IDOT formula were 0.3, 2.3, 10.6 and 6.7%.

Table 6.12-A. Evaluation of Michigan NHI Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest NHI	% of crossings w/acc captured by NHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest NHI	% of acc captured by NHI
200	80	40%	332	127	38%
100	50	50%	232	82	35%
75	37	49%	188	54	29%
50	26	52%	138	37	27%
25	13	52%	88	14	16%

Table 6.12-B. Evaluation of Michigan NHI model using Crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest NHI	% of crossings w/acc captured by NHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest NHI	% of acc captured by NHI
100	17	17%	121	22	18%
75	15	20%	96	20	21%
50	12	24%	71	15	21%
25	5	20%	46	5	11%

Table 6.12-C. Evaluation of Michigan NHI model using Crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest NHI	% of crossings w/acc captured by NHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest NHI	% of acc captured by NHI
100	25	25%	136	32	24%
75	18	24%	111	24	22%
50	12	24%	86	14	16%
25	6	24%	58	7	12%

Table 6.12-D. Evaluation of Michigan NHI model using Crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest NHI	% of crossings w/acc captured by NHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest NHI	% of acc captured by NHI
100	51	51%	175	83	47%
75	43	57%	150	72	48%
50	28	56%	125	41	33%
25	13	52%	78	14	18%

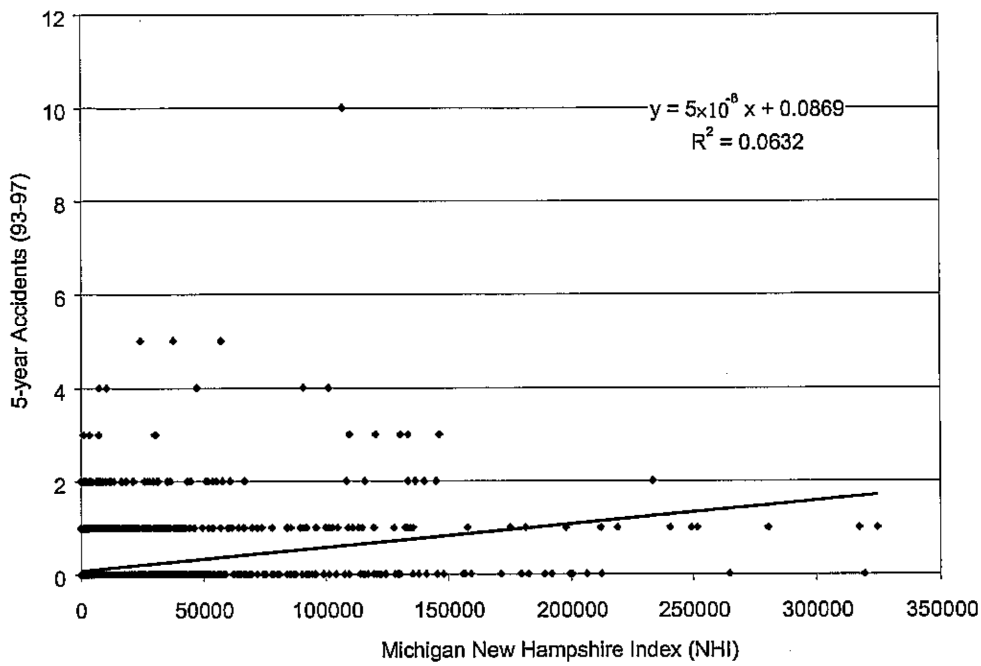


Figure 6.6-A. Relation between NHI and number of crashes for 6,423 locations.

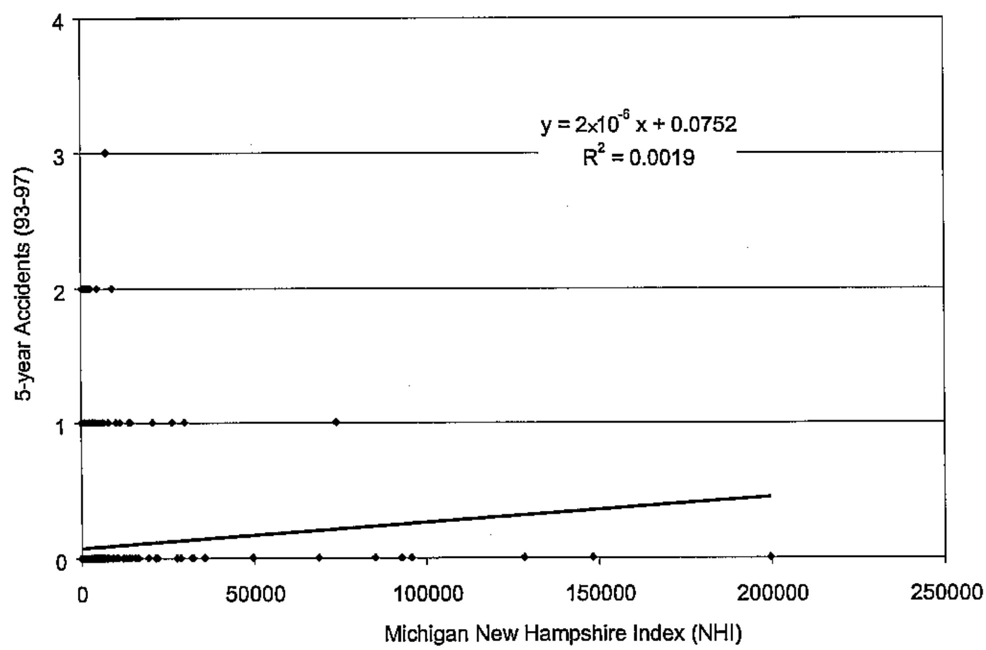


Figure 6.6-B. Relation between NHI and number of crashes for crossings marked with crossbucks.

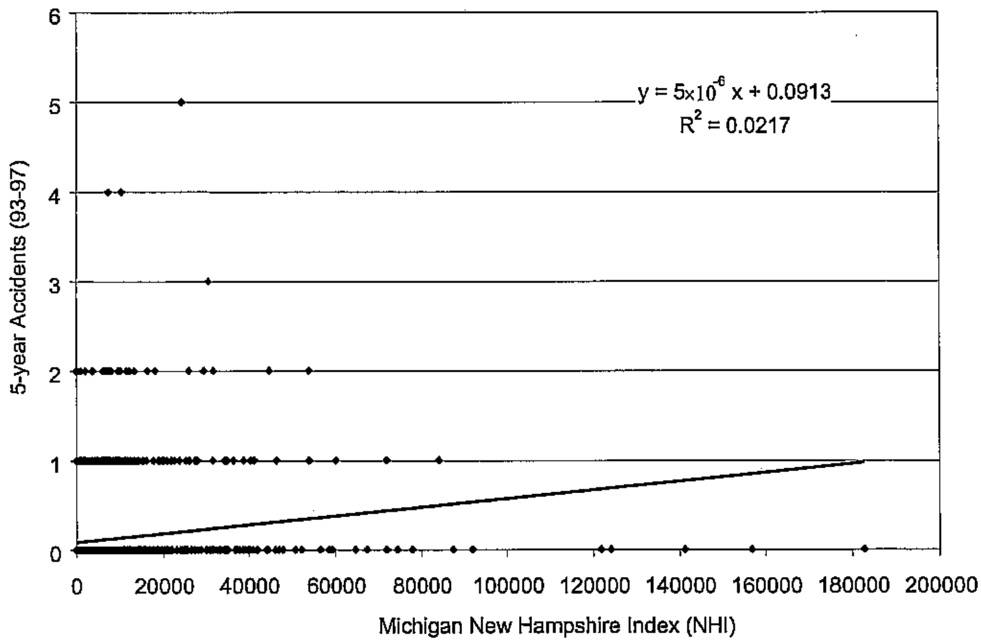


Figure 6.6-C. Relation between NHI and number of crashes for crossings with flashing lights.

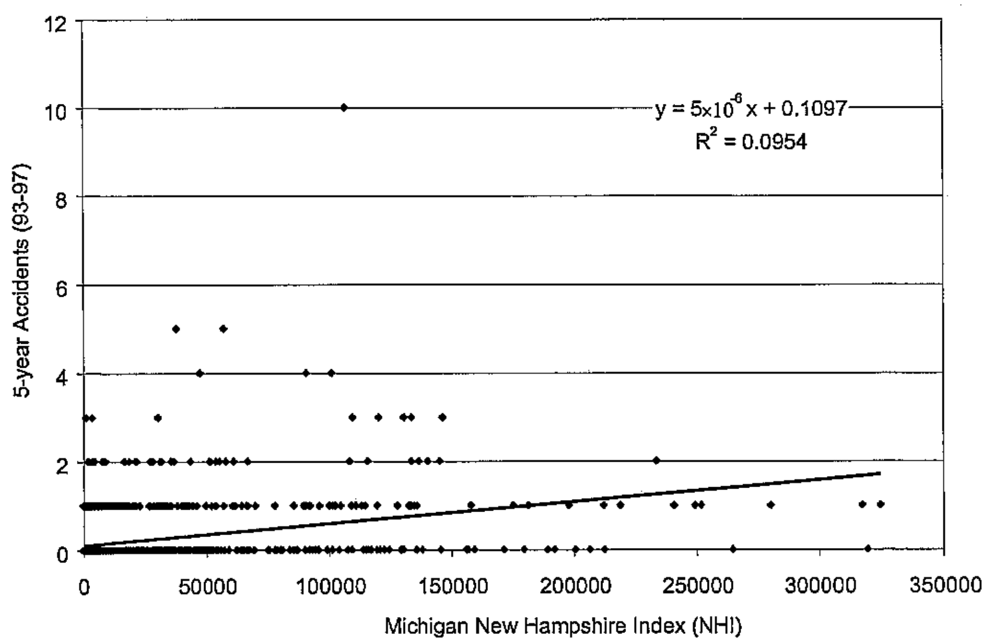


Figure 6.6-D. Relation between NHI and number of crashes for gated crossings.

California Hazard Index Formula

All the project nominations in the State of California are subject to the following Hazard Index Formula.

$$HI = \frac{V \times T \times PF}{1000} + AH$$

Where:

V = number of vehicles
T = Number of trains
PF = warning signal factor, 1.0 for warning devices No.1 (STOP sign or Crossbuck), 0.33 for warning devices No.8 (Flashing Lights) and 0.13 for warning devices No.9 (Gates).
AH = crash history =Total number of Crashes within the last ten years $\times$ 3

Similar to the Connecticut and Michigan formulas, this formula does not compute number of crashes. It produces a hazard index as a surrogate for the number of crashes. The highest priority is assigned to the crossing with the highest calculated index.

In addition to the variables used as input in IDOT EAF formula, this formula also uses the crash history. Thus, this formula is similar to Connecticut formula except that Connecticut formula requires the use of five-year crash history whereas California requires the use of ten-year crash history. In addition, California HI (CAHI) formula uses a gate PF that is much higher than the corresponding value used by Connecticut (0.13 vs. 0.01).

California HI requires the number of crashes in 10 years as an input to the model. The crash data available for this study is for ten years only. Thus we can't make direct comparison between CAHI and others that use 5-year data as input. Nevertheless, tables of percentage of crossings with crash captured by the formula were created for the sake of comparison. Tables 6.13-A to 6.13-D seem to show that CAHI performs better than IDOT EAF. This conclusion is inaccurate due to the fact that the crash data used for computation of CAHI is the same data used for evaluation. Even though the crash data was used twice, Figure 6.7 shows that the regression line between observed number of crashes and CAHI has a coefficient of determination R^2 of only 10%; indicating a weak correlation.

Table 6.13-A. Evaluation of CAHI Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CAHI	% of crossings w/acc captured by CAHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CAHI	% of acc captured by CAHI
200	89	45%	332	139	42%
100	53	53%	232	86	37%
75	41	55%	188	67	36%
50	32	64%	138	56	41%
25	17	68%	88	34	39%

Table 6.13-B. Evaluation of California model using Crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CAHI	% of crossings w/acc captured by CAHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CAHI	% of acc captured by CAHI
100	39	39%	121	55	45%
75	28	37%	96	37	39%
50	17	34%	71	24	34%
25	9	36%	46	12	26%

Table 6.13-C. Evaluation of California model using Crossings marked with **Flashing Lights**.

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CAHI	% of crossings w/acc captured by CAHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CAHI	% of acc captured by CAHI
100	30	30%	136	41	30%
75	20	27%	111	30	27%
50	16	32%	86	25	29%
25	8	32%	58	10	17%

Table 6.13-D. Evaluation of California model using Crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest CAHI	% of crossings w/acc captured by CAHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest CAHI	% of acc captured by CAHI
100	54	54%	175	87	50%
75	43	57%	150	69	46%
50	33	66%	125	57	46%
25	17	68%	78	34	44%

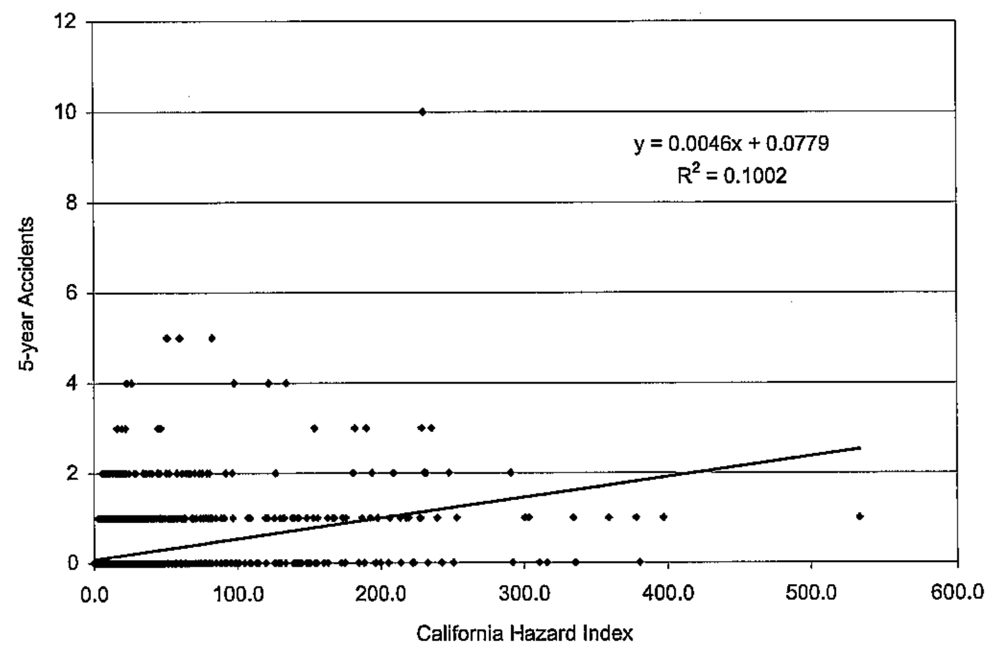


Figure 6.7. Relation between CAHI and 5-year crashes (93-97).

USDOT Accident Prediction Model

The USDOT accident prediction model calculates the expected annual number of crashes at a crossing using three formulas:

- A basic formula that contains geometric and traffic factors from the inventory file.
- A formula that involves crash history.
- A formula that incorporates the effect of the existing warning devices.

The basic formula was developed using a nonlinear regression analysis.

$$a = K \times EI \times DT \times MS \times MT \times HP \times HL$$

where:

a = unnormalized initial crash prediction, in crashes per year at the crossing
K = formula constant
EI = factor for exposure index based on product of highway and train traffic
DT = factor for number of through trains per day during daylight
MS = factor for maximum timetable speed
MT = factor for number of main tracks
HP = factor for highway paved (yes or no)
HL = factor for number of highway lanes

Three sets of equations are used to determine the value of each factor, one for each of the following three categories of warning devices:

Crossing Category	Formula Constant	Exposure Index Factor	Day Through Trains Factor	Maximum Timetable Speed Factor	Main Tracks Factor	Highway Paved Factor	Highway Lanes Factor
	K	EI	DT	MS	MT	HP	HL
Passive	0.0006938	$((c \times t+0.2)/0.2)^{0.37}$	$((d+0.2)/0.2)^{0.178}$	$e^{0.0077ms}$	1.0	$e^{-0.5966(hp-1)}$	1.0
Flashing	0.0003351	$((c \times t+0.2)/0.2)^{0.4106}$	$((d+0.2)/0.2)^{0.1131}$	1.0	$e^{0.1917mt}$	1.0	$e^{0.1826(hl-1)}$
Gates	0.0005745	$((c \times t+0.2)/0.2)^{0.2942}$	$((d+0.2)/0.2)^{0.1781}$	1.0	$e^{0.1512mt}$	1.0	$e^{0.1420(hl-1)}$

Where:

c = number of highway vehicles per day
t = number of trains per day
mt = number of main tracks
d = number of through trains per day during daylight
hp = highway paved? yes = 1.0 and no =2.0
ms = maximum timetable speed, mph
hl = number of highway lanes

The general DOT accident prediction formula can be expressed as follows:

$$B = [To (a)/(To + T)] + [T/(To + T)](N/T)$$

According to the 1992 normalizing constants, the final crash prediction is computed as

$$A = .8239 \times B \text{ for Passive}$$
$$A = .6935 \times B \text{ for Flashing lights}$$
$$A = .6714 \times B \text{ for Gates}$$

where:

A = final accident prediction, crashes per year at the crossing,
a = initial unnormalized accident prediction from basic formula, crashes per year
N = observed crashes in T years at the crossing
T = number of years of recorded crash data
To = formula weighting factor 1.0 /(0.05 + a).

