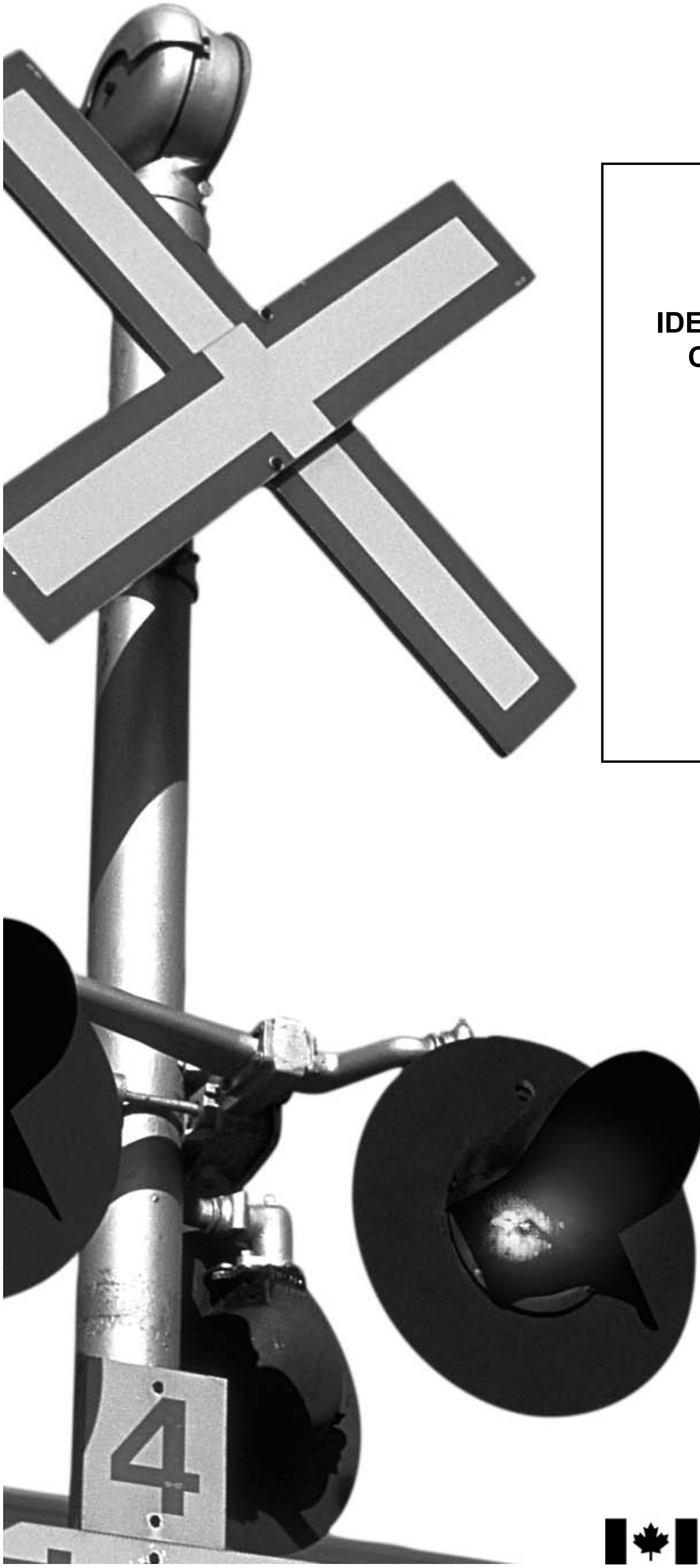
Highway-Railway
GRADE CROSSING RESEARCH



TP 14168E

IDENTIFYING HIGHWAY-RAILWAY GRADE CROSSING BLACK SPOTS: PHASE 1

Prepared for
Transportation Development Centre
Transport Canada

by
Department of Civil Engineering
University of Waterloo

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by

Frank Saccomanno, Liping Fu, Congming Ren and Luis Miranda
Department of Civil Engineering
University of Waterloo

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This report reflects the views of the authors and not necessarily those of the Transportation Development Centre of Transport Canada, the steering committee, or the sponsoring organizations.

Neither the Transportation Development Centre nor the sponsoring organizations endorse products of manufacturers. Trade or manufacturer's names appear in this report only because they are essential to its objectives.

In this report, train speeds are reported in miles per hour (mph) whereas highway speeds are reported in kilometers per hours (km/h). This is consistent with TC reporting format.

Project Team

Frank Saccomanno
Liping Fu
Congming Ren
Luis Miranda

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16. Abstract

This report presents a risk-based model for identifying highway-railway grade crossing black spots in Canada. This model consists of two prediction components: 1) collision frequency and 2) collision consequence. A graphical approach is adopted to identify crossings with unacceptable risk (high expected frequencies and/or consequences). These crossings are referred to black spots. The model was applied to Canadian inventory (IRIS) and collision occurrence (RODS) data for the period 1993-2001. Poisson and Negative Binomial (NB) frequency prediction expressions were developed for crossings with three types of warning devices (crossings with signs, flashing lights and/or gates). Both Poisson and NB models were found to provide a good fit to the collision frequency data.

A weighted consequence score was introduced to represent combined collision severity. The weights used in this combined consequence score were obtained from reported insurance claims for fatalities, personal injuries and property damages. A NB expression was developed for the collision consequence model.

The spatial distribution of black spots is discussed with respect to the type of warning device, upgrades in warning device, geographical location, and historical collision occurrence. A list of black spot crossings is provided for the Canadian data based on crossings whose expected number of collisions and/or expected severity score is exceeded at least 0.1% of the time. The regional breakdown of these crossings is discussed with respect to a selected number of attributes and historical collision experience. A GIS platform was developed for the Ontario region and used to illustrate the spatial pattern of expected and historical collision frequency and associated black spots.

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16. Résumé

Le rapport présente un modèle fondé sur l'appréciation du risque pour la détermination des passages à niveau à haut risque, dits «points noirs», au Canada. Ce modèle comporte deux volets : 1) la prévision de la fréquence des collisions et 2) la prévision des conséquences des collisions. Sur un graphique, on a déterminé les passages à niveau qui posent un risque inacceptable (en raison de la fréquence prévue des collisions et/ou des conséquences prévues de celles-ci). Ce sont ces passages à niveau qui sont appelés «points noirs». Le modèle a été appliqué aux données du Système intégré d'information ferroviaire (SIIF) et à la base de données des événements ferroviaires (BDEF) couvrant la période de 1993 à 2001. Des équations de la fréquence des collisions suivant la loi de Poisson et la loi binomiale négative (BN) ont été définies, pour des passages à niveau munis de trois types de systèmes d'avertissement (panneaux indicateurs, feux clignotants et/ou barrières). Les deux modèles ont montré un bon ajustement aux données sur la fréquence des collisions.

Par ailleurs, une cote pondérée des conséquences a été définie, pour exprimer la gravité des conséquences combinées d'une collision. Les facteurs de pondération de cette cote ont été établis d'après les indemnités versées par les assureurs par suite des morts, blessures et dommages matériels résultant des collisions. Une équation BN des conséquences des collisions a ainsi été définie.

La répartition spatiale des «points noirs» est examinée, selon le type de système d'avertissement, les ajouts faits aux systèmes d'avertissement, l'emplacement géographique et les données historiques sur les collisions. Puis est dressée une liste des passages à niveau du Canada désignés «points noirs», c.-à-d. les passages à niveau pour lesquels le nombre de collisions prévu et/ou la cote de gravité prévue sont dépassés, étant donné des seuils de 0,1 p. 100. La répartition régionale de ces passages à niveau est analysée, selon un certain nombre de caractéristiques et les données historiques sur les collisions. Une plate-forme SIG a été élaborée pour la région de l'Ontario. Elle est utilisée pour illustrer la répartition spatiale de la fréquence prévue et observée des collisions, et des points noirs connexes.

17. Mots clés Chemin de fer, passage à niveau, modèle fondé sur l'appréciation du risque, modèle de prévision des conséquences des collisions, prévision de la fréquence des collisions, points noirs, passage à niveau à haut risque	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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Shaun Hammond, Province of Alberta
Maury Hill, Transportation Safety Board
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Nathalie Lewis, Transportation Safety Board
Bill McCauley, Transport Canada
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Bob Nash, Canadian Pacific Railway
Allen Rao, Volpe Center
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EXECUTIVE SUMMARY

This research provides a methodology for identifying high-risk grade crossings (or black spots) in Canada. Black spots are crossings where the expected number of collisions and/or consequences exceeds some pre-set thresholds. The expected number of collisions and consequences are obtained from model output applied to individual crossings.

Two types of collision frequency models were developed and evaluated: 1) a single model with warning device as an independent variable, and 2) three separate models for the three types of warning devices (crossings with signs, flashing lights and/or gates). For each type of model, Poisson, Negative Binomial and Empirical Bayesian distributions were investigated for their appropriateness to represent the variation in the observed collisions. The best results were obtained using the Poisson model, which allows for separate expressions for different types of warning devices.

A combined consequence score was introduced to represent the total equivalent consequence that may result from a collision at a grade crossing. This score is defined as a weighted sum of fatalities, personal injuries and property damage resulting from each collision. The weights were established on the basis of the published cost estimates associated with each level of severity using a willingness-to-pay approach. The Negative Binomial model best explains the relationship between severity scores and various crossing and collision characteristics.

A two-dimensional graphical approach was adopted for comparing risk at individual crossings on the basis of their expected collision frequency and expected consequence score. The risk graph was used to identify black spots based on a given percentage threshold value. Black spots due to high frequency were found to cluster around urban areas in the Prairie Region, where road volumes were found to be highest. Black spots resulting from high consequence were found to be extensively distributed in rural and urban areas in Ontario and Quebec.

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GLOSSARY

Active Crossing	A highway-railway grade crossing equipped with warning and/or traffic control devices that are activated by train detection. Active devices provide crossing users with a message that a train is approaching the crossing. When a train is detected, typically some form of track circuitry activates the warning device at the grade crossing, such as flashing light signals and bells, or automatic gates.
Average Annual Daily Traffic (AADT)	Average 24-hour traffic volume at a given location obtained over a 365-day period.
Black spots	Crossings where collision risk is unacceptably high and intervention is justified usually because the potential safety benefits exceed the cost of intervention.
Collision	A reportable unexpected event, usually but not exclusively involving an impact between a train and a highway vehicle. Pedestrian accidents are not considered.
Crossing surface width	Width (ft) of the highway at a crossing. It is by regulation the greater of a minimum of 8 ft, or the width of the highway and shoulders plus 0.5 ft on each side of the highway and shoulders, as measured at the approach of the crossing. The distance is measured at right angles to the centre line of the highway.
Expected collision consequence	It is the expected consequence score, which is the weighted sum of fatalities, injuries and property damage resulting from each collision at a given crossing as predicted by the consequence model.
Expected collision frequency	The number of collisions that is expected to occur at a given crossing over a given period of time. It represents long term likelihood of collisions as predicted by the frequency models.
Maximum train speed	Maximum permissible train speed at the crossing (mph).
Negative Binomial regression (NB)	Provides relaxation of the mean = variance assumption of the Poisson model, where the mean is expressed as an exponential function of the number of explanatory variables.
Number of tracks	Total number of tracks at a specific highway-railway crossing. These are categorized into several classes: single main line, double main line, siding, switching, etc.