Since pavement data are not included in the DOT crossing inventory, It was assumed that if the road is one-lane local in rural area with ADT less than 100 vehicle/day, then it is not paved. Otherwise, the road is paved and the hp factor is set to one in USDOT model. The research team also used the crash history (1988-1992) as input to USDOT formula to forecast the crashes for the next five-year period 1993-1997. The results were compared to the actual recorded number of crashes as shown in Table 6.14-A to 6.14-D and Figure 6.8-A to Figure 6.8-D.

Table 6.14-A shows that among the top 200 locations suggested for improvement by USDOT formula, 89 locations were found to have crash history. Those locations had 137 crashes. Thus, on average the number of crashes per crossings identified by USDOT formula was 137/89= 1.54. This rate is comparable to 1.56 crashes/crossings identified by IDOT formula. However, USDOT formula captures a higher number of hazardous crossings than IDOT formula does (89 vs. 84). In addition, the regression lines between observed number of crashes and USDOT predicted number of crashes have a higher R^2 (13.6% vs 6.7% for all crossings, 2.1% vs. 0.3% for crossbucks, 8% vs 2.3% for flashing lights and 20.8% vs 10.6% for gates).

Table 6.14-A. Evaluation of A Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest A	% of crossings w/acc captured by A	Total No of acc in top N locations w/acc	No of acc in top N locations with highest A	% of acc captured by A
200	89	45%	332	137	41%
100	53	53%	232	87	38%
75	43	57%	188	68	36%
50	32	64%	138	55	40%
25	18	72%	88	37	42%

Table 6.14-B. Evaluation of USDOT model using Crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest A	% of crossings w/acc captured by A	Total No of acc in top N locations w/acc	No of acc in top N locations with highest A	% of acc captured by A
100	16	16%	121	19	16%
75	14	19%	96	17	18%
50	10	20%	71	13	18%
25	7	28%	46	8	17%

Table 6.14-C. Evaluation of USDOT model using Crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest A	% of crossings w/acc captured by A	Total No of acc in top N locations w/acc	No of acc in top N locations with highest A	% of acc captured by A
100	33	33%	136	40	29%
75	26	35%	111	32	29%
50	17	34%	86	23	27%
25	10	40%	58	10	17%

Table 6.14-D. Evaluation of USDOT model using Crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest A	% of crossings w/acc captured by A	Total No of acc in top N locations w/acc	No of acc in top N locations with highest A	% of acc captured by A
100	54	54%	175	92	53%
75	44	59%	150	74	49%
50	32	64%	125	57	46%
25	18	72%	78	40	51%

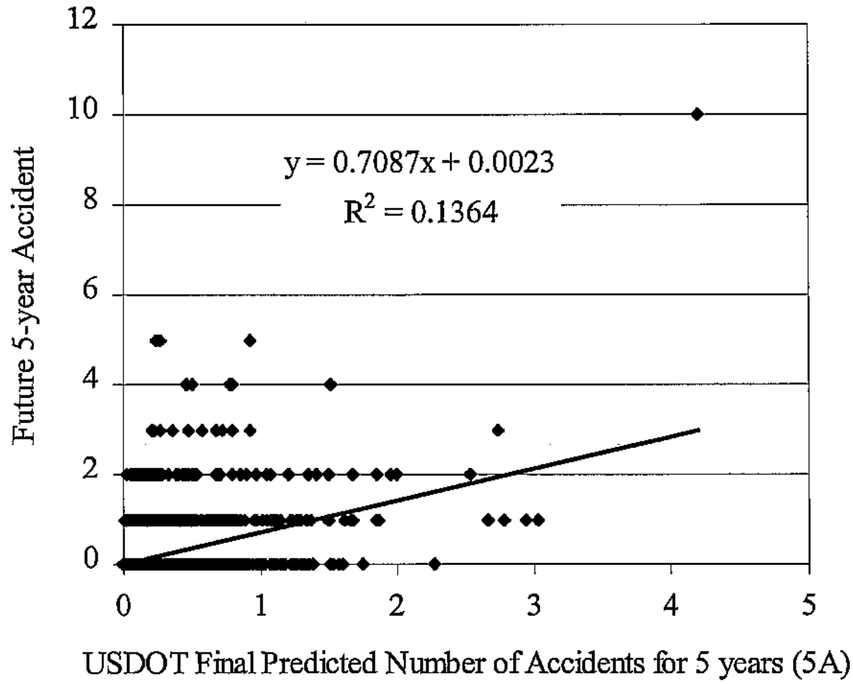


Figure 6.8-A. Relation between A and next 5-year crashes for the entire 6,423 locations.

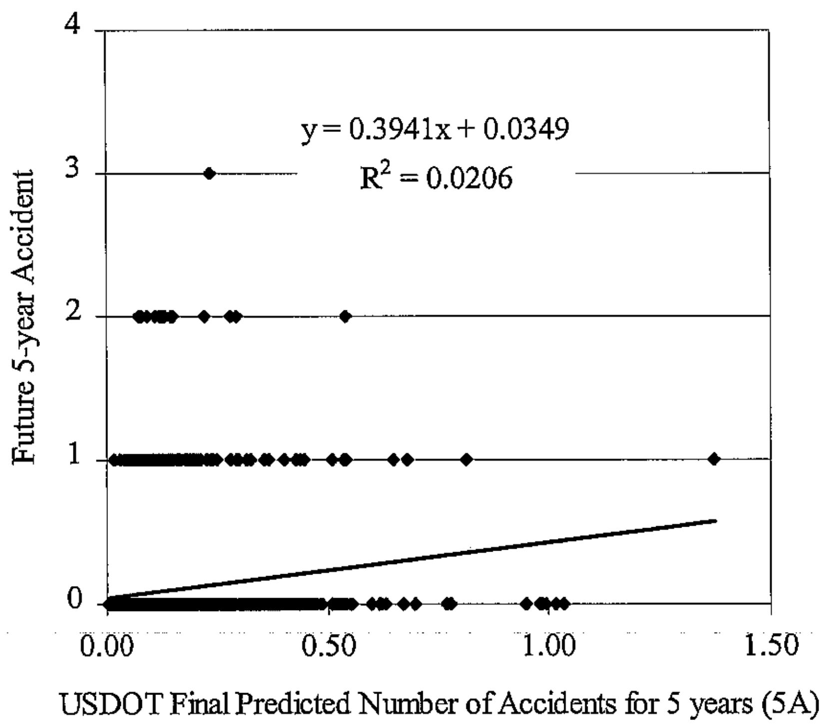


Figure 6.8-B. Relation between 5 A and next 5-year crashes for crossings marked with crossbucks.

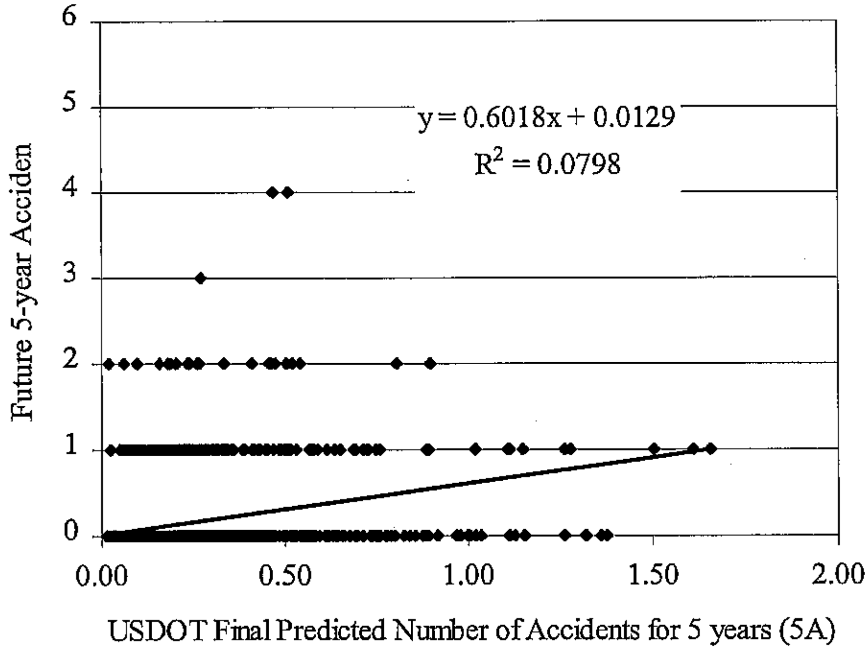


Figure 6.8-C. Relation between 5 A and next 5-year crashes for crossings marked by flashing lights.

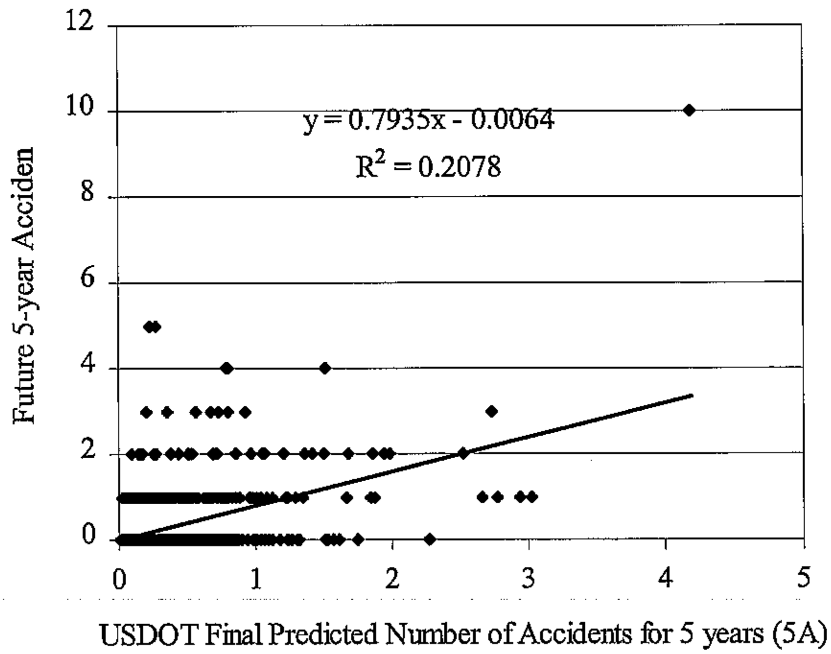


Figure 6.8-D. Relation between 5 A and next 5-year crashes for gated locations.

7. SUGGESTED FORMULAS FOR ESTABLISHING A PRIORITY LIST FOR RAILROAD GRADE CROSSINGS IN ILLINOIS

The previous section showed that IDOT EAF formula and 4 other selected formulas did not produce a strong correlation between crashes and related variables. The research team made several attempts to develop a crash prediction formula using simple and multiple linear regression techniques using the Statistical Analysis System (SAS). In this study, ten-year crash history (1988-1997) and inventory data for 6423 railroad grade crossings were used to develop a new formula. The three basic algorithms for selecting a subset of variables for use in the formula: Backward Elimination (BE), Forward Selection (FS) and Stepwise (SW) were explored. Since linear regression cannot be expected to be appropriate for all problems, nonlinear regression technique was also used. The single most important tool in selecting a subset of variables for use in a model is the analyst's knowledge of the broad area under study and of each of the variables, including expected sign and magnitude of the coefficient. In the following sections, only the most successful attempts to model the relationship between number of crashes and other geometric and traffic variables are reviewed.

The probability of crash at a rail grade crossing may depend on:

- The number of trains (NTT) and vehicles (ADT) that are in conflict at the crossing.
- Train speed (MTS).
- The number of tracks and lanes.
- Warning devices
- Crash history.

The aforementioned variables and non-linear regression technique were used to develop a new hazard index for Illinois. Four potential models were evaluated

1. (WLOG WOACC POWER): A model that includes Ln(ADT×NTT) and the number of crashes is raised to a power of one
2. (WLOG WACC POWER): A model that includes Ln(ADT×NTT) and the number of crashes is raised to a given power.
3. (WOLOG WOACC POWER): A model that includes (ADT×NTT) and the number of crashes is raised to a power of one.

4. (WOLOG WACC POWER): A model that includes (ADT×NTT) and the number of crashes is raised to a given power.

The following sections describe and evaluate each model using the evaluation criteria describe in an earlier section.

1. Illinois Hazard Index (IHI) WLOG WOACC POWER

Similar to Connecticut, New Hampshire and California formulas, our suggested formula computes a hazard index as a surrogate for the number of crashes. The formula was developed using the nonlinear regression analysis procedure in SAS.

$$IHI = 10^{-6} \times A^{3.14816} \times B^{0.26019} \times C^{-0.02405} \times D^{0.45467} \times (18.76 \times N + PF)$$

Where

A	= ln (ADT×NTT)
B	= MTS, Maximum Timetable Speed, mph
C	= (NMT+NOOT), number of main and other tracks
D	= NOL, number of lanes
N	= Average number of crashes per year = AC8892/5
PF	= Protection Factor; 3.31 for Gates, 5.62 for Flashing Lights, 12.00 for Crossbucks
ADT	= Average Daily Traffic
NTT	= Number of Total Trains per day

Table 7.1-A to 7.1-D and Figure 7.1-A to 7.1-D were created to evaluate the suggested formula and to compare the results to IDOT EAF formula using the evaluation criteria set earlier. Comparison of Table 7.1-A and Table 6.6-A reveals that whether we considered the top 25, 50, 75, 100 or 200 locations suggested by each formula, the numbers of the hazardous locations identified by IHI are higher than the numbers identified by IDOT EAF. For example, among the top 25 locations suggested by IHI, 20 locations found to have crash history (41 crashes) over five years. On the other hand IDOT EAF identified only 16 locations with crash history (21 crashes). Thus, IHI formula picked locations with higher crash rate (41/20= 2.05 crashes/crossing versus 21/16=1.31 crashes/crossing when using IDOT EAF).

Figures 6.5-A to 6.5-D reveal that the relation between the observed number of crashes and IHI predicted number of crashes are stronger than the corresponding relation when using IDOT EAF to predict the number of crashes. This is because IHI provides higher R^2, slope closer to 1 and intercept near zero as shown in the following summary table:

Table 7.1. Comparison of the relation between observed number of crashes and IDOT EAF and IHI predicted number of crashes.

	IDOT EAF			IHI		
	R^2	Slope	Intercept	R^2	Slope	Intercept
All Crossings	6.65%	0.264	0.089	15.04%	1.001	0.000
Crossings marked with crossbucks	0.26%	0.111	0.074	3.28%	0.990	0.001
Crossings marked with flashing lights	2.33%	0.602	0.082	7.30%	1.097	-0.015
Crossings marked with gates	10.58%	0.255	0.108	22.47%	0.987	0.004

The table shows that not only the IHI regression lines show stronger correlation, but also they predict on average the right number of crashes (slope is almost one and intercept near zero).

The IHI model indicates that as the number of tracks increases the number of crash decreases. This seems contra-intuitive. To clarify this point, let us assume a train volume of 100 T/day. Thus, there are 100 events that may lead to a crash. Due to having multiple tracks, some trains may arrive simultaneously which reduces the number of events that may lead to a crash. On the other hand, if trains won't arrive simultaneously, a buffer zone is provided downstream the warning device location for the motorist coming towards the unoccupied tracks. If the motorist is not able to stop before the track, the buffer zone will reduce the possibility of a crash and may enable the motorist to secure a safe stop before hitting the train on the far track. However, this explanation needs to be evaluated with crash data collected from crossings with single and multiple tracks that have similar traffic characteristics (train and traffic volume).

In an effort to develop a formula that includes the variables identified earlier as contributing factors and at the same time shows expected sign of the track coefficient, the research team introduced the model described in the next paragraph.

Table7.2-A. Evaluation of IHI WLOG WOACC POWER based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
200	88	44%	332	134	40%
100	54	54%	232	91	39%
75	45	60%	188	76	40%
50	32	64%	138	57	41%
25	20	80%	88	41	47%

Table7.2-B. Evaluation of IHI WLOG WOACC POWER using crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	20	20%	121	26	21%
75	13	17%	96	18	19%
50	9	18%	71	12	17%
25	5	20%	46	6	13%

Table7.2-C. Evaluation of IHI WLOG WOACC POWER using crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	31	31%	136	39	29%
75	22	29%	111	28	25%
50	16	32%	86	18	21%
25	10	40%	58	12	21%

Table7.2-D. Evaluation of IHI WLOG WOACC POWER using crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	52	52%	175	90	51%
75	44	59%	150	81	54%
50	32	64%	125	59	47%
25	20	80%	78	41	53%

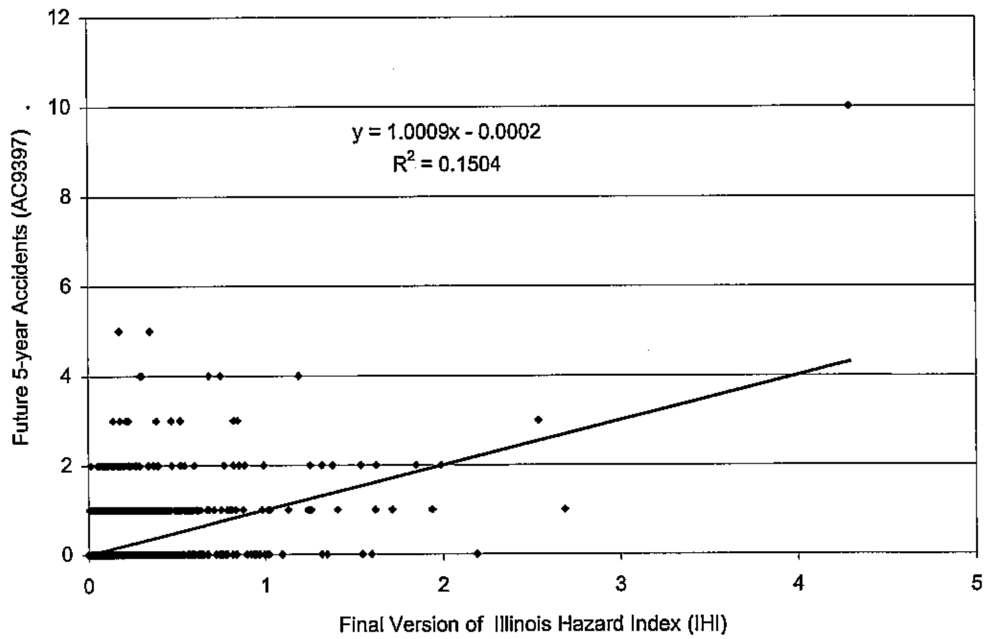


Figure 7.1-A. Relation between IHI and next 5-year crashes for the entire 6,423 locations_ WLOG WOACC POWER.

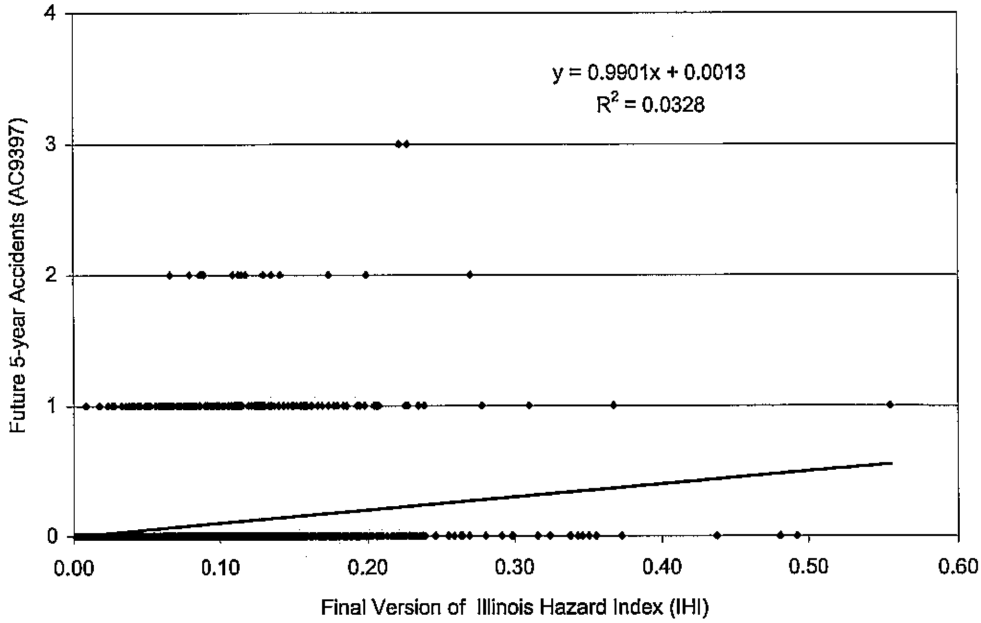


Figure 7.1-B. Relation between IHI and next 5-year crashes for the crossings marked with crossbucks_ WLOG WOACC POWER.

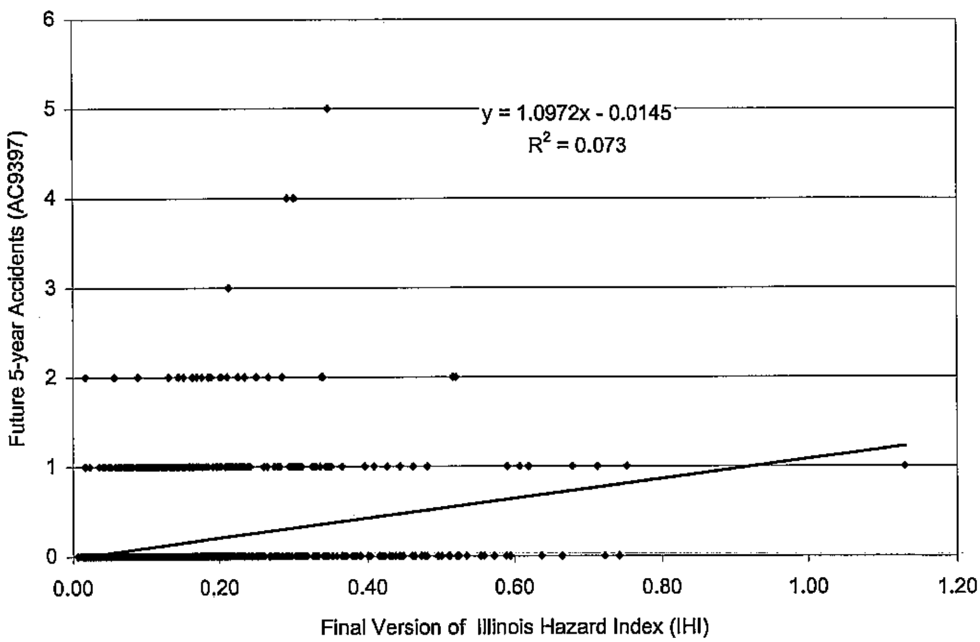


Figure 7.1-C. Relation between IHI and next 5-year crashes for crossings marked with flashing Lights_ WLOG WOACC POWER.

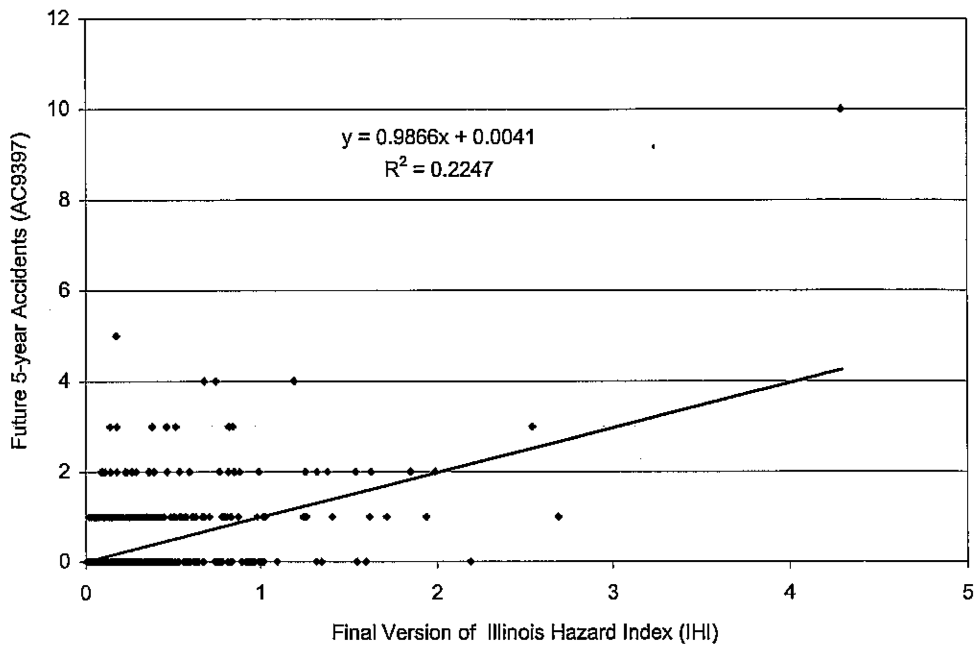


Figure 7.1-D. Relation between IHI and next 5-year crashes for the gated locations WLOG WOACC POWER.

2. Illinois Hazard Index (IHI) WLOG WACC POWER

The model presented here overcomes the issue with the first model. In addition, this model emphasizes the importance of the crash history by assigning a power to the number of crashes.

$$IHI = 10^{-6} \times A^{2.59088} \times B^{0.09673} \times C^{0.40227} \times D^{0.59262} \times (15.59 \times N^{5.60977} + PF)$$

A = ln (ADT×NTT)
B = MTS, Maximum Timetable Speed, mph
C = (NMT+NOOT)
D = NOL
N = Average number of crashes per year = AC8892/5
PF = Protection Factor; 37.57 for Gates, 68.97 for Flashing Lights, 86.39 for Crossbucks
ADT = Average Daily Traffic
NTT = Number of Total Trains per day

Tables 7.3-A to 7.3-D and Figures 7.2-A to 7.2-D were created for evaluation and comparison. Overall, the predicted numbers of hazardous crossings identified by this model are somewhat lower than the numbers predicted by the previously suggested IHI model. On the other hand, this model has a slightly higher R^2 (16.19% vs 15.04%).

Table7.3-A. Evaluation of IHI WLOG WACC POWER Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
200	88	44%	332	131	39%
100	48	48%	232	83	36%
75	40	53%	188	72	38%
50	30	60%	138	58	42%
25	19	76%	88	36	41%

Table7.3-B. Evaluation of IHI WLOG WACC POWER using crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	18	18%	121	24	20%
75	11	15%	96	14	15%
50	8	16%	71	11	15%
25	4	16%	46	4	9%

Table7.3-C. Evaluation of IHI WLOG WACC POWER using crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	29	29%	136	36	26%
75	23	31%	111	29	26%
50	16	32%	86	20	23%
25	7	28%	58	9	16%

Table7.3-D. Evaluation of IHI WLOG WACC POWER using crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	49	49%	175	83	47%
75	40	53%	150	72	48%
50	30	60%	125	58	46%
25	19	76%	78	36	46%

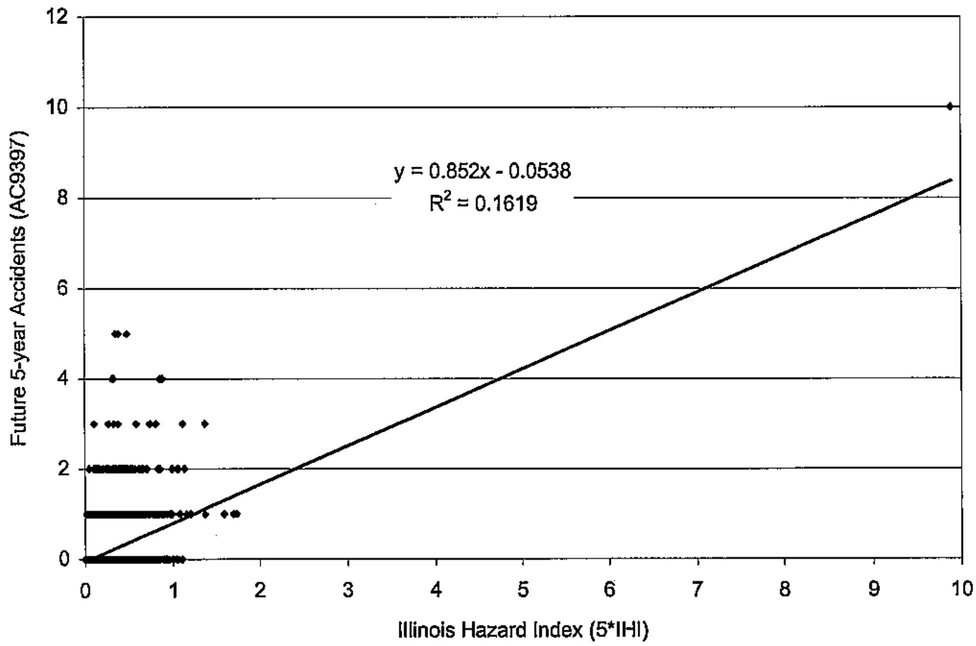


Figure 7.2-A. Relation between 5 IHI and next 5-year crashes for the entire 6,423 locations_ WLOG WACC POWER.

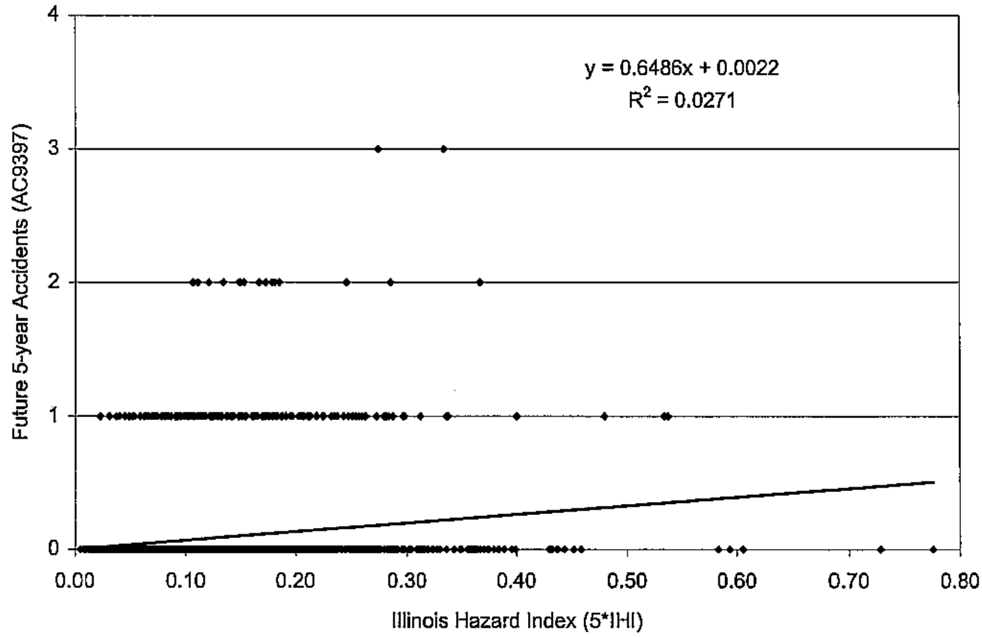


Figure 7.2-B. Relation between 5 IHI and next 5-year crashes for locations marked by crossbucks_ WLOG WACC POWER.