Number of trains daily	Sum of the through trains (freight train and passenger train) and switch trains passing a specific highway-railway crossing.
Passive Crossing	A highway-railway grade crossing with signs and pavement markings as traffic control devices, that are not activated by trains. These signs and markings identify and direct attention toward the location of a highway-rail grade crossing, and advice motorists, bicyclists, and pedestrians to take appropriate action.
Persons involved	Total number of occupants in all road vehicles involved in each collision.
Poisson regression	Assumes that the number of collisions at a grade crossing (collision frequency) follows a Poisson distribution. A log regression equation is commonly assumed for the mean, which has the advantage that the predicted number of collisions is non-negative.
Posted road speed	Maximum permissible vehicle speed on the intersected highway of a grade crossing (km/h).
Risk	Risk is commonly defined as the product of the expected number of collisions and their consequences. This can be expressed as an index (product of the two terms) or graphically with expected frequency and consequences on different axis.
Track angle	Refers to the intersection angle between the roadway and track. The convention is to report this angle with respect to the perpendicular to the track at the intersection with the roadway centre line.
Traffic exposure	Cross product of AADT and the number of trains daily.

1 INTRODUCTION

Highway-railway grade crossing collisions are a source of concern for regulators, railway authorities and the public. Each year in Canada, about 50 people lose their lives as a direct result of grade-crossing collisions (Transport Canada, Railway Safety Facts, 1996). As illustrated in Figure 1.1, the total number of grade crossing collisions per year has decreased by 19 percent in 1999 over the previous six-year average (1993-1999). Over this same period, the average number of injuries and fatalities at grade crossing has remained relatively constant at about 45 fatalities and 62 personal injuries per year. Although there has been a reduction in the number of collisions, the number is still high and needs to be further reduced.

In response to safety concerns at grade crossings, a partnership of federal and provincial organizations established a permanent safety management initiative called Direction 2006. The goal of Direction 2006 is to reduce grade crossing collisions in Canada by at least 50 percent by the year 2006. The question that needs to be addressed is how best to achieve this goal?

There are over 20,000 public highway-railway grade crossings in Canada (and almost as many private and farm crossings) covering a wide spectrum of physical characteristics, control devices and usage. Some crossings are equipped only with crossing signs with reflectors, while others have flashing lights, cantilevers, and gates. These control devices can be synchronized with adjacent traffic lights to improve flow and reduce delays at crossings. Many grade crossings are located in remote rural areas, where road and rail traffic volumes are low. For these crossings, generally no signalized control device is provided. The trend in recent years, however, has been to upgrade many un-signalized crossings to include fully automated warning devices with traffic separation barriers.

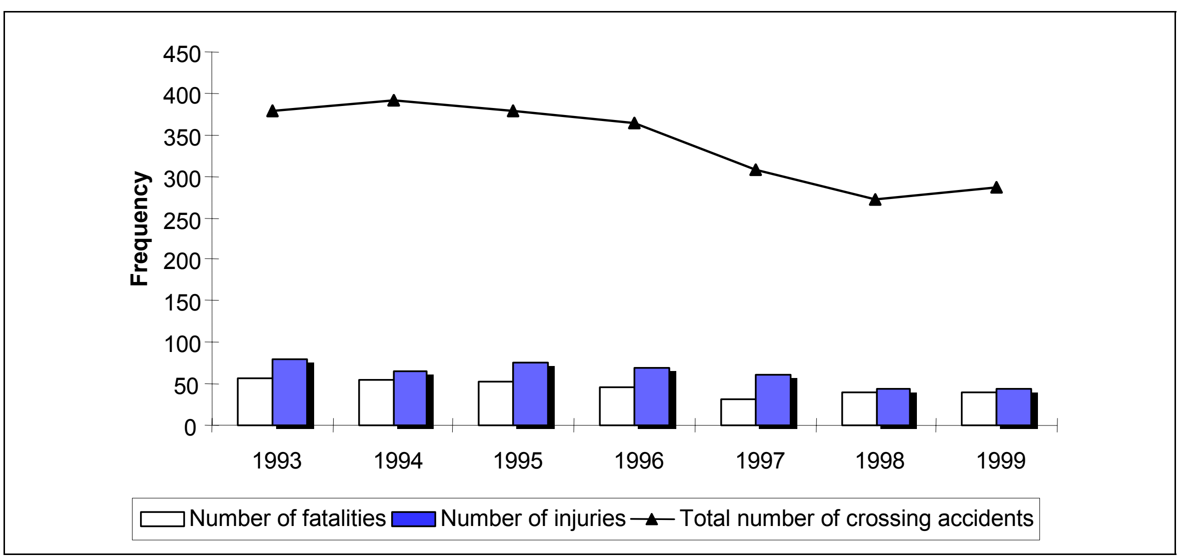

Figure 1.1 Trends in total crossing collisions, fatalities, and injuries (1993-99)
Source: Transportation Safety Board of Canada (1993 to 1999)

Highway-railway grade crossing collisions tend to be spread over a vast number of sites, with few (if any) occurring at any given site in any given year. To improve safety at all 20,000 grade crossings to some uniform standard would be prohibitively expensive and impractical. Accordingly, any comprehensive safety program must begin by first identifying crossings where the risk of collision is unacceptably high, and where safety countermeasures are most warranted. Following established convention, we refer to these high risk crossings as **black spots**.

A recent report prepared by the Transport Research Laboratory (TRL) for the World Bank concluded that a reduction in grade crossing collisions is best achieved by directing appropriate countermeasures at black spot locations (www.worldbank.org/html/fpd/transport/). Since it targets locations where risk is highest, it is suggested that black spot screening methods would result in the best allocation of scarce safety budgets. The TRL report argues that when there is an attempt to allocate funds to all problem areas, lack of funds and poor maintenance capability often results in leaving the most dangerous problems untreated.

1.1 Objectives and Scope of Study

Any program that attempts to achieve the goal of Direction 2006 must be viewed as an integral part of a **comprehensive multi-stage safety management program**, which generally consists of four interconnected steps:

1. Identify crossings where the potential risk of collisions is unacceptably high,
2. Review the causes and consequences of collisions at these locations,
3. Develop cost-effective countermeasures aimed at reducing risk at unsafe locations, and
4. Develop a comprehensive safety intervention program at the regional and national levels that includes prioritization of countermeasures at high risk crossings.

Notwithstanding the importance of considering all of the above steps, the scope of the work discussed in this report deals essentially with the first step, that of identifying grade crossings with high collision risk on the national rail network (so-called black spots).

In this study we treat the terms “collisions”, “accidents” or “crashes” interchangeably, recognizing that one jurisdiction will favour one term over the others. A collision is a **reportable** unexpected event, usually but not exclusively involving an impact between a train and a highway vehicle. Highway vehicle-train collisions take place at public crossings on federally regulated rail lines. Collisions that take place at private or farm highway-railway grade crossings and collisions involving only pedestrians are not considered in this study. Risk refers to both the likelihood of collisions and their consequent damages or severity. Potential risk, which is the focus of this analysis, reflects a long-term stable likelihood that a certain risk will occur at a given crossing over an interval of time and exposure. In many instances, the potential for collisions differs from the historical collision experience. This is due to the fact that collisions are rare, random events that fluctuate over time. Potential reflects a smoothing out of year-to-year variations in the historical collision experience at each crossing location.

This study has five specific objectives:

1. Review existing risk methodologies for predicting collision risk at highway-railway grade crossings for different control factors and conditions.
2. Review methodologies for identifying black spots and prioritizing safety intervention.
3. Develop a "risk-based" model for targeting black spot crossings that are in most need of safety intervention. Risk-based includes both the potential for collisions at specific crossings (frequency), as well as the potential severity of these collisions (e.g. fatalities, personal injuries, and property damages). The model also includes objective measures of risk thresholds for prioritizing intervention.
4. Apply the above model to grade crossings in Canada on a regional and national basis in order to obtain a prioritized list of black spots for safety intervention.
5. Investigate the major attributes of these black spots in terms of geometry, control devices and operating characteristics. Estimate the number of historical collisions and their consequences that would be flagged under the proposed black spot model.

The scope of this study is limited to analysis of predicted collision risk at individual grade crossings. The analysis does not consider the occurrence of "near misses" since they are not normally reported in the occurrence data. Near misses represent breaches in safety that do not result in actual collisions.

1.2 Black Spot Identification

The procedure for black spot identification adopted in this study is illustrated in Figure 1.2. This procedure consists of three related components:

1. Collision prediction
2. Consequence or severity prediction
3. Thresholds for black spot identification and intervention.