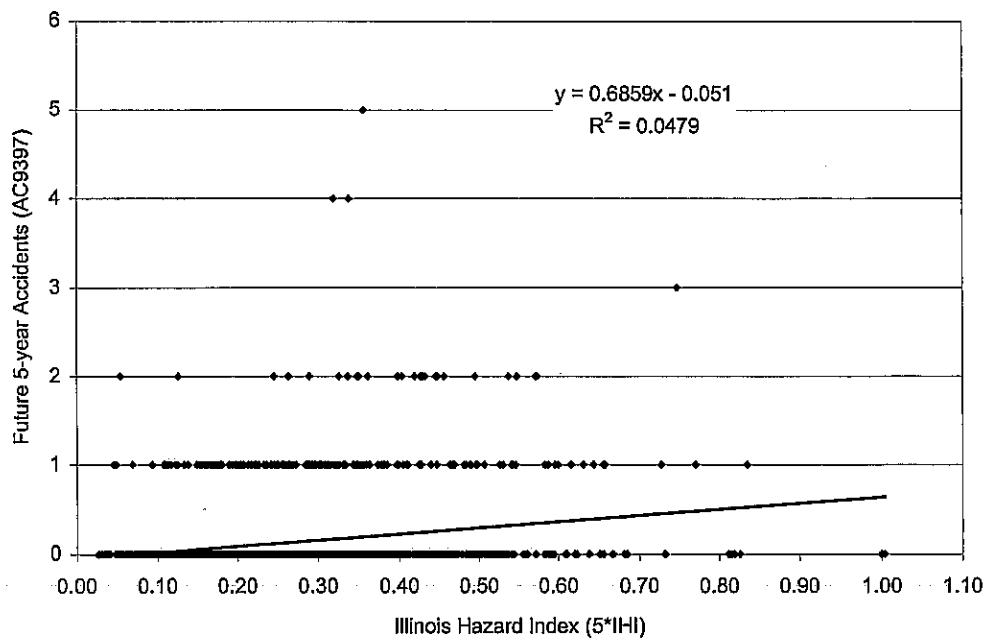


Figure 7.2-C. Relation between 5 IHI and next 5-year crashes for locations marked by flashing lights_ WLOG WACC POWER.

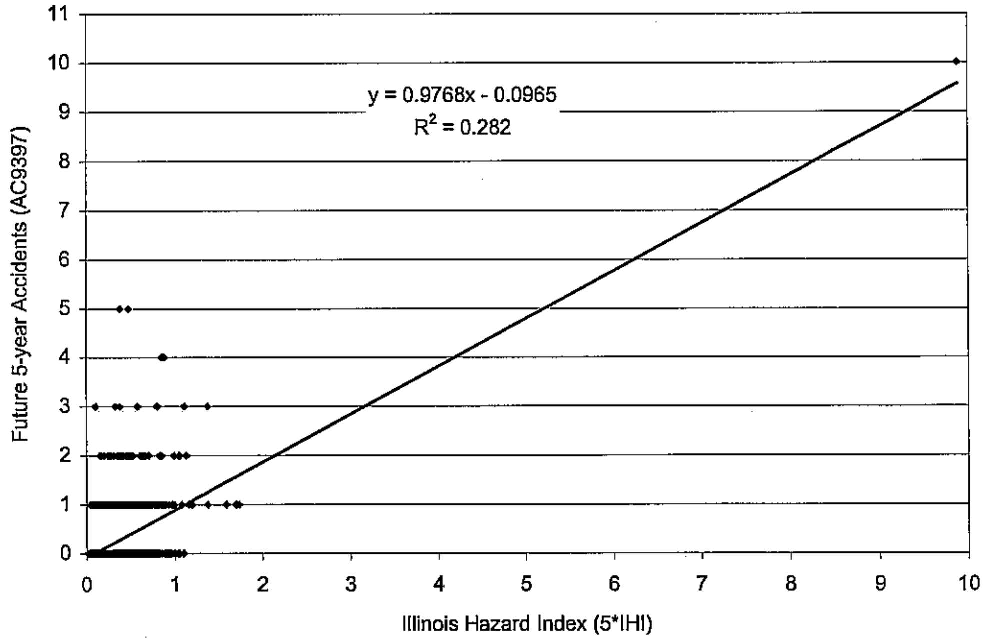


Figure 7.2-D. Relation between 5 IHI and next 5-year crashes for locations marked by gates_ WLOG WACC POWER.

3. Illinois Hazard Index (IHI): WO_LOG_WO_ACC_POWER

In an attempt to reduce the computational steps involved, the research team tried to model the relation between the hazard index and the observed number of crashes without the need to compute the natural logarithm of the cross product of ADT and NTT first. Rather, the cross product was used. The resulting formula was

$$IHI = 10^{-4} \times A^{0.29908} \times B^{0.25536} \times C^{-0.06936} \times D^{0.40088} \times (13.27 \times N + PF)$$

A = (ADT×NTT), cross product of Average Daily Traffic and Number of Total Trains
B = MTS, Maximum Timetable Speed, mph
C = (NMT+NOOT), number of tracks
D = NOL, number of highway lanes
N = Average number of crashes per year = AC8892/5
PF = Protection Factor; 2.46 for Gates, 4.15 for Flashing Lights, 7.32 for Crossbucks

The results as presented in Tables 7.4-A to 7.4-D and Figures 7.3-A to 7.3-D show comparable capabilities with the previous two IHI models. However, similar to the first model, a contra-intuitive sign appears next to the power assigned to the number of tracks.

Table7.4-A. Evaluation of the final version of IHI Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
200	90	45%	332	136	41%
100	55	55%	232	92	40%
75	45	60%	188	79	42%
50	32	64%	138	61	44%
25	20	80%	88	38	43%

Table7.4-B. Evaluation of IHI WOLOG WOACC POWER using crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	22	22%	121	28	23%
75	13	17%	96	18	19%
50	8	16%	71	11	15%
25	3	12%	46	3	7%

Table7.4-C. Evaluation of IHI WOLOG WOACC POWER using crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	33	33%	136	41	30%
75	22	29%	111	29	26%
50	16	32%	86	18	21%
25	10	40%	58	12	21%

Table7.4-D. Evaluation of IHI WOLOG WOACC POWER using crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	53	53%	175	91	52%
75	44	59%	150	78	52%
50	32	64%	125	61	49%
25	20	80%	78	38	49%

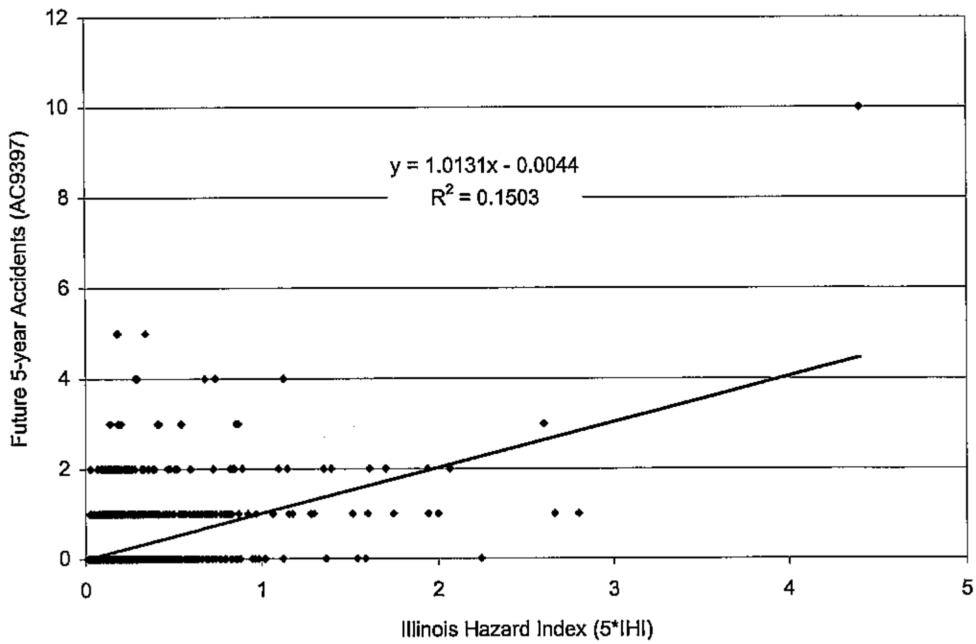


Figure 7.3-A. Relation between 5 IHI and next 5-year crashes for the entire 6,423 locations_ WOLOG WOACC POWER.

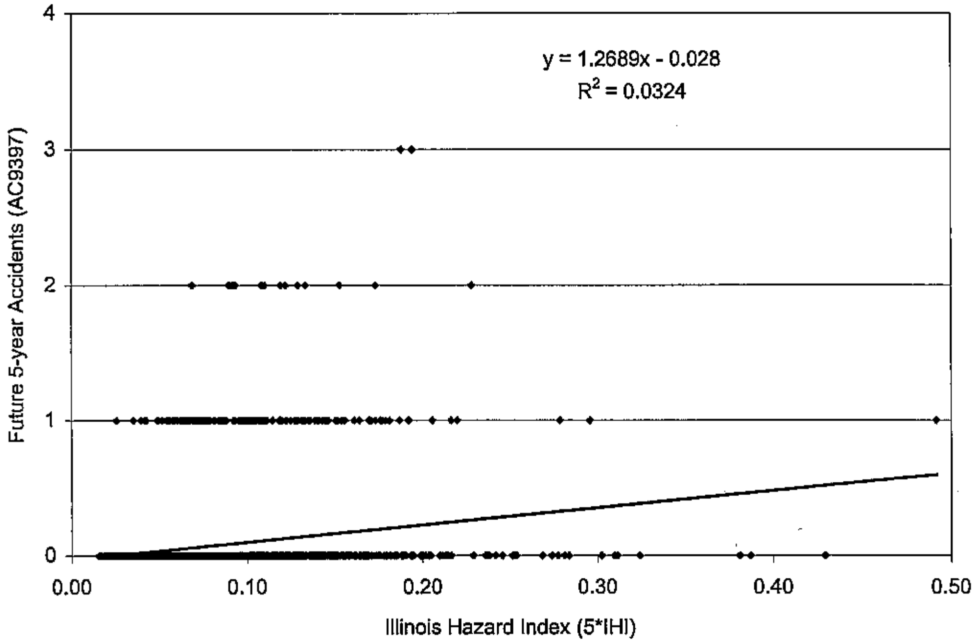


Figure 7.3-B. Relation between 5 IHI and next 5-year crashes for locations marked by crossbucks_ WOLOG WOACC POWER.

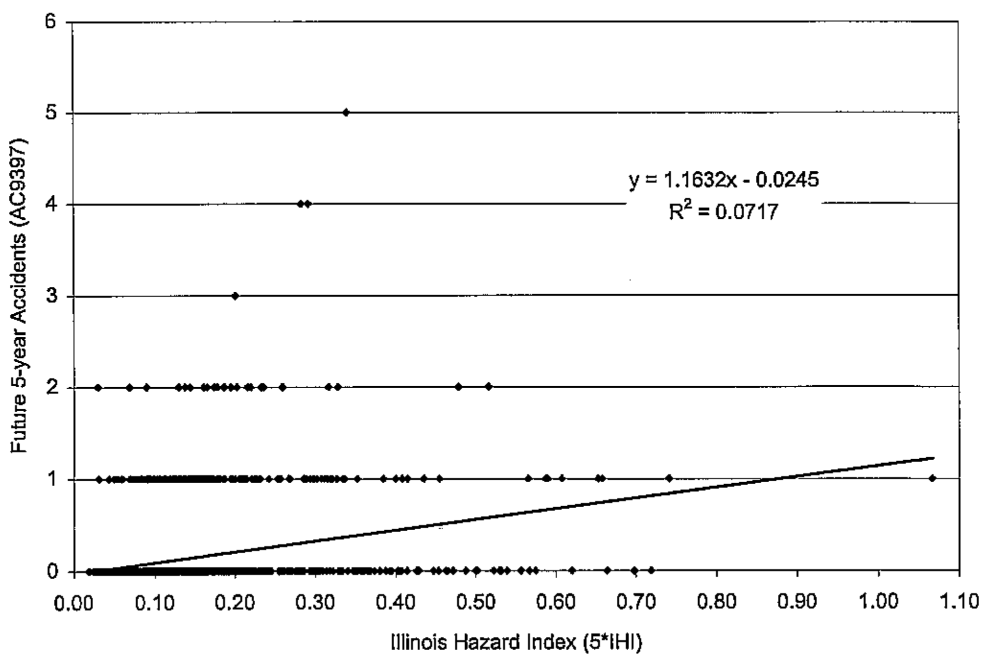


Figure 7.3-C. Relation between 5 IHI and next 5-year crashes for locations marked by flashing lights_ WOLOG WOACC POWER.

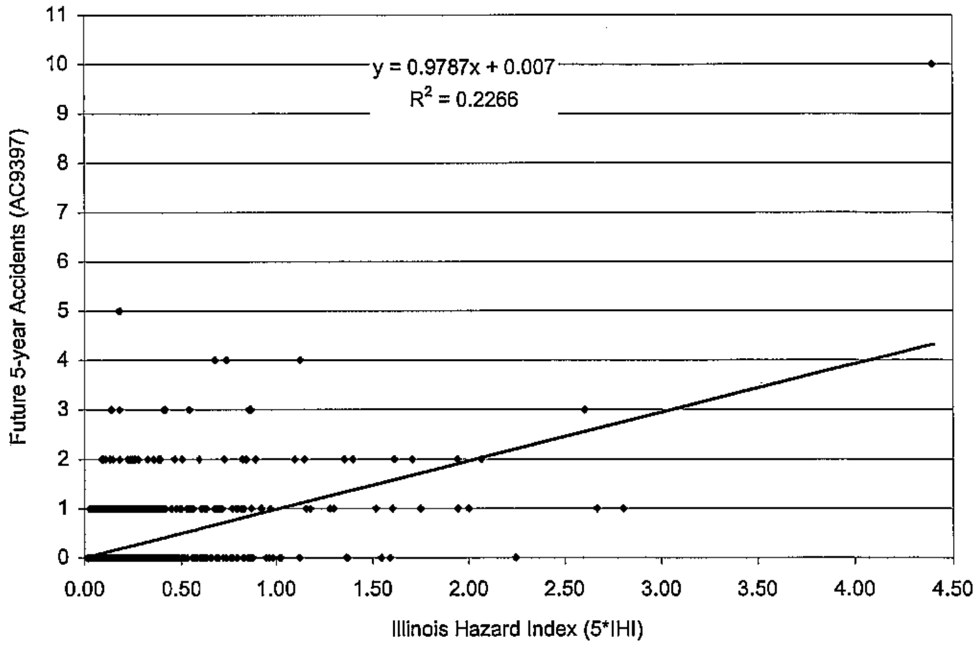


Figure 7.3-D. Relation between 5 IHI and next 5-year crashes for locations marked by gates_ WOLOG WOACC POWER.

4. Illinois Hazard Index (IHI): WO_LOG_W_ACC_POWER

This model is similar to the second suggested IHI model without the need to compute the natural logarithm of the cross product of ADT and NTT.

$$IHI = 10^{-4} \times A^{0.22767} \times B^{0.08989} \times C^{0.37378} \times D^{0.56092} \times (\, 6.26 \times N^{5.68546} + PF\,)$$

A = (ADT×NTT), cross product of Average Daily Traffic and Number of Total Trains
B = MTS, Maximum Timetable Speed, mph
C = (NMT+NOOT), number of tracks
D = NOL, number of highway lanes
N = Average number of crashes per year = AC8892/5
PF = Protection Factor; 16.12 for Gates, 29.40 for Flashing Lights, 30.06 for Crossbucks

The results as presented in Tables 7.5-A to 7.5-D and Figures 7.4-A to 7.4-D show more or less the same trend suggested by model no. 2.

Table7.5-A. Evaluation of the final version of IHI Based on 5-year crashes (ACC93-97).