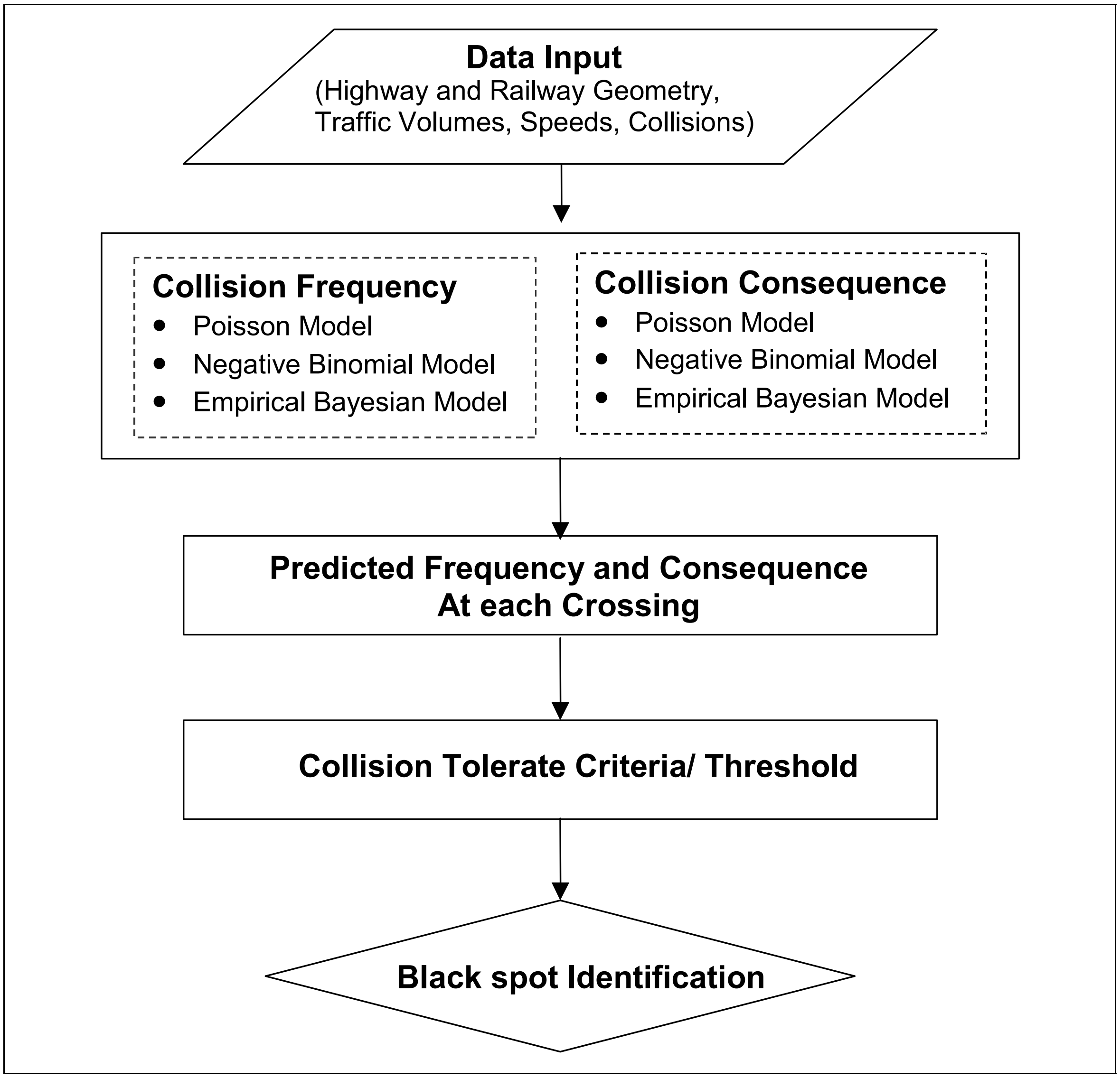

Figure 1.2 Procedure for black spot identification

A two-dimensional risk prescription for comparing predicted frequencies and consequences to established risk thresholds is illustrated in Figure 1.3. This comparison leads to black spot identification. The y-axis represents the **potential for collisions** at a given crossing (long term likelihood for collisions) over a given period of time. The x-axis represents the **expected number of casualties (fatalities, injuries) and property damage** that result from these collisions. In simple terms, as we move away from the origin along each axis, we move to positions of higher risk. Black spots are defined as crossings with unacceptably high expected risks (frequency and/or consequence). The gray area in Figure 1.3 includes crossings with unacceptable risk but where intervention would not be justified on the basis of intervention cost.

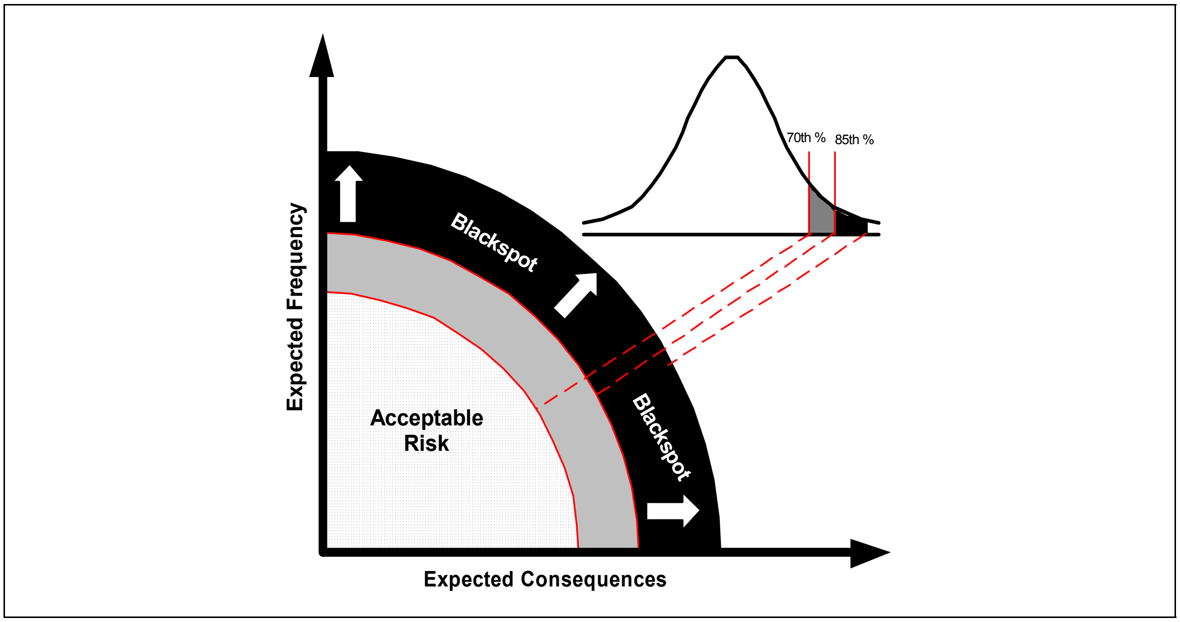

Figure 1.3 Risk-based black spot identification for a given type of crossing

A key element in identifying black spots is an objective definition of risk tolerance or threshold that can be linked to various decision options. For example, if risk exceeds a given threshold, a certain type of intervention would be considered. Risk tolerance can be depicted as a threshold line superimposed on the crossing risk estimates (as in Figure 1.3). Any crossing with expected collision frequency and consequence that lies beyond the acceptable risk thresholds would be designated as a black spot.

From Figure 1.3, crossings in the dark band would be considered high risk (black spots), such that some form of safety intervention would be justified even at high cost. In practical terms, the upper range of the black spot band in Figure 1.3 is limitless, because there is not an upper bound on unacceptably high risk for the purpose of safety intervention. Crossings in the gray shaded band reflect moderate risks, and intervention is justified if its cost does not exceed its potential safety benefits. Crossings in the un-shaded region of Figure 1.3 would be considered acceptable, requiring no intervention. Such an approach was adopted by the UK Health and Safety Commission (HSC, 1991) in their landmark study on the risks of transporting dangerous substances by road and rail in the UK.

In this study, the above prescription requires an in-depth statistical analysis of both expected collision frequency and consequence (severity) to establish objective measures of tolerance. In the absence of an in-depth risk tolerance investigation, we have expressed these thresholds in terms of percentiles (90^{th}, 95^{th}, 99^{th}, etc.) for expected collision frequency and consequence for different classes of grade crossings on the national rail network. These reflect specific crossings where either the expected frequency or consequences is exceeded only 1 percent, 0.5 percent, etc. of the time on the national network (municipal and provincial public crossings).

2 LITERATURE REVIEW

This section reviews a number of models for predicting collision risk and identifying black spots at highway-railway grade crossings in Canada and the United States. Collision risk includes both the expected number of collisions (frequency) and their consequent damages (severity). The discussion highlights a number of independent factors that are instrumental in explaining variations in collision frequency and consequence at individual grade crossings. The discussion also reviews several representative studies that have attempted to identify black spots for both road and rail sectors.

2.1 Predicting Collision Frequency at Grade Crossings

Over the past several decades, a number of collision frequency models have been developed. These models generally have taken one of two basic perspectives: absolute and/or relative risk. Absolute models yield the "expected number of collisions" at a given crossing for a given period of time. Relative models, on the other hand, yield a "hazard index", that represents the relative risk (frequency and/or consequence) of one crossing compared to another.

Typical absolute collision prediction models were developed by Coleman-Stewart (1976) and the US Department of Transportation (US-DOT; Farr, 1987). The US-DOT model is generally recognized as being the industry standard for collision risk prediction at highway-railway grade crossings. Many relative hazard index models were developed in the United States between 1950 to 1970, including the Mississippi Formula (1970), the New Hampshire Formula (1971), the Ohio Method (1959), the Wisconsin Method (1974), Contra Costa County Method (1969), the Oregon Method (1956), the North Dakota Rating System (1965), the Idaho Formula (1964), the Utah Formula (1971), and the City of Detroit Formula (1971).

In this chapter, we will discuss two representative "relative risk" models (Ohio (1959) and City of Detroit (1971) models) and two representative "absolute risk" models (Coleman-Stewart (1976) and the US DOT (Farr, 1987)).

2.1.1 Relative Risk or Hazard Index Models

Ohio formula (1959)

The Ohio model is expressed as:

$$H.I. = A_f + B_f + G_f + L_f + N_f + SDR \quad \textbf{(2.1)}$$

Where:
- $H.I.$ = hazard index
- A_f = collision probability factor
- B_f = train speed factor
- G_f = approach gradient factor
- L_f = angle of crossing factor
- N_f = number of tracks factor
- SDR = sight distance rating

City of Detroit formula (1971)

The City of Detroit model is of the form:

$$H.I. = \frac{T}{1000}\left[\frac{P}{10} + \frac{F}{20} + \frac{S}{30} * SDR + N_f + X_f + R_f\right](100\% - P_f\%) + 2A_e \quad \textbf{(2.2)}$$

Where:
- T = average 24 hour train volume
- P = number of passenger trains in 24 hours
- F = number of freight trains in 24 hours
- S = number of switch trains in 24 hours
- SDR = sight distance rating
- N_f = number of tracks factor
- X_f = condition of crossing factor
- R_f = road approach factor
- P_f = protection factor
- Ae = collision occurrence

Relative risk (hazard index) models are not generally used to justify intervention because they do not provide objective estimates of the risks needed to justify this intervention on a cost-effective basis. Accordingly, relative risk models are of limited use in black spot identification and analysis.

2.1.2 Absolute Risk Models

Absolute collision models were developed by Coleman-Stewart (1976) and by the US-DOT (Farr, 1987), described as follows:

The Coleman-Stewart model

The Coleman-Stewart model uses an expression of the form:

$$Log\ H = C_0 + C_1\ Log C + C_2\ Log T + C_3\ (Log\ T)^2 \qquad \textbf{(2.3)}$$

Where: *C* = vehicle movements per day
T = train movements per day
H = the average number of collisions per crossing per year

A series of collision frequency expressions were developed by Coleman-Stewart for different track classes (number of tracks and region) and warning devices (gates, flashing lights and signs). The results are summarized in Table 2-1.

Table 2-1 Coefficients of Coleman-Stewart model

Category		C_0	C_1	C_2	C_3
Single-track, Urban	Automatic Gates	-2.17	0.16	0.96	-0.35
	Flashing Lights	-2.85	0.37	0.16	-0.42
	Crossbucks	-2.38	0.26	0.78	-0.18
Single-track, Rural	Automatic Gates	-1.42	0.08	-0.15	-0.25
	Flashing Lights	-3.56	0.62	0.92	-0.38
	Crossbucks	-2.77	0.4	0.89	-0.29
Multiple-track, Urban	Automatic Gates	-2.58	0.23	1.3	-0.42
	Flashing Lights	-2.5	0.36	0.68	-0.09
	Crossbucks	-2.49	0.32	0.63	-0.02
Multiple-track, Rural	Automatic Gates	-1.63	0.22	-0.17	0.05
	Flashing Lights	-2.75	0.38	1.02	-0.36
	Crossbucks	-2.39	0.46	-0.5	0.53

In the US-DOT model, the expected number of total, fatal and casualty collisions were expressed as a function of different geometric (inventory), traffic control and volume. The US-DOT model was developed by fitting a non-linear multivariate expression to historical Federal Railroad Administration (FRA) collision occurrences and Association of American Railroads (AAR) inventory data for individual crossings in the US (Farr, 1987).

The US-DOT model consists of three analytical components:

- Basic statistical model,
- Subjective external adjustment for historical observations, and
- Subjective external adjustment for the type of warning device.

Three types of warning devices were considered:

- Type S (signs or cross-bucks),
- Type F (signs with flash lights), and
- Type G (signs + flashing lights + gates).

The expected number of collisions per year at crossing j ($E(m_j)$) was obtained using an expression of the form:

$$E(m_j) = b_j * [T_{0j} / (T_{0j}+T) * a_j + T / (T_{0j}+T) * (N/T)] \quad \textbf{(2.4)}$$

Where: T = number of years of collision history
N = number of collisions recorded in T years

For different crossing types, adjustment factors (b_j) were applied to the basic expected number of collisions, such that:

$$b_j = \begin{cases} 0.8644 \text{ for Type S warning device : Signs Only} \\ 0.8887 \text{ for Type F warning device : Signs + Flashing Lights} \\ 0.8131 \text{ for Type G warning device : Signs + Flashing Lights + Gates} \end{cases}$$

The term a_j in Eq. 2.4 was calibrated using a multiplicative expression of the form:

$$a_j = K_j * EI_j * DT_j * MS_j * MT_j * HP_j * HL_j \quad \textbf{(2.5)}$$

The term a_j represents the basic statistical component of the US DOT collision prediction model and K_j , EI_j , DT_j, MS_j , MT_j, HP_j, HL_j are crossing characteristics originally calibrated using non-linear multivariate regression applied to the FRA/AAR collision and inventory database for crossings in the US.

K_j	=	constant.
Ei_j	=	exposure index factor, which is a function of AADT and number of trains for three different warning devices.
DT_j	=	day train traffic factor, which is a function of number of through trains per day for three different warning devices.
MS_j	=	maximum speed factor, which is a function of maximum train speed for three different warning devices.
MT_j	=	main tracks factor, which is a function of number of main tracks for three different warning devices.
HP_j	=	highway paved factor, which is a function of whether highway is paved or not for three different warning devices.
HL_j	=	highway lanes factor, which is a function of number of highway lanes for three different warning devices.

The term T_{0j} *was* obtained using an expression of the form:

$$T_{0j} = 1/(0.05+a_j) \quad \textbf{(2.6)}$$

Table 2-2 summarizes the parameter estimates for three types of warning devices, as obtained by fitting the US-DOT model to US collision occurrence and inventory data.

Table 2-2 Basic prediction expression for three types of warning devices

	Crossing Characteristics Factors						
Crossing Type	**Formula Constant**	**Exposure Index Factor**	**Day Through Trains Factor**	**Maximum Speed Factor**	**Main Tracks Factor**	**Highway Paved Factor**	**Highway Lanes Factor**
	K	**EI**	**DT**	**MS**	**MT**	**HP**	**HL**
Passive	0.000694	$((c*t+0.2)/0.2)^{0.37}$	$((d+0.2)/0.2)^{0.178}$	$e^{(0.0077*ms)}$	1.0	$e^{(-0.5966*(hp-1))}$	1.0
Flashing Lights	0.000335	$((c*t+0.2)/0.2)^{0.41}$	$((d+0.2)/0.2)^{0.1131}$	1.0	$e^{(0.1917*mt)}$	1.0	$e^{(0.1826*(hl-1))}$
Gates	0.000575	$((c*t+0.2)/0.2)^{0.29}$	$((d+0.2)/0.2)^{0.18}$	1.0	$e^{(0.1512*mt)}$	1.0	$e^{(0.1420*(hl-1))}$

Notation:

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 or not (1 and 0)

ms = maximum timetable speed, mph

h1 = number of highway lanes

2.2 Methods Used in Predicting Road Collisions

Considerable research has been carried out over the last 15-20 years on developing different types of models for predicting road collisions. The main focus of this work has been to establish statistical links between predicted collisions and various road geometric, traffic and exposure attributes.

Early prediction models adopted simple multivariate linear regression techniques to establish a relationship between road geometry, traffic characteristics and collisions (Wright and Burnham, 1985). Multivariate linear regression unfortunately failed to yield good results, since the underlying relationship proved to be essentially non-linear.

A number of researchers adopted Generalized Linear Models (GLM) to predict road collisions (Hauer and Persaud, 1987; Saccomanno and Buyco, 1988). The underlying probability distribution in these GLM models is either Poisson or Negative Binomial. Poisson models attempted to capture the discrete, non-negative and somewhat rare nature of collisions. Maximum likelihood techniques are used to obtain best-fit model parameters. In these models, the expected number of collisions (per exposure) is expressed as a linear function of selected explanatory factors at a given location.

One of the limitations of Poisson models is that the mean (expected number of collisions) is assumed to be equal to its variance. Recent research on road collision prediction, however, has shown that depending on the observed data this assertion is not always valid and must be investigated for different databases. In some databases, historical collisions deviate considerably from the mean equal to variance assumption inherent in the Poisson expression, and this could introduce significant prediction error in the model results.

In many road collision databases, the variance in collision frequency is normally higher than the mean, indicating a lack of explanation in the underlying Poisson model. This is referred to as Poisson over-dispersion. Poisson over-dispersion in road collision data has been addressed by a number of researchers in recent years. Miaou (1993) recommends using a more flexible Negative Binomial model to overcome the over-dispersion problem in the historical data. Bonneson (1993) and Daniel et al. (2002) reached similar conclusions that the Negative Binomial model can overcome much of the over-dispersion error associated with Poisson models.

Hauer and Persaud (1987) suggest using an Empirical Bayesian (EB) approach that adjusts Poisson model estimates externally by historical collision experience. The EB model should be viewed as a parallel approach to the Negative Binomial model rather than its replacement. The EB model has been discussed extensively in the literature to predict most types of rare events. Saccomanno et al. (2001) and Persaud (1990) have used EB models to designate highway black spots.

2.3 Collision Consequence Models

2.3.1 US-DOT Consequence Model (1987)

The US-DOT (Farr, 1987) collision consequence model for highway-railway grade crossings considers two levels of severity: fatalities and casualties. Fatal collisions are defined as collisions that result in at least one fatality, while casualty collisions are defined as collisions that result in either at least one fatality or injury. Both types of collisions are reported in the Federal Railway Administration (FRA) occurrence databases. As considered in the US-DOT consequence model, fatal collisions are a sub-set of casualty collisions.

In the US-DOT consequence model the probability of a fatal collision (FA) given the prior occurrence of a collision (C) is expressed as:

$$P(FA/C) = 1/(1 + KF \times MS \times TT \times TS \times UR) \quad \textbf{(2.7)}$$

Where:
- KF = 440.9, MS = ms $^{-0.9981}$, TT = (tt + 1) $^{-0.0872}$
- TS = (ts + 1) $^{0.0872}$, UR = e $^{0.3571ur}$
- ms = maximum timetable train speed
- tt = through trains per day
- ts = switch trains per day
- ur = urban rural crossing, 0 for rural and 1 for urban

The probability of a casualty collision (CA) given a collision is expressed as:

$$P(CA/C) = 1/(1+ KC \times MS \times TK \times UR) \quad \textbf{(2.8)}$$

Where:
- KC = 4.481
- MS = ms $^{-0.343}$
- TK = e$^{-0.1153tk}$
- UR = e $^{0.3571ur}$
- Tk = total number of tracks

The expected number of fatal and casualty collisions per crossing was obtained by multiplying the expected number of collisions by the conditional probability of a fatal or casualty collision, such that:

$$E(FA) = E[C] \times P(FC/C) \quad \textbf{(2.9)}$$
$$E(CA) = E[C] \times P(CA/C) \quad \textbf{(2.10)}$$

It should be noted that US-DOT consequence model does not take into account the type of warning device found at a given crossing. Moreover, the model treats all fatal collisions in a similar fashion regardless of number of fatalities incurred. The US-DOT consequence model focuses on the likelihood of a fatal and/or casualty collision, not the numbers of fatalities or casualties associated with each collision. This limits its use in distinguishing differences in severity among different collisions at a given crossing.

2.3.2 Road Collision Consequence Models

A number of statistical methodologies for predicting road collision severity or consequence have been documented. Nassar et al. (1994) proposed a series of sequential, nested logit models to predict occupant injury severity for road collisions. Three classes of explanatory factors were considered: physical (energy dissipation), driver condition and action, and occupant passive response (e.g. wearing a seat belt, seating location in vehicle). Since the Nassar model is occupant-specific, the severity of a given collision requires the summation of the severity experienced by all occupants of all vehicles involved.

Some studies suggest using log-linear regression models rather than logit models to predict road collision severity. It is argued that logit models do not provide a systematic means of considering interactions among the various independent risk factors. Chen (1999) adopts a log-linear model to investigate the risk factors affecting bus driver injury severity, and finds significant interaction effects between collision fault, time of collision, and collision type affected severity. It is noted that different levels of severity might be aggregated into a single combined value which can be linked with risk factors for predicting overall collision consequence at a given location (or grade crossing).

2.4 Risk Factors Explaining Collisions at Grade Crossings

Risk factors refer to crossing attributes that explain variation in risk including the expected number of collisions and their consequences. In this analysis we consider the five types of risk-factors: warning device, daily highway traffic volume, highway surface width, number of tracks, number of daily trains, and vehicle and driver characteristics. Exposure at a given crossing is defined as the cross-product between the average daily traffic volume (AADT) and the number of trains per day.

2.4.1 Warning Devices

The type of warning device has a significant effect on risk at grade crossings (Farr, 1987). In general, there are two types of warning devices: passive and active. Passive devices include signs. Active devices include flashing lights and/or gates. In this study, other warning devices have been categorized under these three main classes.

Passive traffic control systems consisting of signs, pavement markings, and grade crossing illumination, identify and direct attention to the location of a grade crossing. Passive devices themselves provide no information to motorists on whether a train is actually approaching. Instead, crossing users must, upon being notified that they are entering a grade crossing, determine for themselves whether a train is approaching and if it is safe to cross the tracks.

Active traffic control systems provide crossing users with the message that a train is actually approaching the crossing. The user must surmise as to where the train could be with respect to the crossing (e.g., 5 secs, 10 secs, 15 secs, etc). When a train is detected, typically some form of track circuitry activates the warning device at the grade crossing, such as: 1) flashing light signals and bells, or 2) automatic gates.

2.4.2 Highway Characteristics

Previous research has highlighted a number of highway characteristics affecting collisions at grade crossings. These include traffic volume on roads, vehicle speed, road surface type and width, number of lanes, etc. This section summarizes the main findings on the effects of highway characteristics on grade crossing collisions.

Traffic volume

Traffic volume on an intersected highway of a grade crossing has obvious impact on the collision risk. The more traffic volume on highway, the more vehicles are exposed to conflicts with train movements, the greater the probability of collision. Previous collision studies such as Coleman-Stewart (1976) and the US-DOT model (Farr, 1987) have used the traffic volume as one of the important variables in their collision prediction models. Traffic volume is expressed in terms of the Average Annual Daily Traffic volume (AADT).

Surface width

Surface width affects vehicle-train collisions as well as vehicle-vehicle collisions. Width can be used to reflect the number of lanes. An increase in the number of traffic lanes translates into higher traffic volume on the grade crossing and greater chances for collisions. In addition, driver visibility usually decreases as traffic at a grade crossing increases.

Crossing surface width refers to the width of the highway in metres plus shoulders (0.5 metres on each side) as measured at the crossing approach. The distance is measured at right angles to the centre line of the highway.

2.4.3 Railway Characteristics

The main railway characteristics that affect risk at grade crossings include number of tracks and number of trains per day.