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
200	89	45%	332	132	40%
100	50	50%	232	86	37%
75	41	55%	188	73	39%
50	29	58%	138	56	41%
25	19	76%	88	36	41%

Table7.5-B. Evaluation of IHI WOLOG WACC POWER using crossings marked with **Crossbucks.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	15	15%	121	19	16%
75	11	15%	96	14	15%
50	8	16%	71	11	15%
25	4	16%	46	4	9%

Table7.5-C. Evaluation of IHI WOLOG WACC POWER using crossings marked with **Flashing Lights.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	29	29%	136	36	26%
75	23	31%	111	29	26%
50	16	32%	86	20	23%
25	7	28%	58	9	16%

Table7.5-D. Evaluation of IHI WOLOG WACC POWER using crossings marked with **Gates.**

No. of crossings selected, N	No of Xings w/acc in top N locations with highest IHI	% of crossings w/acc captured by IHI	Total No of acc in top N locations w/acc	No of acc in top N locations with highest IHI	% of acc captured by IHI
100	50	50%	175	85	50%
75	42	56%	150	74	56%
50	31	62%	125	62	62%
25	19	76%	78	36	76%

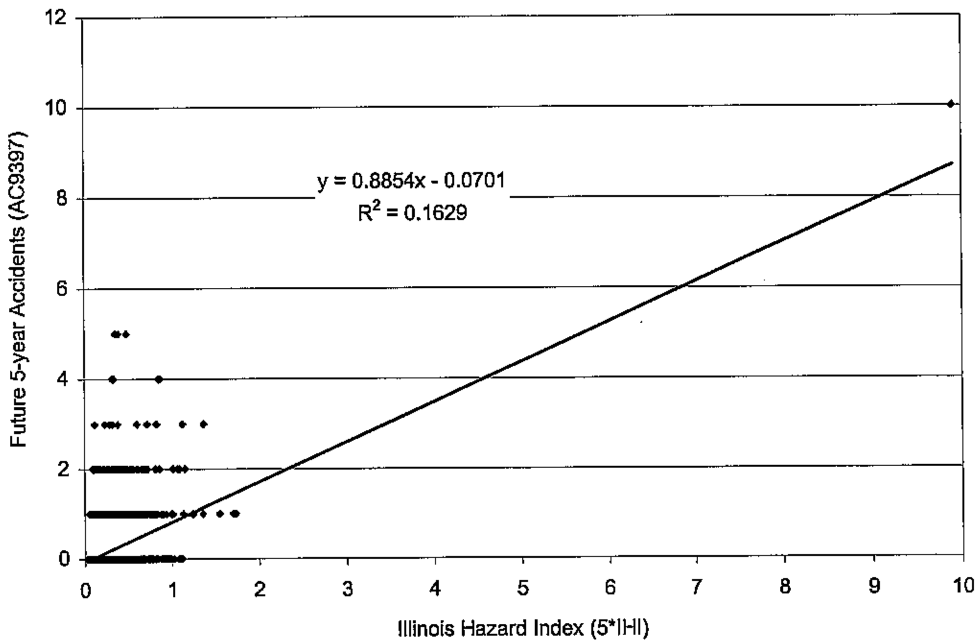


Figure 7.4-A. Relation between 5 IHI and next 5-year crashes for the entire 6423 locations_ WOLOG WACC POWER.

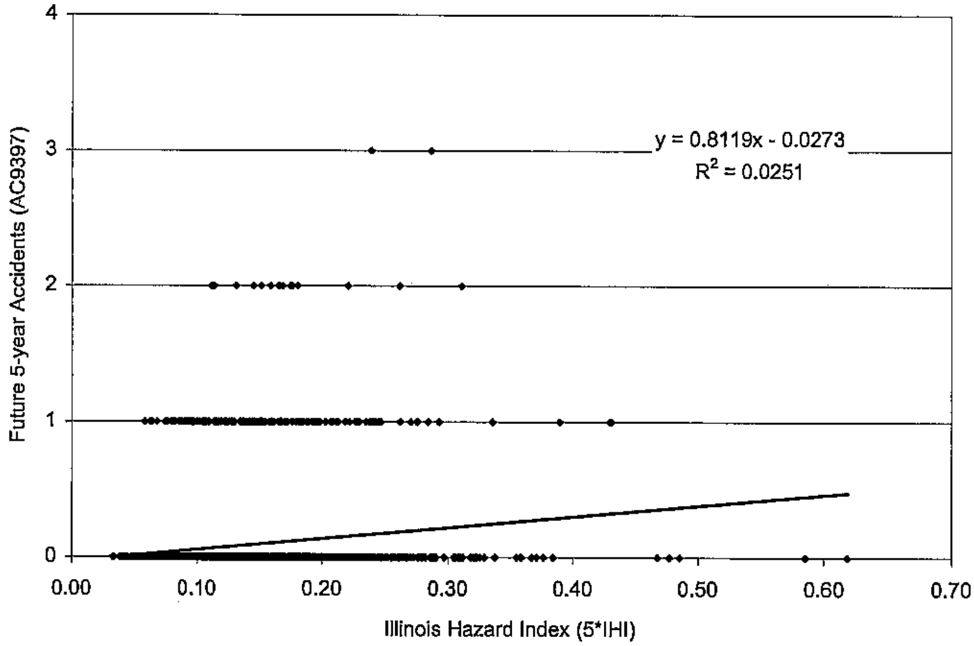


Figure 7.4-B. Relation between 5 IHI and next 5-year crashes for locations marked by Crossbucks_ WOLOG WACC POWER.

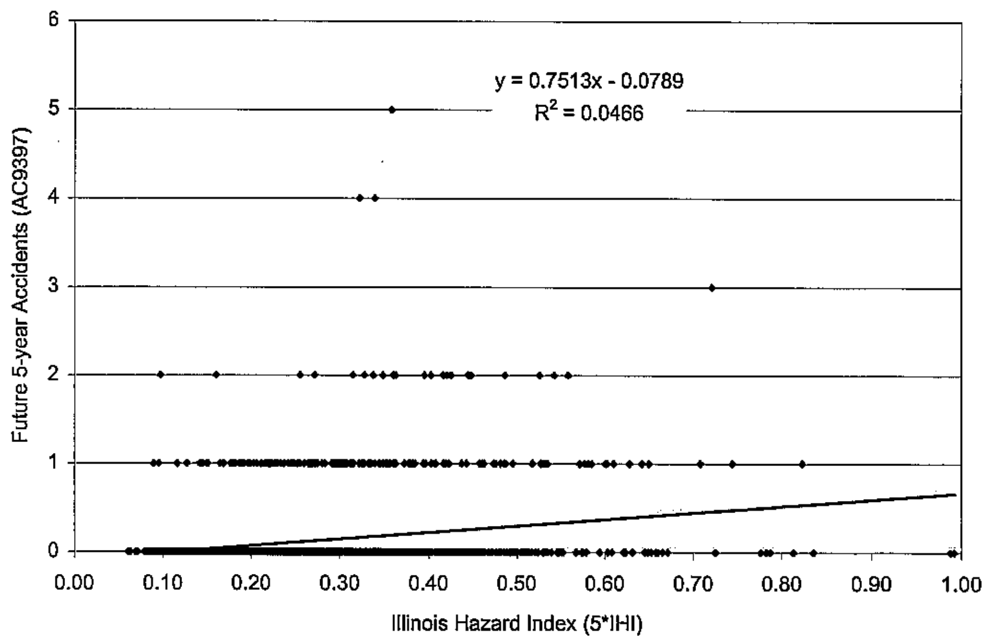


Figure 7.4-C. Relation between 5 IHI and next 5-year crashes for locations marked by flashing lights_ WOLOG WACC POWER.

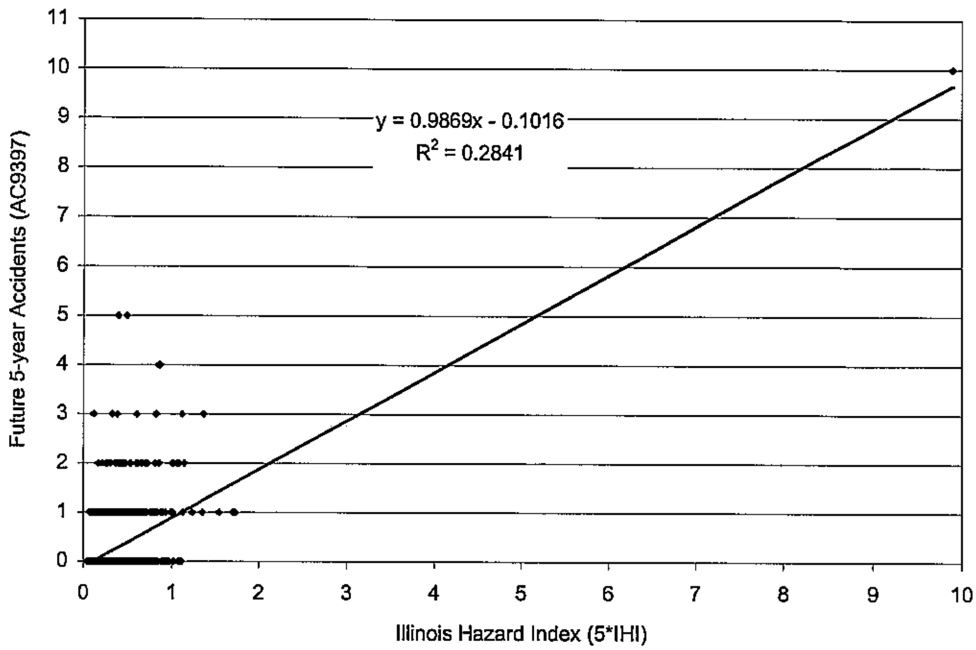


Figure 7.4-D. Relation between 5 IHI and next 5-year crashes for locations marked by gates_ WOLOG WACC POWER.

Crash Model by Time of the Day

Since night vision is one of the factors that may influence the safety at rail grade crossings, the research team decided to divide the crash data for the 6,423 crossings used in this study into two categories: daytime crashes and nighttime crashes. Daytime was defined as the time from 6:00 AM to 6:00 PM and the nighttime was defined as the time from 6:01 PM to 5:59 AM. The crash distribution by the time of the day was as follows:

Table 7.6. Distribution of Illinois crashes by time of the day.

	Daytime	Nighttime	Total
Crashes (1988-1992)	560	510	1070
Crashes (1993-1997)	459	322	781
Crashes (1988-1997)	1019	832	1851

Then the non-linear procedure in SAS was used to model the relationship between hazard index and the number of observed crashes. Two models were developed: one for daytime crashes and the other for nighttime crashes. The ANOVA tables for the regression lines of observed daytime as well as nighttime crashes versus IHI (WLOG WO ACC POWER) were as follows:

Model: Daytime
Dependent Variable: IHI

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	3.19939	3.19939	975.995	0.0001
Error	6421	21.04857	0.00328		
C Total	6422	24.24796			

Root MSE	0.05725	R-square	0.1319
Dep Mean	0.01429	Adj R-sq	0.1318
C.V.	400.59466		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-0.002697	0.00089783	-3.004	0.0027
PREDICT	1	1.883865	0.06030118	31.241	0.0001

Model: Nighttime
Dependent Variable: IHI

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.35780	0.35780	146.929	0.0001
Error	6421	15.63649	0.00244		
C Total	6422	15.99430			

Root MSE	0.04935	R-square	0.0224
Dep Mean	0.01003	Adj R-sq	0.0222
C.V.	492.17594		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.004345	0.00077385	5.615	0.0001
PREDICT	1	0.629997	0.05197377	12.121	0.0001

As shown the daytime model has R^2 of 13.2% and slope of 1.88 which does not make it a better model than the previous suggested models that combine the daytime and nighttime crashes in one model. The nighttime model was even a weaker one. The coefficient of determination was 2.2% and the slope was 0.63. Thus, the statistical analysis shows that developing separate models based on the time of the crash is not supported.

Crash Model by Type of Area

Likewise, the research team divided the 6,423 crossings used in this study by type of area. 4,187 crossings exist in rural area, whereas 2,236 crossings exist in urban area. Then the non-linear procedure in SAS was used to model the relationship between hazard index and the number of observed crashes for each category separately. Each model was used to predict the number of crashes for the five-year period 1993-1997, given the traffic, geometric characteristics and crash history for the five-year period 1988-1992. Then the predicted numbers of crashes were compared to the observed numbers using linear regression. The following are the ANOVA tables for both cases

Model: Rural
Dependent Variable: IHI

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	0.55928	0.55928	172.861	0.0001
Error	4185	13.54032	0.00324		
C Total	4186	14.09960			

Root MSE	0.05688	R-square	0.0397
Dep Mean	0.01466	Adj R-sq	0.0394
C.V.	387.88354		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	-0.000196	0.00143189	-0.137	0.8910
PREDICT	1	1.008309	0.07669112	13.148	0.0001

Model: Urban
Dependent Variable: IHI

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	1	5.07603	5.07603	470.441	0.0001
Error	2234	24.10473	0.01079		
C Total	2235	29.18075			

Root MSE	0.10387	R-square	0.1740
Dep Mean	0.04240	Adj R-sq	0.1736
C.V.	245.00389		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob > |T|
INTERCEP	1	0.001125	0.00290627	0.387	0.6987
PREDICT	1	0.988449	0.04557242	21.690	0.0001

As shown the rural model has a low R^2 of 3.9%, while the model for urban areas has higher R^2 of 17.4%. Both models have a slope that is not different from one and intercept near zero. The model for urban areas is

$$IHI = 10^{-6} \times A^{2.54452} \times B^{0.27322} \times C^{0.06548} \times D^{0.50230} \times (7.39 \times N + PF)$$

A = ln (ADT×NTT)
B = MTS, Maximum Timetable Speed, mph
C = (NMT+NOOT)
D = NOL
N = Average number of crashes per year = AC8892/5
PF = Protection Factor; 0.36 for Gates, 2.32 for Flashing Lights, 4.05 for Crossbucks
ADT = Average Daily Traffic
NTT = Number of Total Trains per day

Crash Model by Type of Warning Devices

In this attempt, the data were divided by warning devices: 2,700 crossings marked with crossbucks, 1,976 crossings marked with flashing lights and 1,747 crossings marked with gates. Three models were fitted using non-linear regression as described previously. The following table summarizes the regression results.

Table 7.7. Relation between observed number of crashes and number of crashes predicted by different warning devices models.

	R^2	Slope	Intercept
Crossings marked with crossbucks	3.35%	1.062	-0.001
Crossings marked with flashing lights	8.25%	1.027	-0.001
Crossings marked with gates	21.53%	1.462	-0.004

As shown, models fitted for specific warning device do not outperform one model developed for all warning devices.

8. ASSESSMENT OF THE THRESHOLD OF 0.02

Typically, IDOT considers 2 crashes per 100 years, i.e.; EAF of 0.02 indicative of the need for a possible upgrade in warning device. The Illinois Commerce Commission (ICC) uses an alternate criterion of train-vehicle product of 3,000, which corresponds to an EAF of approximately 0.015. In this section, the EAF values for each of the 6,423 crossings were computed and compared to the threshold of 0.02. In addition, the ICC threshold value of 0.015 was evaluated.

Out of the 6,423 crossings, 1,168 crossings were found to have EAF of 0.02 or greater. The following table shows the crossings with EAF of 0.02 or greater grouped by the warning devices and crash history. As shown, close to 60% of the crossings with EAF of 0.02 or higher are gated locations. Only 13% of the locations suggested by IDOT EAF threshold were marked with crossbucks. Over 85% of the crossings suggested by IDOT EAF and marked with crossbucks did not have crash history over five years. Overall, 77% of all crossings suggested by IDOT EAF threshold did not have any crashes.

Table 8.1. Crossings with EAF of 0.02 or higher distributed by warning devices and crash history.

Warning Devices	Based on 1993-1997 Crashes				total	%
	Xings W/o crashes	%	W crashes	%		
Xbucks	131	85.1%	23	14.9%	154	13.2%
FL	264	80.0%	66	20.0%	330	28.3%
Gates	504	73.7%	180	26.3%	684	58.6%
Total	899	77.0%	269	23.0%	1168	100.0%

The next table presents similar statistics for the ICC threshold of 0.015. In this case, 1,494 crossings were selected by ICC threshold for possible upgrading. Close to 80% of the selected crossings were found to have no crashes over five-year period (1993-1997).

Table 8.2. Crossings with EAF of 0.015 or higher distributed by warning devices and crash history.

WD	Based on 1993-1997 Crashes				total	%
	W/o crashes	%	W crashes	%		
Xbucks	203	85.7%	34	14.3%	237	15.9%
FL	378	80.9%	89	19.1%	467	31.3%
Gates	600	75.9%	190	24.1%	790	52.9%
Total	1181	79.0%	313	21.0%	1494	100.0%

Comparing the Top 200 Crossings Sorted by IDOT EAF to the Top 200 Crossings Sorted by IHI (WLOG WOACC POWER)

This section presents comparison of the top 200, 300 and 500 crossings sorted by both IDOT EAF formula and IHI formula. Among the top 200 locations, 105 locations were captured by both formulas as shown in the following table. Among the remaining 95 crossings, IDOT EAF formula identified 27 crossings with crash history for possible upgrade. Only one crossing was marked with crossbucks, and 26 were marked with gates, which represent the highest protection available for rail grade crossings. On the other hand, IHI formula identified 31 crossings with crash history for possible improvement. Thirteen crossings were marked with crossbucks and should be upgraded to flashing lights or gates and 17 crossings were marked with gates.