Number of tracks

Tracks are categorized into several classes (single main line, double main line, siding, switching, etc). Mainline tracks usually carry through train movement, while other tracks serve switching movements or terminal movements. The number of tracks affects collision frequency and consequence.

Track angle

Track angle refers to an intersection angle between the roadway and track. The convention is to report this angle with respect to a perpendicular line to the track at its intersection with the roadway centre line. Previous research suggests that track angle has a slight effect on collision frequency and consequence.

Number of trains daily

Trains are classified into through trains (freight train and passenger train) and switch trains. The train characteristics, such as train length, weight, braking system, speed, and number of daily trains influence the safety at highway-railway grade crossings. In the US DOT model, in addition to considering train exposure as one variable for both collision frequency and consequence, the number of daily through trains was also found to affect collision frequency.

In the US-DOT model, train speed was found to affect both collision frequency and consequence. For consequence, an increase in train speed results in an increase in collision severity.

2.4.4 Driver and Vehicle Attributes

Driver attributes are a key component to explaining the occurrence of highway-railway grade crossing collisions. Driver's decision and reaction time, as well as his ability to judge train speed and observe multiple events at once, are all important factors. At passive crossings, driver error and misperception may lead to collisions. Active crossings can reduce recognition errors, but produce other forms of driving behavior error.

Highway-railway grade crossings are exposed to diverse vehicles, from motorcycles to tractor-trailers. These vehicles have contrasting characteristics that directly influence safety at grade crossings. Equally important is the cargo these vehicles carry, such as children in school buses and dangerous goods in trucks. Vehicle speed, size and weight, accelerating and braking performances are important attributes affecting the risk at grade crossings. On average, heavy trucks are involved in 16 percent of all crossing collisions.

3 DATA SOURCES

This chapter describes the data used to develop the highway-railway grade crossing risk prediction models described in sections four and five. The discussion focuses on the data sources, their consolidation for analysis, and explanatory variables used in the prediction models.

This study uses the combined IRIS inventory and RODS occurrence database provided respectively by Transport Canada (TC) and the Transportation Safety Board (TSB). The IRIS database contains an inventory of approximately 29,500 grade crossings for all regions in Canada including information on highway and railway geometric characteristics, traffic volumes and selected train operating features. The RODS database includes information on collision occurrence at these crossings for the period 1993-2001. The occurrence database is assembled by TSB, whereas IRIS is the crossing characteristics database assembled by TC. The inventory and occurrence databases share a common reference number that permits linkage of each collision occurrence to public crossings specified by municipality and province.

3.1 Inventory Database (IRIS)

This database provides information on geometric characteristics, traffic control and volume for each of the 29,507 grade crossings in Canada. Six data attributes are included in this database (sample distributions of these attributes are given in Appendix A).

Location data

Each crossing in the data set has a location ID, which indicates its location by street, municipality and province. This data set contains crossing information from the following regions of Canada:

- 7357 crossings in Ontario
- 6469 crossings in Saskatchewan
- 4127 crossings from Quebec
- 4074 crossings in Alberta
- 3161 crossings in Manitoba
- 2185 crossings in British Columbia
- 1291 crossings in New Brunswick
- 809 crossings in Nova Scotia
- 16 crossings in Northwest Territory
- 9 crossings in Newfoundland
- 8 crossings in Yukon
- 1 crossing in Prince Edward Island

This yields a total number of 29,507 crossings Canada-wide.

Type of warning device

Nine types of warning devices are cited in the database:

1. Flashing light signals and bell
2. Flashing light signals and bells with gates
3. Traffic lights
4. Flashing light, bell and traffic lights
5. Flashing light, bell, gate and traffic lights
6. Railway crossing sign (wigwags or cross-bucks)
7. Signals and bell
8. Manual gates
9. Reflectorized signboard
10. Unknown/information not available

For the purpose of this analysis, three of the nine types of warning devices were considered, including signs only (S, Type 9), signs and flashing lights (F, Type 1), and signs, flashing lights and gates (G, Type 2), which account for 77 percent of the 29,507 crossings. The rest were not considered, since most are not assigned warning types (Unknown).

Grade crossing type

Five types of grade crossings are reported, namely: public automated, public passive, private, farm, and grade separation. For this study, only public grade crossings (automated and passive) were considered, which account for 77 percent of the grade crossings in Canada.

Highway geometric data

The database provides information on highway geometric characteristics at grade crossings, including highway surface material, road surface width (ft), road type and posted road speed (km/h). Roads are classified into nine types: arterial, collector, bikeway path, farm road, local low volume road, pedestrian path, private access, snowmobile path, and unopened road. Surface materials include: asphalt, concrete, gravel and other. Crossings with non-motor vehicle roads were not considered.

Railway geometric data

The database provides information on railway geometric characteristics, including number of tracks, track angle, maximum train speed (mph), maximum passenger train speed (mph), maximum freight train speed (mph) and maximum switching train speed (mph).

Traffic volume data

Traffic volume data includes average annual daily traffic volume (AADT) for the road and the number of daily trains through each crossing, number of freight, passenger and switching trains daily at each crossing.

3.2 Collision Occurrence Database (RODS)

Collision occurrence data collected by TSB includes detailed information on each collision for the 29,000 plus Canada-wide crossings for the period 1993 to 2001. The collision occurrence database is organized into four types of information:

- **Basic collision data**
  This includes the collision reference number, the date and time of collision, location, weather conditions, road conditions (wet, dry, slippery, and snow/ice), road and rail geometry, traffic volume, train daily, etc. The data also specifies collision impact types, such as “train struck vehicle”, “train struck by vehicle” and “train struck pedestrian”.

- **Involved driver and vehicle data**
  The driver data includes information on driver action, visibility, gender, age, and so on. Driver action indicates the driver behavior at time of collision, such as: “driver skidded on track”, “drove around warning device”, “stopped then proceeded”, “failed to stop”, “stalled on track”, “was stuck on track”, “stopped too close to track”, “drove through gates”, “ignored warning device”. Vehicle data contains information on vehicle type, such as automobile, truck, tractor-trailer, bus, emergency vehicle, motorcycle, etc.

- **Involved person data**
  This data provide information on the number of vehicles involved in a collision and the average occupancy of each vehicle. This information is used to provide an estimate of the total number of persons involved in each collision, as an input in the consequence prediction model.

- **Consequence data**
  This data include information on the number of fatalities, serious injuries and extent of property damage for each collision. Crossing reference numbers (TC_NO) are provided to link collisions to the inventory database.

3.3 Consolidation of Databases

The RODS/IRIS database contains information on 29,507 crossings in Canada with 2905 collisions reported over the period 1993-2001. A number of crossings was found to be poorly specified for our purposes, that is, they did not include variables needed in our models, and these were removed from the usable database. Fortunately, most of these removed crossings (crossings with missing or erroneous data) are private or pedestrian/bike crossings. As a result, the data set used in this study includes collision history and inventory information for 10,381 usable crossings in Canada for the period of 1993 to 2001. The crossings for which warning devices were changed over the period 1993-2001 were considered twice in our database (before and after warning device change), yielding a total of 10,797 observations.

Since more than half of the original crossing data were deleted from our analysis, sampling bias is possible. To address this issue, the average values of train speed, road speed, number of daily trains and AADT for selected crossings was determined and compared with average values from the total population. The results are summarized in Table 3-1. Some slight differences occur but the two estimates tend to agree with each other.

Since collision information and grade crossing characteristics are specified in two separate data tables, data are linked by common crossing reference numbers (TC_NO). Queries were created in MS Access to link these two databases.

The inventory and occurrence databases were subsequently combined to calibrate and validate the collision frequency and consequence prediction models discussed in this report. A total of ten explanatory variables were considered for these models, as illustrated in Table 3-2. The dependent variable is the expected number of collisions for frequency models and the expected consequence score per collision for consequence models.

3.4 Description of Collision Occurrences

For the 10,797 usable observations (10,381 unique crossings) in the data, a total of 1,724 collisions were reported over the nine-year period (1993-2001) in Canada. These collisions resulted in 242 fatalities and 347 serious injuries. Tables 3-3a and 3-3b summarize the distribution of crossings and collisions by type of warning device (WD) and consequence. The WD specified in this table corresponds to the status of the crossings for the year for which the collisions were reported in RODS. This information was obtained by comparing warning device (WD) status with the Transport Canada work plan (with WD upgrades) for the period 1993-2001.

Property damage was reported for 12 categories of property type and four categories of damage. The twelve categories are: rail buildings, private buildings, private vehicles, locomotives, passenger cars, freight cars, truck unit, tunnel, culvert, bridges, shed, and track. The four categories of damage are: destroyed, major damage, minor damage and no damage.

Table 3-1 Comparison of selected sample data with total crossing population

	Train Speed	Road Speed	Number of Daily Trains	AADT
Data selected	41	59	10	1657
Data Total	37	57	7	1218

Table 3-2 Explanatory and dependent variables

Category	Variable	Description
Warning Devices	Signs, Flashing lights, Gates	
Highway Characteristics	Road Speed	km/h
	Surface Width	ft
	Surface Type	
	Road Class	
Railway Characteristics	Number of Tracks	Number
	Train Speed	mph
	Track Angle	Degree
Traffic Volume	Number of Vehicles Daily	Average annual daily traffic
	Number of Trains Daily	
Collision Observations	Number Collisions	
	Number Fatality	
	Number of Serious Injuries	

Table 3-3a Crossings inventory based on warning device (2001)

Warning Type	Number of Crossings
Crossings with signs	5184
Crossings with signs and flashing lights	3695
Crossings with signs, flashing lights and gates	1502
Total	**10381**

Table 3-3b Collision frequency and consequence (1993-2001)

Warning Type (at the time when a collision occurred)	Number of Collisions	Number of Fatalities	Number of Serious Injuries
Crossings with signs	698	109	143
Crossings with signs and flashing lights	733	86	154
Crossings with signs, flashing lights and gates	293	47	50
Total	**1724**	**242**	**347**

3.5 Statistical Description

Tables 3-4 and 3-5 provide a summary of the statistics for the different variables, as reported in the RODS/IRIS database. These have been used in the development of frequency and consequence prediction models. Sample distribution of each variable is given in Appendix A. Traffic exposure for crossings is defined as the cross product of AADT and number of trains daily. In these tables, note that the maximum number of collisions per crossing as reported in the database is seven, with a maximum of two fatalities and three serious injuries for the 1993 to 2001 period. A significant amount of variation is observed for train speed, road speed (in km/h), number of tracks, and track angle. There is also a significant variation in exposure among various crossings in the data set.

A separate correlation analysis indicates that most variables, except road speed and road class, were not correlated. Reported variables demonstrated significant variation in values for factors input into the regression models.

Table 3-4 Statistical description of prediction data used in collision frequency

Variables	Unit	Mean	Sample Standard Deviation	Minimum	Maximum
Track_Angle	Degree	70.26	19.17	3	90
Track_No	Number	1.23	0.58	1	9
Train_Speed	mph	41.00	20.72	4	100
Road_Speed	km/h	59.39	21.16	5	110
Surface_Width	ft	10.62	5.42	2	99
Road_Class	1, arterial; 0, others				
Highway_Paved	1, paved; 0, unpaved				
Warning_Type	1, signs; 0, others				
AADT	Vehicle/day	1602.32	4054.34	1	57,000
No of Trains Daily	Trains/day	9.50	13.06	1	338
Number of Collisions	Over 9 years period	0.177	0.52	0	7

Table 3-5 Statistical description of prediction data used in collision consequence

Variables	Unit	Mean	Sample Standard Deviation	Minimum	Maximum
Track_Angle	Degree	71.64	18.18	11	90
Track_No	Number	1.36	0.72	1	6
Train_Speed	mph	44.41	21.80	5	95
Road_Speed	km/h	57.80	19.63	10	100
Surface_Width	ft	12.58	5.95	3	53
Road_Class	1, arterial; 0, others				
Highway_Paved	1, paved; 0, unpaved				
Warning_Type	1, signs; 0, others				
AADT	Vehicle/day	3689.03	6287.01	1	57000
No of Trains Daily	Trains/day	13.46	13.04	1	122
Number Collision	Number	1.03	0.19	1	3
Number Fatalities	Number	0.13	0.36	0	2
Number serious Injuries	Number	0.20	0.48	0	3

4 PREDICTING COLLISION FREQUENCY

This section describes the development of collision prediction models for highway-railway grade crossings in Canada. Distinctive collision prediction models were developed for each type of warning device: signs only (S), flashing lights (F) and gates (G). Various assumptions on the distribution of observed collisions were investigated. Based on validation analysis using a data set independent of calibration, a Poisson prediction model was found to yield the best results. This model was used to investigate the sensitivity of collisions at crossings to various factors, including crossing type, road speed, AADT, surface width, train speed, number of tracks, number of trains, and warning device.

This section is organized into three parts. First, the transferability of the US-DOT collision prediction model to Canadian data is reviewed. Second, a set of collision models are developed and validated for the Canadian data. Third, the sensitivity of the Canadian model is investigated with respect to selected crossing characteristics.

4.1 Transferability of the US-DOT Collision Prediction Model to Canadian Data

Initially the transferability of the US-DOT model was tested to predict collisions for Canadian crossings in the RODS/IRIS database. A number of crossings in the RODS/IRIS database were found to be poorly specified for our purposes (did not include variables cited in the original US-DOT model), and these were removed from further analysis.

Differences between predicted and observed collisions were compared using a Chi-squared goodness-of-fit test. The Chi-squared goodness-of-fit test provides a comparison between observed and estimated (from the model) number of collisions for different combinations of crossing attributes. For this test, crossings in the database were classified according to three types of warning device, three levels of train speed and two levels of traffic exposure. A low Chi-Sq value (not statistically significant) suggests a good match between observed and expected results for the attributes considered.

For the above classification, the US-DOT model was found to over-estimate collisions for all crossings regardless of type of warning device (Chi-Sq greater than critical at the 5 percent level). Overall, the model predicted 349 more collisions than were observed in RODS/IRIS database for the period 1993-2001. On the basis of these aggregate results, we concluded that the US-DOT model did not adequately transfer to the Canadian data, and a separate collision prediction model was recommended. The reason for this lack of transferability is not immediately obvious. The result may be influenced by some subjective adjustments introduced in the US-DOT model reflecting conditions unique to the United States.

4.2 Collision Prediction Model Results

Two types of Poisson collision prediction models were developed. Model I includes “Type of Warning Device” at each crossing as a separate explanatory variable in a single prediction expression. Model II treats the warning devices separately. Model II consists of three distinctive expressions, one for each type of warning device (signs, flashing lights and gates). This model is similar to the approach adopted in the US-DOT model.

In obtaining the data set of 10,797 crossings for model calibration and validation, all private, farm and grade separated crossings were eliminated from the RODS/IRIS database. Other crossings with missing information were also deleted.

4.2.1 Data Splitting

Before developing a new collision prediction model for Canadian crossing observations, the RODS/IRIS data was divided into two random samples based on a 75 percent/25 percent split: one sample of 8,098 observations for model calibration and another sample of 2,699 crossings for model validation (Figure 4.1).

A total of 1724 collisions were reported in the usable RODS/IRIS database during the 1993-2001 period for all regions of Canada. The crossings breakdown with observed collisions is summarized in Table 4-1. Over 86 percent of crossings did not experience any collision during this nine year period. Crossings that reported collisions were found to experience mostly one or two collisions in the nine year period. This suggests that the data are dominated by zero collision occurrences. This presents some unique problems in using Poisson models to predict collisions at highway-railway grade crossings.

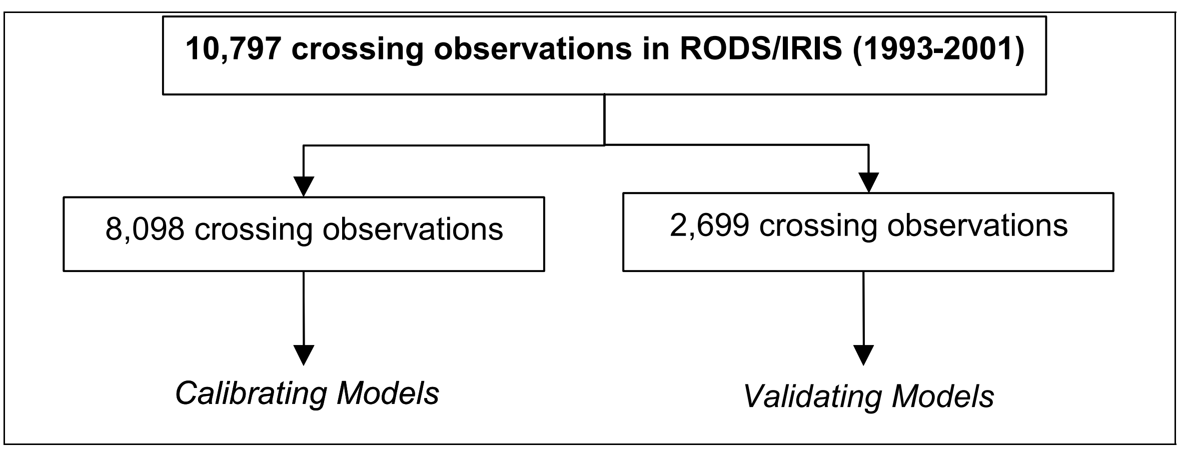

Figure 4.1 Crossing data splitting for model calibration and validation

Table 4-1 Crossing observations and observed collisions by type of warning devices

Warning Type	Total Data Set	Data used to Calibrating Model		Data used to Validating Model	
		Number of Crossings	Number of Collisions	Number of Crossings	Number of Collisions
Type S	5329	3983	496	1346	202
Type F	3966	2982	560	984	173
Type G	1502	1133	214	369	79
Total	**10797**	**8098**	**1270**	**2699**	**454**

4.2.2 Collision Prediction Model Results

Model I (Poisson)

For Model I, the type of warning device was introduced as a dummy variable: 1 for crossings with signs and 0 for crossings with flashing lights and/or gates. The "warning device" variable was found to be statistically significant at a level of 5 percent. A number of other variables were investigated including road class (arterial, or other road class), road pavement condition (paved or unpaved), track angle, number of tracks, train and road vehicle speed, road surface width and traffic exposure. Four of the eight factors were found to be statistically significant at the same 5 percent level.

The expected number of collisions per year at each crossing (E(m)) is expressed as:

$$E(m) = e^{[-6.3142 \; + 0.9798 \; * \mathrm{WD} \;\; 0.1057 \; * \mathrm{TN} + 0.0051 \; * \mathrm{TSPD} \; + 0.3933 \; * \; \ln(\mathrm{EXPO})]} \quad \textbf{(4.1)}$$

Where: WD = type of device dummy variable (1 for signs, and 0 for flashing lights or gates)

TN = number of railway tracks (both directions)

TSPD = maximum train speed (mph)

EXPO = cross product of AADT and number of trains daily

Note that all variables in equation 4.1 were also included in the US-DOT model. However, unlike the US-DOT model, the above expression does not include variables representing "Number of lanes", "Number of Through Trains" or "Road Pavement Type".

The above expression yielded a Scaled Deviance or G^2 statistic of 0.61 and Pearson Chi-square (X^2) of 1.098. Wood (2002) and Maher and Summergill (1996) argue that the X^2 statistic should be used to evaluate the model adequacy when the mean is low (as in values less than 0.5). In this case, it is noted that the Scaled

Deviance *(G^2)* is considerably less than 1.0 for this collision frequency prediction model. Based on the Pearson X^2 value close to 1.0, it is possible to conclude that the data is Poisson distributed. The problem of over-dispersion is not serious.

At the aggregate level, Model I yielded poor Chi-square goodness-of-fit results. It was noted that traffic exposure related to three types of warning device had different ranges. Crossings with gates had higher exposures than the other two crossing types. The model would not yield accurate results for crossings with gates at lower levels of exposure since there are fewer observations at these lower levels for this type of warning device. Similarly, for crossings with signs, there are fewer observations at higher levels of exposure. Model II overcomes this problem by separating the collision prediction for the three types of warning devices. In Model II, exposure is bound by the range for which observations are available.

Model II (Poisson)

For Model II, three separate regression expressions were obtained for each of the three types of warning devices (Type S, F and G as defined above). The results are as follows.

Type S Crossings

The Poisson model for crossings with signs only is:

$$E(m_S) = e^{[-5.66 \ + 0.0128 \ * \text{TSPD} \ + 0.3791 \ * \ln \ (\text{EXPO})]} \tag{4.2}$$

Where: *TSPD* = maximum train speed (mph)
EXPO = cross product of AADT and number of trains daily

In the above model, train speed and traffic exposure were found to be statistically significant. Despite these results, the model yielded a Pearson X^2 close to 1.0 (1.03) suggesting a small amount of over-dispersion in the data.

Next the above Poisson model was used to predict collisions at the crossings that were classified by train speed and traffic exposure. A Chi-square goodness-of-fit test was applied to the results. The calculated Chi-square (12.87) is close to the critical value ($\chi^2_{0.05,\ 5}$ =11.07) at the 5 percent level. Notwithstanding the problem of over-dispersion in the data, the results are reasonable and statistically sound for crossings with signs.

Type F Crossings

The model for crossings with signs and flashing lights is of the form:

$$E(m_F) = e^{[-9.1620 + 0.0112 * \text{TSPD} + 0.0151 * \text{SW} + 0.6103 * \ln(\text{EXPO})]} \quad \textbf{(4.3)}$$

Where: *TSPD* = maximum train speed (mph)
SW = surface width (ft)
EXPO = cross product of AADT and number of trains daily

This expression contains three statistically significant explanatory variables. Again the variables are consistent with the US DOT model for this type of warning device. A Pearson X^2 value of 1.15 indicates a small amount of over-dispersion in the data.

The Chi-square goodness-of-fit value (14.87) comparing observed and predicted collisions for different train speeds and traffic exposure is slightly higher than critical value ($\chi^2_{0.05,\,5}$ =11.07) at a 5 percent level of significance.

Type G Crossings

A third collision prediction expression was obtained for crossings with signs, flashing lights and gates. The expression is of the form:

$$E(m_G) = e^{[-7.2304 + 0.0118 * \text{RSPD} + 0.1912 * \text{TN} + 0.3526 * \ln(\text{EXPO})]} \quad \textbf{(4.4)}$$

Where: *RSPD* = road speed (km/h)
TN = number of railway tracks (both directions)
EXPO = cross product of AADT and number of trains daily

Three explanatory variables were found to be statistically significant in this expression, similar to those included in the original US-DOT model for this type of crossings. The additional variable included in the US-DOT model is the number of highway lanes. In this analysis, the number of highway lanes or surface width was not significant at the 5 percent level. A Pearson X^2 value of 1.15 suggests a small amount of over-dispersion in the data.