Table 8.3. Comparison between top 200 crossings sorted by EAF and top 200 crossings sorted by IHI.

	In both files			In EAF file only			In IHI file only		
	W acc	W/o acc	Total	W acc	W/o acc	Total	W acc	W/o acc	Total
Xbucks	-	3	3	1	5	6	1	-	1
FL	-	1	1	-	5	5	13	25	38
Gates	57	44	101	26	58	84	17	39	56
Total	57	48	105	27	68	95	31	64	95

When considering the top 300 locations, 172 crossings were suggested by both models for upgrade. Among the remaining 128 crossings, IDOT EAF identified 32 crossings with crash history for possible upgrade. Twenty-eight of them were gated locations. On the other hand, IHI formula identified 40 crossings with crash history for possible improvement. Only 50 % were gated locations and the rest were crossings marked with crossbucks or flashlights.

Table 8.4. Comparison between top 300 crossings sorted by EAF and top 300 crossings sorted by IHI.

	In both files			In EAF file only			In IHI file only		
	W acc	W/o acc	Total	W acc	W/o acc	Total	W acc	W/o acc	Total
Xbucks	1	4	5	2	9	11	1	3	4
FL	1	5	6	2	7	9	19	44	63
Gates	76	85	161	28	80	108	20	41	61
Total	78	94	172	32	96	128	40	88	128

Among the top 500 locations, IDOT EAF formula identified 5 crossings with crash history and marked with crossbucks and 17 crossings with crash history and marked with flashing lights for possible upgrade. On the other hand, IHI formula identified 5 crossings with crash history and marked with crossbucks and 48 crossings with crash history and marked with flashing lights for possible upgrade.

The previous comparison shows that IDOT EAF formula identifies more gated locations for possible upgrade where the only feasible solution is the grade separation. On the other hand, IHI formula identifies more locations marked with crossbucks or flashing lights for improvement.

Model Selected

Based on the discussion presented in the previous two chapters, we recommend using IHI (WLOG WACC POWER) to prioritize crossings for safety improvement.

$$IHI = 10^{-6} \times A^{2.59088} \times B^{0.09673} \times C^{0.40227} \times D^{0.59262} \times (15.59 \times N^{5.60977} + PF)$$

Where,

A = ln (ADT×NTT)

B = MTS, Maximum Timetable Speed, mph

C = (NMT+NOOT), Number of main and other tracks

D = NOL, Number of highway lanes

N	= Average number of crashes per year = AC8892/5
PF	= Protection Factor; 37.57 for Gates, 68.97 for Flashing Lights, 86.39 for Crossbucks
ADT	= Average Daily Traffic
NTT	= Number of Total Trains per day.

9. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Conclusions

Survey of other state DOTs indicated that states use a variety of hazard indices or accident prediction formulas to compile their annual list of recommended railroad crossings for safety improvements with no specific methodology widely used. About one-third of the DOTs participated in the survey reported using the USDOT model.

Field data collected from three railroad corridors and 93 crossings in Illinois showed that 21% of the current DOT inventory data have outdated entries for warning devices and should be updated. Regression analysis of the field data indicated that the variables that should be considered in accident prediction models are ADT, number of night trains, number of day trains, number of highway lanes, and number of main tracks, whereas the sight distance was not an important factor.

The results indicated that IDOT expected accident frequency (EAF) formula fell short of identifying crossings with crossbucks that may need safety improvements, but worked relatively better in identifying gated locations where warning devices upgrade is not feasible. The analysis of ICC inventory and FRA accident files showed that close to 60% of the crossings with EAF of 0.02 (IDOT uses this threshold) or higher were crossings with gates and only 13% of the locations were marked with crossbucks. About 77% of crossings that had an EAF of 0.2 or higher, regardless of the warning device type, did not have any crash. Similarly, 85% of the identified locations with crossbucks did not have any crashes in the five years time period. Four potential models (Connecticut, Michigan, California, and USDOT models) were evaluated using Illinois data and none of them consistently outperformed IDOT EAF formula.

A new Illinois Hazard Index (IHI) formula was developed. The variables used in IHI are ADT, number of trains per day, maximum timetable speed, number of tracks, number of lanes, 5-year crash history, and control devices factor. Similar to Connecticut, Michigan and California formulas, the suggested IHI formula computes a hazard index as a surrogate for the number of crashes. The IHI was compared to IDOT EAF formula. Results revealed that the percentage of the locations that may need safety improvement identified by IHI formula are higher than the percentage given by IDOT EAF. Moreover, In identifying locations that need safety improvement, IHI formula selected locations with higher crash rate than IDOT EAF formula. In addition, the relation between the actual number of crashes and IHI predicted values was stronger than the corresponding relation using IDOT EAF.

Recommendations

The Illinois Hazard Index (IHI) introduced in this study more accurately identifies the locations that may need safety improvements. However, since IHI is developed based on the current IDOT/ICC inventory, which is estimated to have 21% outdated entries for warning devices, it wouldn't seem prudent to switch from the current EAF formula until IHI can be tested against the new inventory file, which is about to be completed, to revise its coefficients. It is recommended that the IHI be used in combination with other criteria to identify those crossings in needs of safety improvements.

IHI is a single model that can be applied for both urban and rural areas. It is recommended to use the updated inventory data to develop a detailed model for each area and to consider the highway functional class.

In addition, IHI can be applied for all crossings regardless of existing warning devices. It is recommended to use the updated inventory to explore whether a stand-alone model for each control device is needed.

Data from sites selected for improvement over the past few years should be compared to sites selected by IHI to compare its reliability in selecting crossings in need of improvement.

APPENDIX A: LITERATURE REVIEW
ACCIDENT PREDICTION AND HAZARD INDEX FORMULA

Highway engineers have been attempting for some time to develop a methodology to predict the number of crashes at a railroad-highway grade crossing. Many statistical techniques have been used to investigate the relationship between characteristics of grade crossings, crash frequency, vehicle and train traffic, and expected number of crashes.

One motor vehicle and one train arriving at a grade crossing at or about the same time are required for a crash. Therefore, the two most obvious variables, which affect the probability of a crash, are vehicle and train volumes. The type or degree of protection may also be important. Early research and hazard formulas were based fundamentally on these three variables.

Some formulas are termed "absolute" formulas, such as the Peabody-Dimmick Formula and the USDOT Formula. This is because they estimate numbers of crashes and casualties. Other formulas, such as the New Hampshire Formula, are termed "relative" formulas since they provide an index which is associated with expected crashes or casualties only on a relative basis, i.e., a larger index means more expected crashes or casualties but the relationship is not linear. The distinction between absolute and relative formulas is important when considering use of a formula to assist in determining cost-effective allocations of improvement funds. If program effectiveness is to be measured in terms of tangible benefits such as reduced crashes, an absolute formula must be used to ensure that the benefits or alternative actions are consistently evaluated. The use of absolute formulas, such as the USDOT formulas, is therefore recommended to support resource allocation decisions. Both relative and absolute formulas can be used to provide rankings of crossings on the basis of their relative hazards. The following sections present examples of each category.

Many crossing hazard formulas have been developed in the past and used extensively by those concerned with rail-highway crossing safety. Examples of these formulas are presented in the next section

Accident Prediction Formulas

Peabody-Dimmick Formula (Bureau of Public Roads Formula, 1941)

L. E. Peabody and T. B. Dimmick, in a 1941 study performed by the Division of Transport, Public Roads Administration, analyzed data on 1,254 crossings in 29 states for a five-year study period. The protection coefficients calculated for the various types of crossings were based on the following empirical formula relating the protection coefficients to exposure units and crash experience.

$$A_s = 1.28\frac{V^{0.170} * T^{0.151}}{P_c^{0.171}} + K$$

A_s	= *Expected number of crashes in five years*
V	= *Daily highway traffic*
T	= *Daily train traffic*
K	= *Additional Parameter*
P_c	= *Protection coefficient*

The additional parameter accounts for a correction factor.

It is believed that this was the first predictive equation. This hazard index is only depending on vehicular volumes and train volumes for a crossing of a given warning device class.

Oregon Highway Commission (1950)

The Oregon State Highway Department concluded a five-year study of 378 crash crossings in the year 1950. Protection coefficients were calculated using the relationship between rail and highway volumes and the crash experiences of the various warning devices. This formula was first developed in 1954. Then, in 1957 some refinements were made to produce an index of hazard. This study found that nighttime crashes were 40% more likely to occur than daytime crashes (Oregon State Highway Department, 1956). Finally the following predicted equation was formulated in 1959.

$$\text{Predicted accidents (5 yr.)} = 0.25 + 8.03 \times 10^{-5}\, v\, t\, p\, d - 1.58 \times 10^{-10}\, v\, t\, p\, d^2$$

v	= average daily traffic
t	= daily train volume
p	= protection factor
d	= darkness factor

NCHRP Report 50 (1968)

This formula predicts crash rate for individual crossings based on number of trains per day. The equation applied for individual crossing did not explain a significant amount of the variation in crashes (Coleman and Stewart).

$$\text{Expected Train Accidents/year} = A \times B \times T$$

where:

A = Vehicular traffic factor can be determined from a table based on 10 year ADT

B = Protection factor 'B' factor can be determined from a table according to the existing warning device and type of area (Urban vs. Rural)

T = current train volume per day

Coleman-Stewart Model (1976)

This model was developed by analyzing groups of crossings. As a group, crossings are considered similar if they have similar characteristics as location , number of tracks, warning device, and highway and traffic volumes. In consequence, the crash prediction equation focused on the relations between observed crash rates for groups of crossings with similar physical characteristics and the associated average daily train and vehicle volumes. The results of the regressions reported for this model explained from 63 to 78 percent of the variance of group means. However, this model does not consider the variance of individual crossings within groups, although it would have a substantial effect on the variability of a prediction for a single crossing. (Lavette, Robert, 1977).

$$log_{10} A = B_0 + B_1\, log_{10} C + B_2\, log_{10} T + B_3\, (log_{10} T)^2$$

where

A = Average number of crashes per crossing-year

C = Average daily vehicular movements. (If C = 0, use ½ instead)

T = Average daily train movements. (If T = 0, use ½ instead)

TSC Model (Mengert Report) (1980)

This model was referred to as USDOT old model and was developed during the late 1970s using the 1975 national inventory and crash database for all public crossings in the United States. The model consists of three sets of equations, one for each of three categories of warning devices: passive (including crossbucks and STOP signs), flashing light signals, and gates.

$$\text{Comprehensive model: } H = 0.389\ EXP^{2X_1}$$

$$\text{Volume model: } H = 0.389\ EXP^{2HVOL_1}$$

Where

$$X_1 = 0.74982\ HVOL_1 + 0.19474\ LOG_{10}(DT + 1) + 0.17491\ MAIN\ TRACKS + 0.17780\ HWY\ PAVED + 0.045405\ POP - 0.13139\ FC$$

$$HVOL_1 = -0.13711 + 0.38069h_1 - 0.66800\, h_1^{\,2} - 0.1917\, h_1^{\,3}$$

$$h_1 = -3.0264 + 1.1580\, LOG_{10}(T + 1) + 0.48654\, LOG_{10}(C + 1) - 0.22122\, [LOG_{10}(T + 1)]^2$$

Where

H	= expected number of crashes per year
T	= number of trains per day
C	= number of cars per day
DT	= Number of day thru trains per day
MAIN TRACKS	= Number of main tracks
HWY Paved	= 1 if highway is paved, 0 if not paved
POP	= Population.
FC	= The units digit of functional classification of road over crossing

DOT Accident Prediction Formula – Farr (1987)

This set of accident prediction models was released in 1987. These models were calibrated using 1981 through 1985 crash data and 1986 inventory data.

The DOT formulas provide a means of calculating the expected annual number of crashes and casualties at a crossing on the basis of the crossing's characteristics described in the Inventory and the crossing's historical crash experience described in the FRA Railroad Accident/Incident Reporting System (RAIRS). The crash and severity predictions are produced by the DOT formulas in two steps. Predicted crashes are obtained in the first step using a set of formulas described below. The resulting crash predictions are expressed as the expected number of crashes per year at a crossing. If desired, predicted crash severity is then obtained in the second step using another set of formulas as described in a following Section. The severity calculations depend on the use of predicted crash results from the first step. The severity predictions for a crossing are expressed in three ways: (1) expected number of fatal crashes per year, (2) expected number of casualty crashes per year, and (3) total combined casualty index (a weighted combination of fatal and injury crashes per year).

Crash predictions are produced by combining two independent predictions of a crossing's crashes to produce a more accurate resultant prediction. The two independent predictions are obtained from the following sources:

- A formula provides an unnormalized initial prediction of crashes on the basis of a crossing's characteristics. This formula, termed the "basic formula", is used in a manner similar to other common formulas such as the Peabody-Dimmick formula.
- A second prediction is provided by the observed crash history at a crossing. This prediction assumes that future crashes per year are approximated by the average historical crash rate. It is referred to as a crossing's "accident history".

The above two independent predictions are combined as a weighted average using the general accident prediction formula. This consists of computing a weighted average value, which is then multiplied by a normalizing constant.

Basic Formula

The unnormalized initial prediction of a crossing's crash (a) is determined from the basic accident prediction formula given in equation below. The basic formula produces a prediction on the basis of a crossing's characteristics as described in the Inventory. The technique used for developing the basic formula involved applying nonlinear multiple regression techniques to crossing characteristics stored in the Inventory and to crash data contained in the FRA Railroad Accident/Incident Reporting System (RAIRS). The 1981 through 1985 crash file and the April 1986 Inventory were used to develop the formula.

The resulting basic formula can be expressed as a series of factors which, when multiplied together, yield the unnormalized initial predicted crashes per year (a) at a crossing. Each factor in the formula represents a characteristic of the crossing described in the Inventory. The general expression of the basic formula is shown below:

$$a = K \times EI \times DT \times MS \times MT \times HP \times HL$$

where:

a	= unnormalized initial accident prediction, in accidents per year at the crossing
K	= formula constant
EI	= factor f or exposure index based on product of highway and train traffic
DT	= factor for number of thru trains per day during daylight
MS	= factor for maximum timetable speed
MT	= factor for number of main tracks
HP	= factor for highway paved (yes or no)
HL	= factor for number of highway lanes

Three sets of equations are used to determine the value of each factor, one for each of the following three categories of warning devices:

1. Passive, including the following warning device classes:
   Class l - No signs or signals
   Class 2 - Other signs
   Class 3 - Stop signs
   Class 4 - Crossbucks

2. Flashing lights, including the following warning device classes:
   Class 5 - Special, e.g., flagman
   Class 6 - Highway signals, wig-wags or bells

Class 7 - Flashing lights

3. Gates, including the following warning device class:
   Class 8 - Automatic gates with flashing lights

The crossing characteristic factors for the three warning device categories are shown in Table A.1.

Table A.1. Crossing Characteristic Factors

Crossing Category	Formula Constant	Exposure Index Factor	Day Through Trains Factor	Maximum Timetable Speed Factor	Main Tracks Factor	Highway Paved Factor	Highway Lanes Factor
	K	EI	DT	MS	MT	HP	HL
Passive	0.0006938	$((c*t+0.2)/0.2)^{0.37}$	$((d+0.2)/0.2)^{0.178}$	$e^{0.0077ms}$	1.0	$e^{-0.5966(hp-1)}$	1.0
Flashing	0.0003351	$((c*t+0.2)/0.2)^{0.4106}$	$((d+0.2)/0.2)^{0.1131}$	1.0	$e^{0.1917mt}$	1.0	$e^{0.1826(h1-1)}$
Gates	0.0005745	$((c*t+0.2)/0.2)^{0.2942}$	$((d+0.2)/0.2)^{0.1781}$	1.0	$e^{0.1512mt}$	1.0	$e^{0.1420(h1-1)}$

Where:

c = number of highway vehicles per day
t = number of trains per day
mt = number of main tracks
d = number of through trains per day during daylight
hp = highway paved? yes = 1.0 and no =2.0
ms = maximum timetable speed, mph
hl = number of highway lanes

Each set of factor equations should be used only for crossings with the warning device classes for which it was designed. For example, if it is desired to estimate the unnormalized number of crashes at a crossing with crossbucks, then the passive set of equations should be used. If it is desired to estimate the unnormalized number of crashes at a crossing recently upgraded from one warning device category to another, use the formulas for the prior category and apply the effectiveness factor for the upgrade.