The Chi-square goodness-of-fit test yielded good results, when crossings were classified by train speed and traffic exposure, i.e. Chi-square value (6.12) less than the critical value at 5 percent level. This indicates a good match to the observed data.

4.3 Empirical Bayesian Adjustment to Poisson Results

A number of researchers have suggested that the Empirical Bayesian model provides a good solution for problems of data over-dispersion. We have included the EB prediction model in this paper solely for the purposes of comparison to the Poisson model.

As shown in Equation 4.5, the EB model provides an estimate of predicted collisions at individual crossings (ε) based on both statistical (Poisson model) and historical input. The inclusion of historical input may reflect the zero collision events in the observed data. As such, it is expected to give a better prediction than the Poisson model alone.

The expression is of the form:

$$\varepsilon = \alpha * E(m) + (1-\alpha) * X \qquad \textbf{(4.5)}$$

Where: *E(m)* = Poisson predicted collisions from equations 4.1 – 4.4.
X = observed collisions per crossing

This expression includes a factor (α) that represents a weighted link between historically observed and Poisson predicted collisions at individual crossings. The expression for this factor is of the form:

$$\alpha = \frac{E(m)}{E(m) + K * E(m)^2} \qquad (4.6)$$

Since the EB method requires historical input, the RODS/IRIS data were separated time-wise into two samples. The first sample includes collisions reported in the first four years (1993-96). This sample was used to provide an estimate of ε in the EB expression. The second sample (1997-2000) was used to validate the model.

In the EB approach, the degree to which the data is under or over-dispersed, is expressed by the K-factor. This factor is estimated using iterative empirical methods in which the residual sum of squares (observed–predicted) for all crossings in the calibration data set is minimized. The procedure is discussed at length by Hutchinson and Mayne (1977) and is not discussed further in this report.

Three separate K-factors were estimated for each type of warning device, as follows:

Type of Warning Device	K-Factor
Type S	0.001
Type F	0.200
Type G	3.080

The EB model results were subsequently aggregated by warning device, train speed and traffic exposure and compared to observed collisions. From Figure 4.2, note that the EB model does not yield much improvement over the previous Poisson model. The EB model estimates depend on historical observations. In this case, historical observations in the first four years were higher than in the latter four years. As such, a major requirement of the EB model is the need to obtain sufficient years of observations to provide a realistic representation of historical collision risk at each crossing. Given the rare nature of crossing collisions, four years of observations may be insufficient. **As a result, we have adopted the Poisson model to predict grade crossing collisions in Canada for the three types of warning devices.**

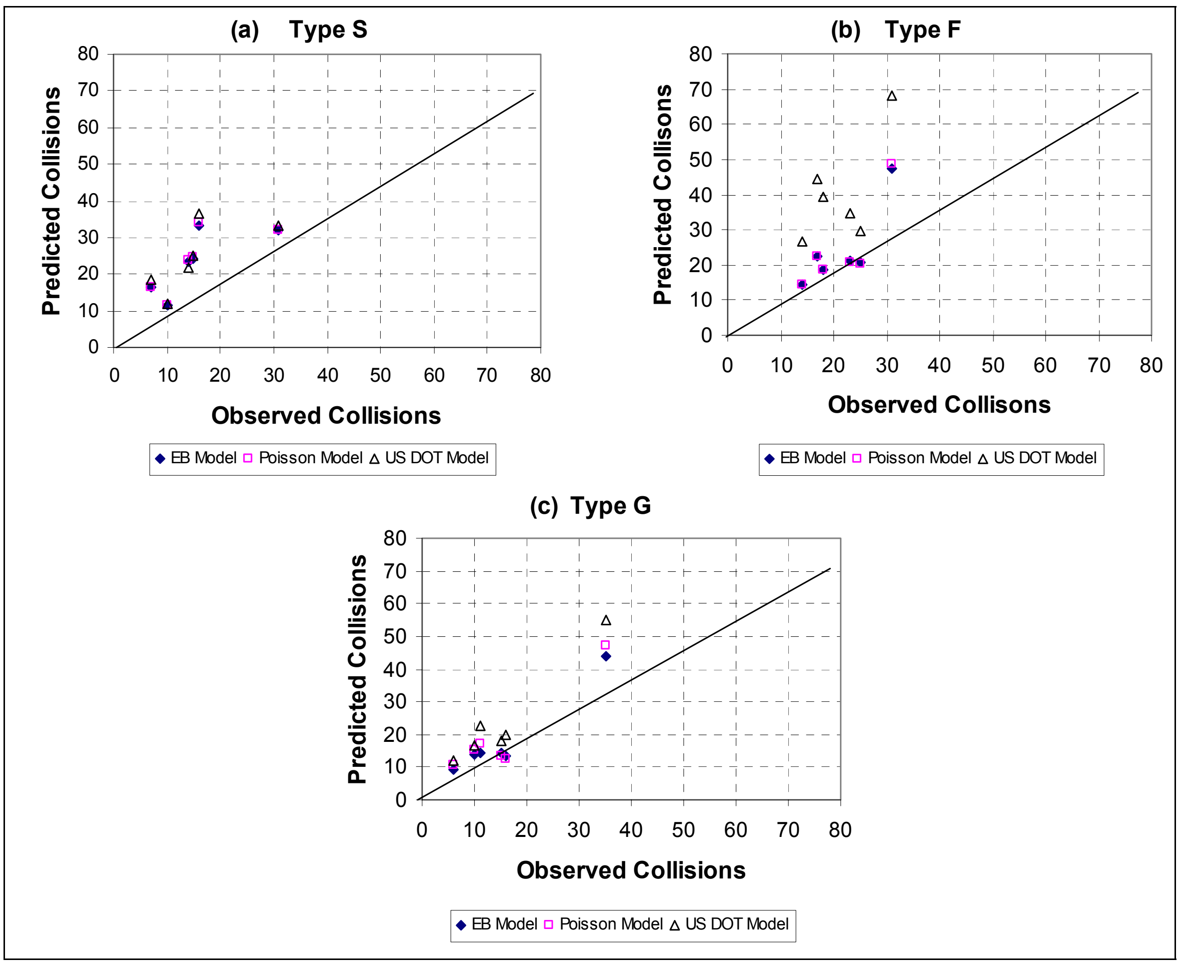

Figure 4.2 Comparison of Poisson, EB and US DOT model

4.4 Sensitivity Analysis (Poisson Collision Prediction Model)

This section describes a sensitivity analysis to identify those risk factors that have a significant impact on collisions at grade crossings. This analysis can shed some light on possible cost-effective strategies for reducing collisions at these crossings.

4.4.1 Effects of Warning Device

Figures 4.3(1) and 4.3(2) show the ratios of expected collisions among the three types of warning devices as related to AADT and train speed. Three observations emerge from this analysis:

First: the ratios of predicted collisions for flashing lights (Type F) and gates (Type G) as compared to signs (Type S) are consistently lower than 1.0 for all levels of AADT and train speeds. This suggests that if crossings are upgraded from signs to flashing lights or gates, some reduction in the number of collisions could occur. A word of caution is advised here. The results could be affected by lack of crossings with flashing lights and gates in the lower ranges of exposure (AADT).

Second: the expected benefit of upgrading from signs to flashing lights appears to be insensitive to train speed, but dependent on AADT. As expected, the higher the AADT, the lower the benefit obtained from the introduction of flashing lights, but the higher the benefit from installing gates.

Third: the model suggests that it is always beneficial to upgrade crossings from signs to flashing lights or gates. This finding depends on the range of exposure experienced at crossings for different types of warning devices. Collision reduction resulting from WD upgrading appears to be higher at crossings with higher train speeds.

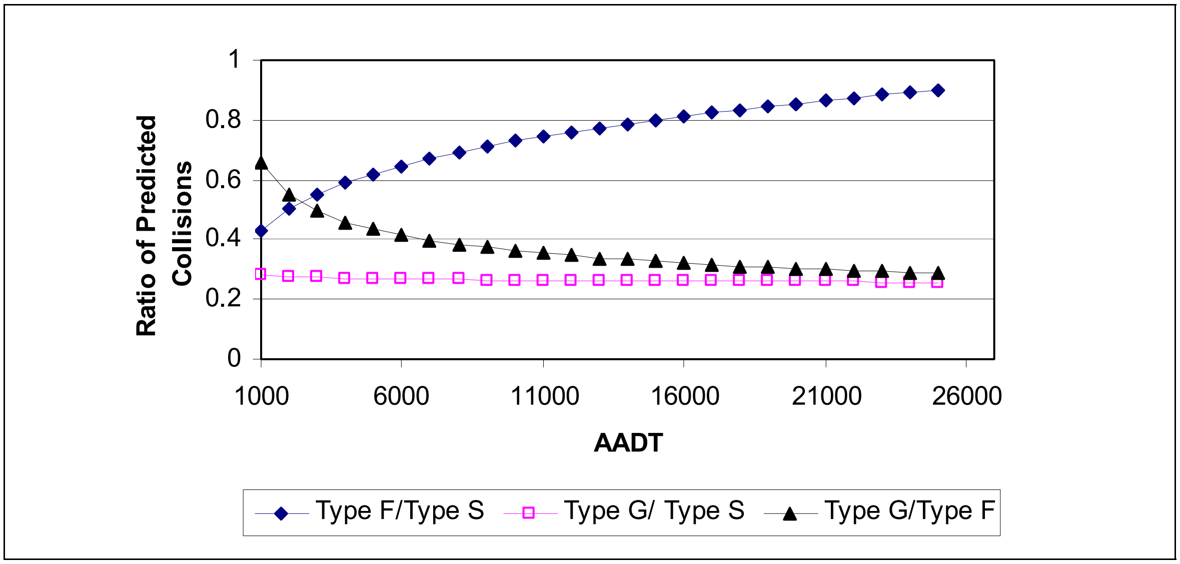

Figure 4.3(1) Relationship between collision ratios and AADT for three types of warning devices (controlled by train speed = 30 mph, road speed = 50 km/h, number of tracks = 2, surface width = 12 ft, and trains daily = 6)