The numerical value of each factor is related to the degree of correlation that a specific crossing characteristic was found to have with crossing crash rates. For those cases in the table where the value of the factor is indicated as a constant 1.0, it was found that the characteristic did not have a significant relationship to crossing crashes.

To evaluate the basic formula at a particular crossing whose Inventory characteristics are known, the values of the factors are determined from the table and multiplied together.

An inspection of the factor value tables shows that exposure index (EI), based on the product of annual average daily highway traffic (c) and average daily train traffic (t), has the strongest relationship to predicted crashes. All other factors can be seen as having a weaker relationship to predicted crashes.

Accident History

The second independent prediction of a crossing's crash rate is derived from the crossing's crash history. This information is obtained from the FRA RAIRS file, which contains records of all crashes that occurred at crossings. The required measure of crash history is the ratio N/T, where N is the number of crashes which occurred at a crossing over a period of T years.

Use of crash history, along with the unnormalized prediction obtained from the basic formula, improves the overall prediction. This improvement comes about because crash history serves as a surrogate for other characteristics which affect crossing hazards but are not included in the Inventory; e.g., sight distance, or the timing of highway and train traffic. The most accurate predictions, in theory, will result from the use of all the available crash history, assuming crossing characteristics remained constant. However, the extent of improvement is minimal if data for more than 5 years are used. It is therefore recommended that only data for the most recent 5 years of crash history be used. This ensures good performance from both the accident prediction formula and use of the most relevant data.

Crash history information more than 5 years old may be misleading because of changes that occur to crossing characteristics over time. If it is known that a significant change has occurred to a crossing during the most recent 5 years, such as a warning device upgrade, only the crash data since the change should be used.

The general DOT accident prediction formula can be expressed as follows:

$$B = [To\,(a)/(To + T)] + [T/(To + T)](N/T)$$

A = .7159*B for Passive
A = .5292*B for Flashing lights
A = .4921*B for Gates

where:
A = final where accident prediction, accidents per year at the crossing,
a = initial unnormalized accident prediction from basic formula (1), acc/yr
N = accident history prediction, accidents per year
T = observed accidents in T years at the crossing,
To = formula weighting factor 1.0 /(0.05 + a).

The general DOT accident prediction formula calculates a weighted average of crossing's unnormalized predicted crashes from the basic formula (a) and crash history (N/T).

The normalizing constants used in the formula are reset periodically so that the sum of the predicted crashes in each group (passive, flashing lights, gates) for the top 20 percent most hazardous crossings exactly equals the number of crashes which in a recent period for the top 20 percent of that group. Simply stated, the constant is the ratio of the actual number of crashes to the predicted number of crashes. In theory, these constants could be calculated for subsets of (e.g., for individual States) so that final prediction (A) would reflect the recent experience of that subset. The efficiency of such fine-tuning has not been tested by the DOT.

It is expected that the basic formula and the crash history formula will not change significantly in the near future. However, the normalizing constants used could change slightly from year-to-year as crash experience and Inventory changes applied. The normalizing constants will be recalculated periodically and will be published annually in FRA's Rail-Highway Crossing Accident/Incident and Inventory.

Hazard Indexes

Many indices of hazard have been developed as a result of the studies previously mentioned such as Peabody and Dimmick and Oregon Highway Commission.

Illinois Commerce Commission (Warren Henry Formula - 1934)

In 1934 Henry examined various factors to build a hazard index equation. The five factors considered by Henry were view (F_1), attention (F_2), user (F_3), inherent hazard (F_4), and pedestrian (P). The hazard index was obtained as the sum of these factors times the product of factors for daily train (T) and highway traffic (V).

$$\textit{Index of Hazard} = V\,T\,(1 + F_1 + F_2 + F_3) + P\,T\,(1 + F_4)$$

Mississippi Formula (1947)

A method of rating grade crossings in terms of sight distance hazard was developed by the Division of Planning in Mississippi. The formula was developed based on recording of sixteen clear sight distances at different crossings. These distances were obtained from eight different points in the road. The distances recorded were the maximum distances that a train would be from the crossing when it could be first seen by a motorist from the designated point of observation. This sight distance rating was combined with the Public Road Administration formula in "Special Rating" which gave slightly more significant results when applied to the crossing crash record.

$$H.I. = \frac{\frac{SDR}{8} + A_5}{2}$$

The Oregon Method (1956)

The index of hazard formula was calculated based on five years crash data. This formula takes as the most significant variables vehicle (v) and train (t) volumes. It also establishes protection factors (p) according with the type of protection. The formula also considers crash history (a), but the most important factor incorporated into the formula was the darkness factor. The product of the five factors produced an index of hazard (NCHRP Report 50).

$$\text{Index of Hazard} = V\ A$$
$$V = v_1\ t_1\ p + 1.4\ v_2\ t_2\ p$$
$$A = a_1/a_2$$

New Hampshire Formula (1959)

This formula is a very simple relative index, which states that for a given warning device class the relative hazard index is proportional to the product of the average vehicular volumes (V) and the average train volume (T). The New Hampshire formula is useful for its combination of power and simplicity. (Mengert, Report 80-02).

$$H.\ I. = V\ T\ P_f$$

Where
P_f is the protection factor for each crossing device (crossbucks, flashing lights and gates).

Contra Costa County (California) (1969)

They suggest that the product of vehicles and trains per day was not a good measure of hazard or exposure because it gave too much weight to the highway traffic. However, they considered that the number of trains per day was proportional to the hazard and exposure. Contra Costa model assumed a random distribution of vehicle arrivals to express the index of hazard, as follow:

$$H.I. = TZ\left(1 - 2.718^{\frac{V*t}{1400Z}}\right)$$

In which

T = number of trains per day

Z = number of traffic lanes

V = number of highway vehicles per day

t = time, in min/day, that the crossing is blocked

Other crash/hazard index formulas are presented in Appendix A.

Prioritization

The methods used for prioritization could be crash prediction formulas, warrants or other economic analysis procedures.

Warrants

The warrant technique is based on the following idea: "Any crossing where the savings in crashes are equal to or greater than the cost of installing improved protection, warrants installation of such protection". (NCHRP Report 50, 1968).

The procedure is as follows. It is necessary to determine the number of crashes at a crossing with the current warning device (if any). Then, determine the expected number of crashes with the improvement proposed. The difference is the number of crashes prevented. Assigning monetary values to the crashes it is possible to estimate the saving in money terms. Finally, compare these savings to the annual cost of providing and maintaining the new device. If the benefit (savings) is greater than the cost, then the improvement is warranted. After determine which crossings warrant an upgrade; then, priorities are assigned using a benefit /cost ratio.

The procedure is very straightforward; nevertheless the monetary value of the different crashes is subjective. The final outcome depends completely on these values. Furthermore, these studies are economic based and don't take into account factors which influence safety at the crossings. But perhaps the most important drawback is that the prioritization of the crossings is done based on rate of return of investment rather than the potential risk present in the crossing.

Economic Analysis Procedures

These methods involve the estimates of expected costs and safety and operational benefits to determine an economic index that can be compared with other alternatives. Based on that comparison, the improvement required can be determined. The project prioritization is obtained also by comparing these expected economic index for each project.

A considerable problem for the methods, as noted on the warrants section, are the estimates on monetary in terms of human life or personal injury. There are two sources of this information: National Safety Council (NSC), estimates include wage losses, medical expenses, insurance administrative costs and property damage. National Highway Traffic Safety Administration (NHTSA), their estimate include in addition to the elements mentioned above, the cost to society (consumption and production lost).

The interest rates can be obtained from the highway agency. The service life can be found in the Highway Safety Improvement Program User's Manual (FHA).The accepted methods are the following: Cost Effectiveness Analysis, Benefit-Cost Ratio, and Net Annual Benefit

These methods are acceptable but they lack in the sense that they don't go deep into the probable causes of the crashes. They just work with the expected effectiveness of the improvement. For the same reason that they don't quantify the factors that lead to the crashes, they can't help to identify the causes and prevent them. They just strictly accomplish their function: establish certain economic base for project comparison and prioritization.

Resource Allocation Procedure

The U.S. Department of Transportation developed this procedure as a means to help the States to effectively prioritize their projects and allocate the Federal resources assigned for crossing traffic control improvements. This procedure helps to identify the projects with the "greatest accident reduction benefits on the basis of cost-effectiveness considerations for a given budget" (RHGC Handbook, 1986).

The only traffic control improvement alternatives considered in this procedure are:
For passive crossings, single track, two upgrade options exist: flashing lights or gates.
For passive, multiple-track crossings, only upgrade to gates.
For flashing light crossings, only improvement to gates.

The input data required for this procedure is the following: number of annual crashes per crossing (could be obtained from the US DOT Accident Prediction Model or from any other model that yields this data), the safety effectiveness of the flashing lights and automatic gates (see table 34, RHGC Handbook, 1986), improvement costs (installation and maintenance costs for the life cycle), and amount of available funding.

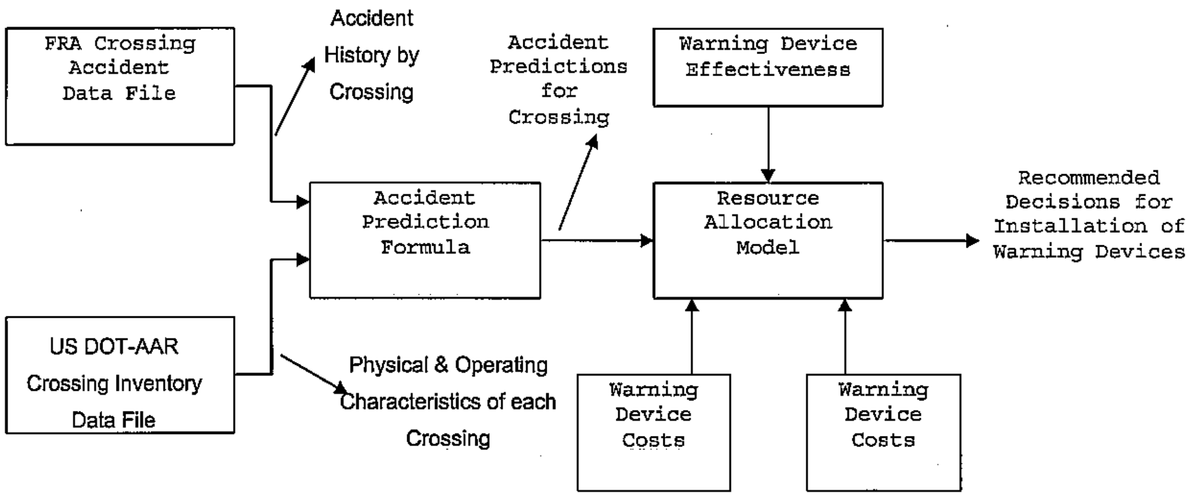


Figure A.1. Crossing Resource Allocation Procedure (RHGC Handbook, 1986).

"The individual accident reduction / cost ratios which are associated with these improvements are selected by the algorithm in an efficient manner to produce the maximum crash reduction which can be obtained for a predetermined total cost". (RHGC Handbook, 1986).

Evaluation

The evaluation can be made in terms of different groups of elements identified as the most important. The Rail-Highway Grade Crossings Handbook the formulas "require the computation of at least three basic variables": the relative effectiveness of the various types of traffic control devices, the probability of conflict between trains and vehicles, and sight distance ratings. Some formulas presented in the Handbook are extremely simple, others are very complex.

When evaluating a crossing, it is important to remember that only one third of the crashes in highway-rail crossings actually involve trains. "The other two thirds are equally distributed between crashes which occurred when the train was present but not involved, and those which occurred when the train was not even present" (NCHRP Report 50,1968). This is of special relevance when considering the relative importance of each of the variables to be included in the formula(s) because different variables may be involved in each of these different types of crashes. Or at least each could need to have a different relative weight within the formulas.

The Rail-Highway Grade Crossings Handbook (1978) presents a study conducted by John Sanford (1977) of the University of Illinois where the most frequent elements considered in determining a hazard index, priority ranking or accident prediction equation are reviewed. The results are presented in Table A.2.

Improvement Alternatives

In some cases it may be more convenient, prior to the evaluation of the crossing analysis, to consider if improvements such as crossing closure, railroad consolidation and relocation could be more pertinent or are going to be applied in the near future.

Table A.2. Frequent elements considered in Hazard Index (Sanford, 1977 cited in RHGC Handbook, 1978).

	Data Element	Number of States
*	Number of Trains per day	42
*	Number of vehicles per day	42
*	Existing Traffic Control or Advance Warning Devices	27
	Visibility and Sight Distance	17
*	Speed	12
	Accidents	12
	Angle of Intersection	11
*	Number of Tracks	10
	Highway Approach Grades	6
	Highway Alignment	5
*	Number of Highway Lanes	5
	Surface Condition	3
	Type of Train	2
*	Urban/Rural Land Use	2
*	Nearby Intersections	1

* Indicates data element is included in National Inventory data File

Sight Distance

Sight distance is a primary consideration at crossings without train-activated warning devices. Railroad-highway grade crossing sight distance is defined as the length of the roadway ahead and along the tracks that can be seen by a driver (Messick, 1993). Under unlimited sight distance along both the roadway and track, the grade crossings should provide the optimum amount of safety and maximum traffic flow. However, because of the high costs incurred to maintain the right of way, this is not always possible.

There are three types of sight distance (FHWA Railroad-Highway Grade Crossing Handbook, 1986) that can define the visibility of a grade crossing: approach sight distance, quadrant sight distance, and track sight distance.

Approach sight distance is the distance measured along the roadway from the driver of the vehicle to the nearest track. An adequate approach sight distance allows the driver to stop the vehicle before the tracks to avoid a train crash.
Quadrant sight distance is the visibility in the quadrants to the driver's left and right. This distance allows the driver to perceive the approaching train from either direction and make a decision (cross the tracks or stop).
Track sight distance is the distance required for the driver stopped at a crossing in order to decide when it is safe to cross the tracks.

The basic assumption for the adequacy of sight distance at railroad crossings establishes that, whatever the situation, the driver must be able to see a train in time to whether stop or proceed across the tracks. It is then reasonable to conclude that any limitation on sight distance should be associated with a greater crash rate. If proper sight distance is available to the operators of motor vehicles, then the probability of a train-car crash is primarily a function of driver attention and motor vehicle performance. The necessity of providing adequate sight distance for motor vehicle operators is particularly critical in railway-highway intersections as the train operator is powerless to avoid a collision due to the fixed travel-way (Basha, 1985).

Ward and Wilde (1996) compared the driver behavior at an unprotected crossing before and after enhancing the lateral sight distance. They measured the amount and length of drivers' head movements left and right over the tracks and the approach speeds, and classified the drivers as safe or unsafe based on their approach behavior. They found that the right side head movements increased as well as length being the differences significant at 95% level of confidence. As for the left side, the head movements and length also increased, but the results not were significant. The results obtained for Ward et al., 1996, allow them to infer that as the drivers realized that the site had improved safety due to better sight distance the drivers approached the crossing at higher speeds while keeping constant their safety margin. However, as a consequence of the enhancement of lateral sight lines, the results of the study showed that as the approaching speed increases, the possibility of rear-end collisions also increases when drivers do not behave the same way in the traffic flow.

Additionally, there are another studies (Van Belle et all, 1975; Zalinger et al., 1977; Rusell, 1974) mentioned by Ward et al., (1996) that shows that "sight distance has not been found to relate reliably to crossing crashes rates". In 1995, Messick made an analysis of sight distances in 81 grade crossings with a database of five years. The results of the analysis indicated that there is not any significant relationship between sight distance and the number of crashes at a crossing. The possible explanation of this apparent disassociation is given by Wilde et al., (1996) stating that "...motorist realize that their view of the track is restricted, and thus engage in compensatory modification on their approach behavior". Finally, they conclude " if motorists make such behavioral adjustments to variations in visual obstructions of the track, then there is no reason to expect a significant association between visibility characteristics of crossings on the one hand and their crash frequency on the other".

Current Practice

Currently the required Sight Distance is calculated using the principles described in the FHWA Railroad Highway Grade Crossing Handbook (1986) and the AASTHO policy on geometric design of highways and streets (1994). These two books define three different situations for which a minimum sight distance needs to be provided.

These three cases are: the visibility of the crossing for an approaching vehicle (approach sight distance), the visibility in the quadrants to the driver's left and right for a moving vehicle (quadrant sight distance) and, the visibility from the stopped position to the driver's left and right quadrants (track sight distance). The first two sight distances are analyzed at the same time in case 1 and the third in case 2.

Case 1. Moving vehicle

In the first case, a sight distance is required so the driver, after observing the approaching train, can make a decision between two alternatives: either continue moving and safely cross the intersection before the train arrives, or slow down and stop before the crossing.

In this case, two distances are defined: one, is the visibility of the crossing (sight distance along the highway, d_H) and the other, is the distance that the train travels during the time that the vehicle takes to reach the crossing and clear it (sight distance along the tracks, d_T). This distances help to define the sight triangle.

Sight distance along the highway, d_H

d_H consists of the minimum stopping sight distance defined for the highways plus the distance from the stop line to the first rail plus the distance from the driver to the front of the vehicle. These distances in total comprise d_H and effectively require that a decision be made to stop at or before d_H.

$$d_H = 1.47 \times V_V \times t + \frac{V_V^{\,2}}{30 \times f} + D + d_e$$

where:

d_H = sight distance along the highway (ft);

V_V = velocity of vehicle (mph);

t = driver perception / reaction time (assumed to be 2.5 sec);

f = braking coefficient of friction (see Table A.3);

triangle is now formed by the distance from the stop line to the first rail (known) and a different distance over the rail.

The distance over the rail (d_T) is calculated using the following formula:

$$d_T = 1.47 \times V_T \left[\frac{V_G}{a_1} + \frac{L + 2 \times D + W - d_a}{V_G} + J \right]$$

where:

d_T = sight distance along the tracks (ft);
V_T = velocity of train (mph);
V_G = maximum speed of vehicle in first gear (assumed to be 8.8 fps);
a_1 = acceleration of vehicle in first gear (assumed to be 1.47 ft / sec^2);
L = length of vehicle (assumed to be 65 ft);
W = distance between outer rails (for a single track assumed to be 5 ft).
D = distance from front of stopped vehicle to nearest rail (assumed to be 15 ft);
d_a = distance vehicle travels while accelerating to maximum speed in first gear (ft)

$$d_a = \frac{V_G^2}{2 \times a_1}$$

J = perception / reaction time, which is assumed to be 2.0 sec.

Table A.4. Distances along railroad and highway from crossing for different vehicle and train speeds.

Train Speed (mph)	Case 2 Departure from Stop	Case 1 Moving Vehicle						
	Vehicle Speed (mph)							
	0	10	20	30	40	50	60	70
	Distance Along Railroad from Crossing, dt (ft)							
10	240	145	103	99	103	112	122	134
20	480	290	207	197	207	224	245	269
30	719	435	310	296	310	337	367	403
40	959	580	413	394	413	449	489	537
50	1200	725	517	493	517	561	611	671
60	1439	870	620	591	620	673	734	806
70	1679	1015	723	690	723	786	856	940
80	1918	1160	827	789	827	898	978	1074
90	2158	1305	930	887	930	1010	1101	1209
	Distance Along Highway from Crossing, dh (ft)							
		69	132	221	338	486	659	865

APPENDIX B: ACCIDENT PREDICTION/HAZARD INDEX FORMULA EXISTED IN LITERATURE

Name of Formula	Formula
Peabody and Dimmick Formula	$A_s = 1.28 \frac{V^{0.170} * T^{0.151}}{P_c^{0.171}} + K$
Mississippi Formula	$H.I. = \frac{\frac{SDR}{8} + A_5}{2}$
The Ohio Method	$H.I. = A_f + B_f + G_f + L_f + N_f + SDR$
Wisconsin Method	$H.I. = \frac{T\left(\frac{V}{20} + \frac{P^1}{50}\right)}{5} + SDR + A_e$
Contra Costa County Method	$H.I. = TZ\left(1 - 2.718^{\frac{V*t}{1400Z}}\right)$
The Oregon Method	$H.I. = \left[V_1T_1P_f + 1.4V_2T_2P_f\right]\frac{A_e}{A_5}$
North Dakota Rating System	$H.I. = \left[N_f + L_f\right] + \left[P_f + D_f + G_f + X_f\right] + \left(VT_f\right) + SDR$
Idaho Formula	$H.I. = V_f + T_f\left(CB_f + SDR + N_f + Y_f\right)$

Utah Formula	$H.I. = \frac{T}{1000}\left[\left(\frac{P}{10}+\frac{F}{20}+\frac{S}{30}\right)+SDR+N_f+X_f+R_f\right]+$ $+2A_e+\frac{P^1}{100{,}000}\left(\frac{P}{10}+\frac{F}{20}+\frac{S}{30}\right)-P_f$
City of Detroit Formula	$H.I. = \frac{T}{1000}\left[\left(\frac{P}{10}+\frac{F}{20}+\frac{S}{30}\right)SDR+N_f+X_f+R_f\right](100\%-\%P_f)+2A_e$
New Hampshire Formula	$H.I. = VTP_f$
Variations of the New Hampshire Index	
	$H.I. = V*(2T_f)(T_S)\frac{(SD+AN+NTR)}{4}$
	$H.I. = \frac{V(T)(A_5)}{P_f}$
	$H.I. = V(T)\frac{(TT+TTR+SD+AN+AL+L+G+VSD+W+LI)}{100}$
	$H.I. = \frac{(P_f)(V_f)(T)(TS)(NTR)}{160}+(70A_a)^2+1.2(SD)\ ;\ A_a=\left(V+\frac{SBP}{1.2}\right)(HM)$
	$H.I. = 0.1(P_f)(A_f)(T_1)+(AN)(NTR)(S)(0.5L)+TS\left((FC*P)+\left(\frac{V*T}{10{,}000}\right)+SB\right)$
	$H.I. = \frac{(V_f)(P_f)(T)}{TR+TN+T_f+HS+G+SD+AN}$

	$H.I. = (0.01)(V)(T) + (0.1)(HS)(TS) + (SD)(AN)(TR)(NTR)(AL) + + (A_a^2 + 1)(RF)(LP)(P_f) + (SB)(SBP) + (10)(HM)$
	$H.I. = \frac{\sqrt{(V)}(T)}{P_f}$
NCHRP 50 Hazard Index	A*B*Current Trains per Day
NCHRP 50 Hazard Index Modified	$\frac{\text{NCHRP 50 Hazard Index}}{\text{Site Evaluation + ACC/Yr}}$
U.S. DOT Accident Prediction Equations	
Basic Formula	$a = k * EI * MT * DT * HP * MS * HT * HL$
Final Accident Prediction Formula	$A = \frac{T_O}{T_O + T}(a) + \frac{T}{T_O + T}\left(\frac{N}{T}\right)$; $T_O = \frac{1.0}{(0.05 + a)}$
Probability of a fatal accident	$P(FA\|A) = \frac{1}{1 + CF * MS * TT * TS * UR}$
Probability of a injured accident	$P(IA\|A) = \frac{1 - P(FA\|A)}{1 + CI * MS * TK * UR}$

Florida DOT Accident Prediction Model	
Passive traffic control devices y: number of accidents per year	$y = \exp(0.968t_p + 1.109)/4$ $t_p = -8.075 + 0.318 \ln S_t + 0.484 \ln T + 0.437 \ln A + 0.387 \ln V_v +$ $+\left(0.28 - 0.28\frac{MASD}{RSSD}\right)^{**} + \left(0.33 - 1.23\frac{MCSD}{RSSD}\right)^{*} + 0.15(\text{no. crossbucks})$ *NOTES*: * Variable omitted if crossing is flagged or the calculation is less than zero ** Variable omited if sight restriction is due to parallel road
Active traffic control devices y: number of accidents per year	$y = \exp(0.938t_a + 1.109)/4$ $t_p = -8.075 + 0.318 \ln S_t + 0.166 \ln T + 0.293 \ln A + 0.387 \ln V_v +$ $+\left(0.28 - 0.28\frac{MASD}{RSSD}\right) + 0.225(L-2)^{***} - 0.233(\text{gates})$ *NOTE*: *** Variable omitted when gates are present
Adjusted for accident history	$Y = y\sqrt{H/(y)(P)}$
Safety (Hazard) Index	$R = X(1 - \sqrt{Y})$

Symbols for formulas up to City of Detroit

A_5 = Expected number of accidents in 5 years
A_e = Accident experience
A_f = Accident probability factor
B_f = Train speed factor
CB_f = Type and speed of train factor
D_f = Alignment of track and highway factor
F = Number of freight trains in 24 hours
G_f = Approach gradient factor
H.I. = Hazard Index
K = Additional parameter
L_f = Angle of crossing factor
N_f = Number of tracks factor
P = Number of passenger trains in 24 hours
P^1 = Number of pedestrians in 24 hours
P_c = Protection coefficient
P_f = Protection factor
R_f = Road approach factor
S = Number of switch trains in 24 hours
SDR = Sight Distance Rating
t = Time crossing is blocked
T = Average 24-hour train volume
T_1 = Average daylight train volume
T_2 = Average train volume during dark hours
T_f = Train volume factor
V = Average 24-hour traffic volume
V_1 = Average daylight traffic volume
V_2 = Average traffic volume during dark hours

Symbols for variations of the New Hampshire Index

A_5 = Number of accidents in 5 years
A_a = Number of accidents per year
A_f = Accident factor
AL = Factor for highway alignment
AN = Factor for approach alignment
FC = Factor for functional class
G = Factor for approach grades
HI = Hazard Index
HM = Factor for hazardous materials vehicles
HS = Factor for highway speed
L = Factor for number of lanes
LI = Factor for local interference
LP = Factor for local priority
NTR = Factor for number of tracks
P = Factor for population
P_f = Protection factor
RF = Factor for rideability
S = Factor for surface type
SB = Number of school buses
SBP = Number of school bus passengers
SD = Factor for sight distance
T = Average number of trains per day
T_f = Number of fast trains
T_S = Number of slow trains
T_1 = Train factor
TN = Factor for number of night trains
TR = Factor for number and type of tracks

V_f = Traffic volume factor
VT_f = Exposure factor
X_f = Condition of crossing factor
Y_f = Severity factor
Z = Number of traffic lanes

TS = Factor for train speeds
TT = Factor for type of train movements
TTR = Factor for type of tracks
V = Annual average daily traffic
V_f = Factor for annual average daily traffic
VSD = Factor for vertical sight distance
W = Factor for crossing width

Symbols for US DOT

a = Initial accident prediction
K = Formula constant
EI = exposure index based on product of ADT & train traffic
MT = Factor for number of main tracks
DT = Factor for number of thru trains per day during daylight
HP = Factor forhighway paved (yes or no)
MS = Factor for maximum timetable speed
HT = Factor for highway type
HL = Factor for number of highway lanes
A = Final accident prediction, accidents/year at the crossing
N / T = Accident history prediction, accidents per year, where N is the number of observed accidents in T years at the crossing.
T_O = Formula weighting factor

P(FA|A) = Probability of a fatal accident given an accident
CF = Formula constant = 695
MS = Factor for maximum timetable train speed
TT = Factor for thru trains per day
TS = Factor for switch trains per day
UR = Factor for urban or rural crossing
P(IA|A) = Probability of an injury given an accident
CI = Formula constant = 4.280
TK = Factor for number of tracks

Symbols for the model of Florida DOT

A = Vehicles per day
L = Number of lanes
MASD = Actual minimum stopping sight distance along highway

Y = Accident prediction adjusted for accident history
H = Number of accidents for six-year history or since year of last improvement
P = Number of years of the accident history period

MCSD = Clear sight distance (ability to see approaching train along the highway, recorded for the four quadrants)

RSSD = Required stopping sight distance on wet pavement

S_t = Maximum speed of train

T = Yearly average of the number of trains per day

t_a = Logarithm of predicted number of accidents in four year period at crossings with active traffic control devices

t_p = Logarithm of predicted number of accidents in four year period at crossings with passive traffic control devices

V_v = Posted vehicle speed limit unless geometric dictate a lower speed

y = Predicted number of accidents per year at crossing

R = Safety Index

X = 90 when less than ten school buses per day traverse the crossing
85 when ten or more school buses per day and active traffic control devices exist without gates
80 when ten or more school buses per day and passive traffic control devices exist

APPENDIX C: VARIABLES USED IN ACCIDENT PREDICTION AND HAZARD INDEX FORMULA

	Veh/Day	Train/Day	Sight Distance	Train Speed	Type of Protection	Highway Veh. Speed	Approach Grade & Cond.	No. of Traffic Lanes	Angle of Appr.	No. of Track	Weather condition	Accident history	Pedestrian Hazard	Type of Train	Delays	Time Cross. Block	No. of Night Veh.	No. of Night Train	No. of Switch trains
Peabody and Dimmick	X	X			X														
Mississippi Formula			X																
New Hampshire Formula	X	X			X														
The Ohio Method	X	X		X	X		X		X	X									
Wisconsin Method	X	X	X									X	X						
Contra Costa County Method	X	X						X								X			
The Oregon Method	X	X			X		X					X					X	X	

	Veh/Day	Train/Day	Sight Distance	Train Speed	Type of Protection	Highway Veh. Speed	Approach Grade & Cond.	No. of Traffic Lanes	Angle of Appr.	No. of Track	Weather condition	Accident history	Pedestrian Hazard	Type of Train	Delays	Time Cross. Block	No. of Night Veh.	No. of Night Train	No. of Switch trains
North Dakota Rating System			X		X		X	X	X	X									X
Idaho Formula	X	X	X	X						X				X					
Utah Formula	X	X	X		X		X			X		X	X	X					X
City of Detroit Formula		X	X				X			X				X					X
NCHRP 50	X	X			X														
U.S.D.O.T.	X	X		X	X		X	X		X		X		X				X	
Florida D.O.T.	X	X	X	X	X	X		X	X			X							

APPENDIX D: SURVEY OF STATE DOTS ON METHODOLOGY FOR PRIORITIZING RAIL-HIGHWAY GRADE CROSSING SAFETY IMPROVEMENTS AND POLICIES RELATED TO RAIL-BICYCLE TRAIL CROSSINGS

The purpose of this survey is to collect data on the methodology currently used by state DOTs for prioritizing rail-highway crossing safety improvements and policies related to rail-bicycle trail crossings. This study is conducted by the University of Illinois at Urbana-Champaign for the Illinois Department of Transportation. If you have any questions or comments, please call Professor Ray Benekohal at 217-244-6288 or send email to: rbenekoh@uiuc.edu. You will get a summary of the survey, if you respond. Thank you for your cooperation in this study.

1. What are the procedures and guidelines your organization uses to develop an annual list of recommended railroad-highway crossings for warning device improvements? Please describe or attach a copy of your current procedure.

2. What are the criteria your organization uses to identify needs and prioritize the crossings for warning device improvements? Please describe or attach a copy of your criteria

3. What is the expected crash (accident) frequency formula or the priority index formula used by your organization? Please describe or attach a copy of your formula.

4. What are the thresholds your organization uses for the formula in Question 3?

5. Are there any other criteria used in addition to the formula? Please describe or attach a copy of the text.

6. Are there any of the following stand-alone crossings (such as rail-recreational trail grade crossings, not including sidewalk crossings adjacent to roadway) in your state?

   a. Rail-pedestrian crossings (do NOT include rail-bicycle trail)
   No Yes, if yes how many ________

   b. Rail-bicycle trail crossings (multi use)
   No Yes, if yes how many ________

   c. Other (Please specify________________________________) How many________

7. What kind of warning devices does your organization use for the crossings in Question 6? Please describe or provide a schematic sketch for each.

   a. For rail-pedestrian crossings

   b. For rail-bicycle trail crossings (multi use)

   c. For Others

8. What criteria are used to determine the kind of warning devices used for the stand-alone crossings?

9. Do you have any additional comments or suggestions?

10. In addition to your organization, is there another agency in your state that is responsible for the tasks mentioned in Questions 1 through 8?
    a. No,
    b. Yes, (Please provide the name and address of that organization)

        Name ______________________________
        Organization ______________________________
        Address ______________________________
        Phone ______________ Fax______________

11. Please provide the following Information about yourself

    Your Name: ______________________
    Title: ______________________
    Address: ______________________
    Phone/ Fax: ______________________
    E-mail: ______________________

THANK YOU FOR YOUR PARTICIPATION IN THIS STUDY

Please mail your response to the following address by December 6, 1999.

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