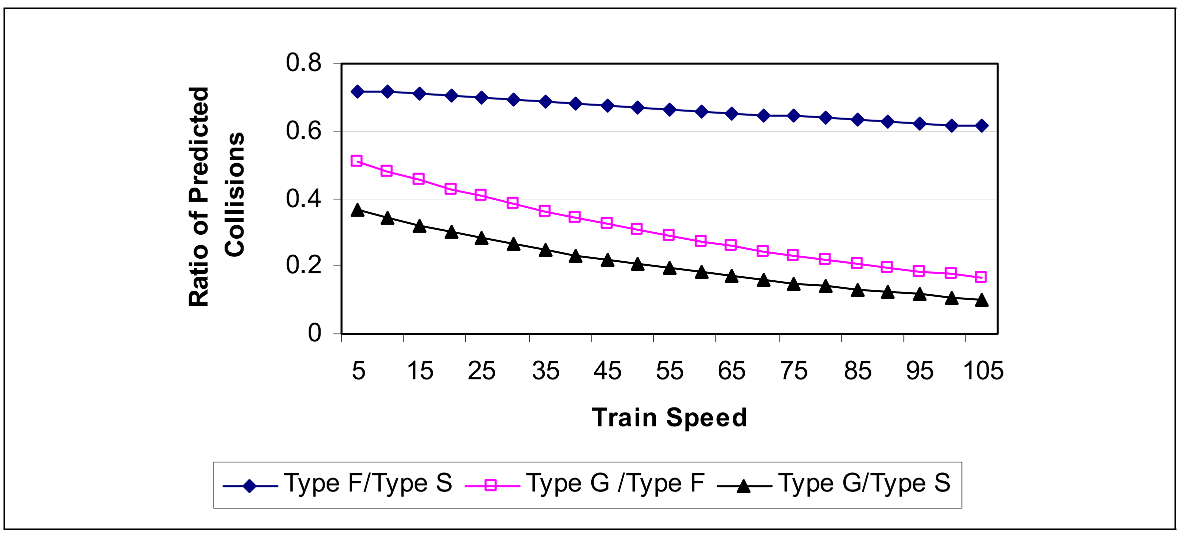

Figure 4.3(2) Relationship between collision ratios and train speed for three types of warning devices (controlled by AADT = 8000 vehicle/day, road speed = 50 km/h, number of tracks = 2, surface width = 12 ft, and number of trains daily = 6)

4.4.2 Effects of Highway Characteristics

The key highway-related risk factors that were found to explain collisions at grade crossings are: highway traffic volume or AADT (included in the variable *exposure*), road speed and surface width. Figures 4.4(1) and 4.4(2) illustrate the relationship between expected collisions per year versus AADT and Road Speed for the three types of warning devices.

As expected, traffic volume has a negative effect on the safety of grade crossings, regardless of the type of the warning device. Also, the expected number of collisions at crossings increases as traffic volume increases. The rate of increase depends on the type of warning devices, with sign and flashing light crossings having the highest and the gate crossings having the lowest. This means that traffic volume has a greater effect on collisions at sign and light crossings than those at flashing light and gate crossings. We note that at higher levels of AADT the predicted collisions at flashing lights increases to a value close to that obtained for signs. This implies that at higher levels of AADT the effectiveness of flashing lights diminishes.

Road speed has significant effect on the occurrence of collisions at gate crossings, but a negligible effect at crossings equipped with signs and flashing lights. Increases in road speed at gates result in an increased number of expected collisions. This result differs from that obtained in the US-DOT model, where road speed was not included for all types of warning device.

Other factors such as road "surface width" were found to have a significant effect on collisions at crossings equipped with flashing lights, their overall contribution to predicted collisions was not as large as that obtained for traffic exposure and road speed.

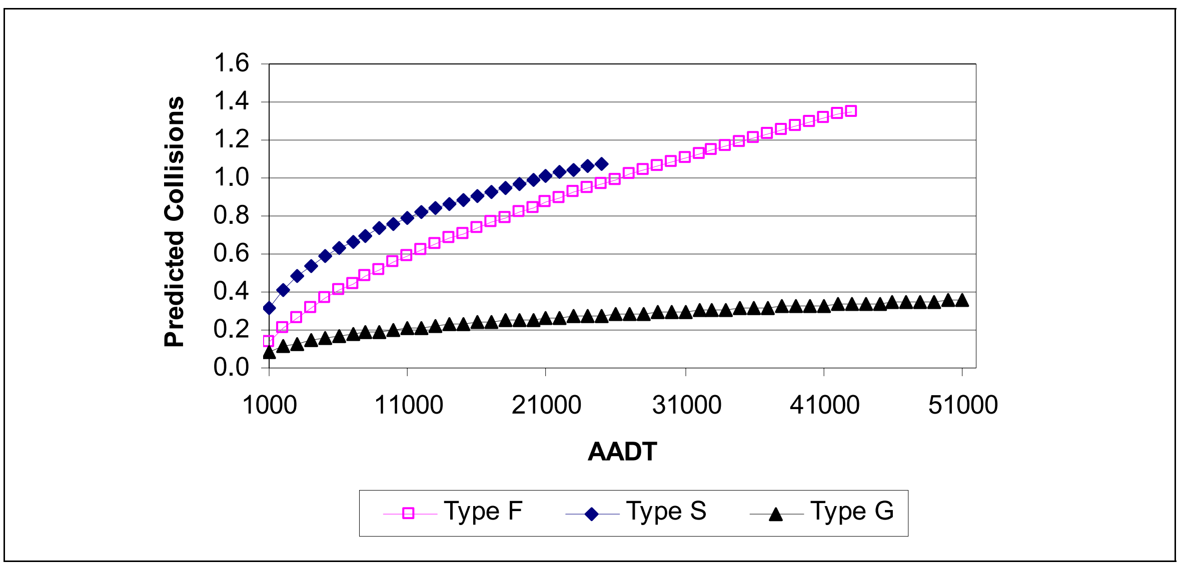

Figure 4.4(1) Relationship between collisions and AADT for three types of warning devices (controlled by train speed = 30 mph, road speed = 50 km/h, number of tracks = 2, surface width = 12 ft, and number of trains daily = 6)

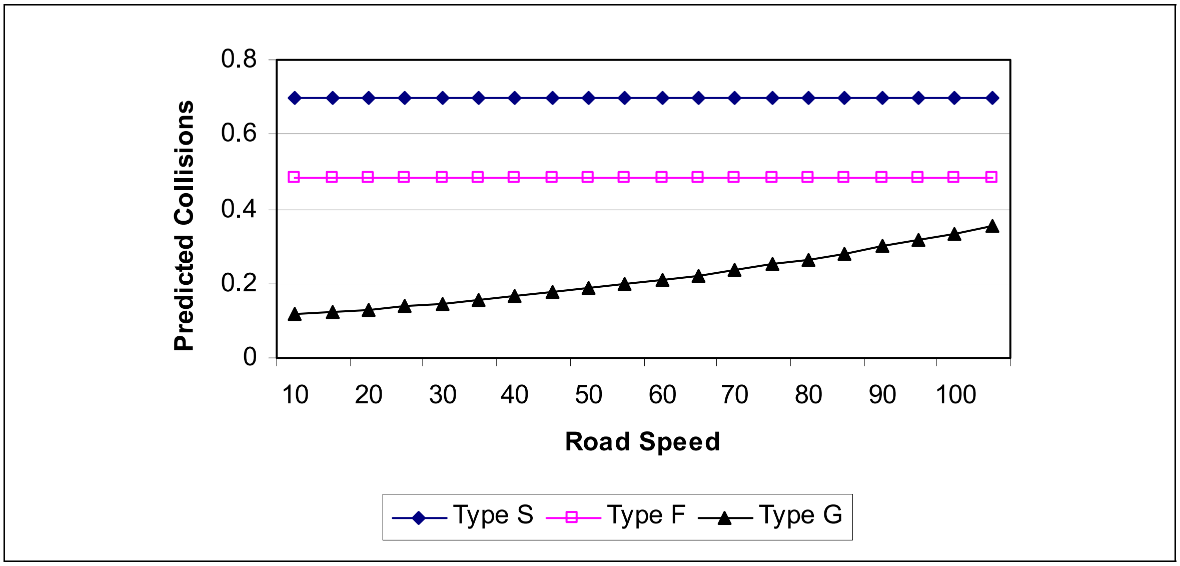

Figure 4.4(2) Relationship between collisions and road speed for three types of warning devices (controlled by AADT = 8000 vehicle/day, train speed = 30 mph, number of tracks = 2, surface width = 12 ft, and number of trains daily = 6)

4.4.3 Effect of Railway Characteristics

The railway-related characteristics that influence the expected number of collisions at crossings are number of trains daily, train speed and number of tracks. Figures 4.5(1) and 4.5(2) illustrate these relationships for the three types of warning devices. The number of tracks has no effect on collisions at crossings with signs and flashing lights, but a positive effect at gates.

Train speed has a positive (adverse) impact on collisions at sign crossings and flashing light crossings. With increases in train speed, collisions at these two types of crossings increase exponentially. At crossings equipped with gates, train speed has no affect on collisions. For the same train speed, sign crossings tend to experience more collisions than the other two types of crossings, and crossings with flashing lights tend to experience more collisions than crossings equipped with gates.

More collisions are expected with increases in the number of trains daily. At lower train volume, sign crossings tend to experience more collisions than at crossings equipped with flashing lights and gates. At higher train traffic levels, the expected collisions at crossings with flashing lights are close to those experienced to those for signs.

At lower values of trains daily, the sign crossings have the most collisions among the three types of crossings, followed by flashing light crossings. At these levels, crossings equipped with gates experience fewer collisions than for the other two types of crossings. At lower levels of “trains daily”, the models suggest that it would be beneficial to upgrade warning devices from signs to flashing lights or gates, but at higher values upgrading from signs to flashing lights would yield reduced safety dividends. At this level, upgrading to gates is recommended.

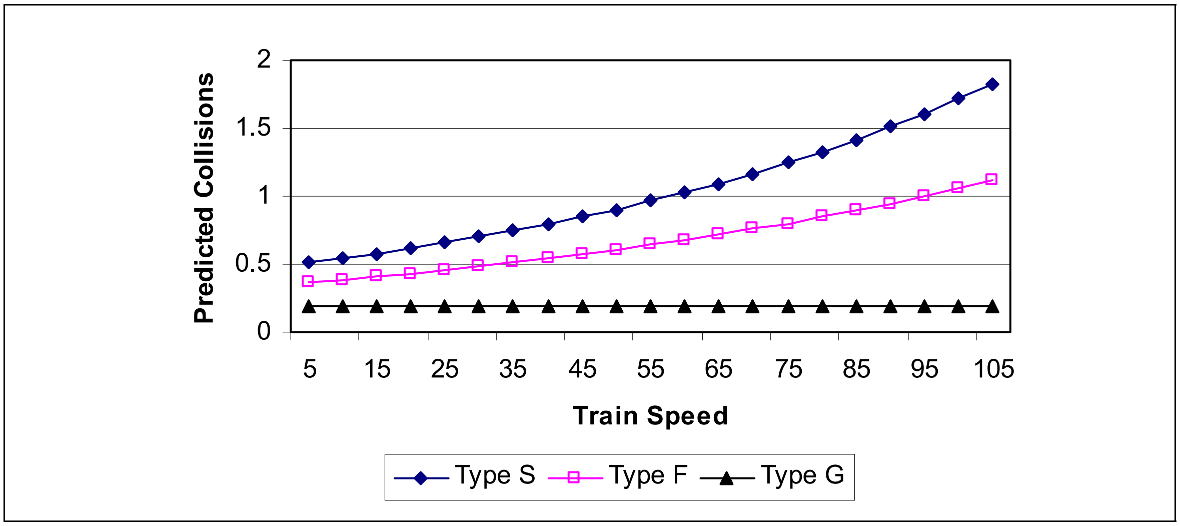

Figure 4.5(1) Relationship between collisions and train speed for three types of warning devices (controlled by AADT = 8000 vehicle/day, road speed = 50 km/h, number of tracks = 2, surface width = 12 ft, and number of train daily = 6)

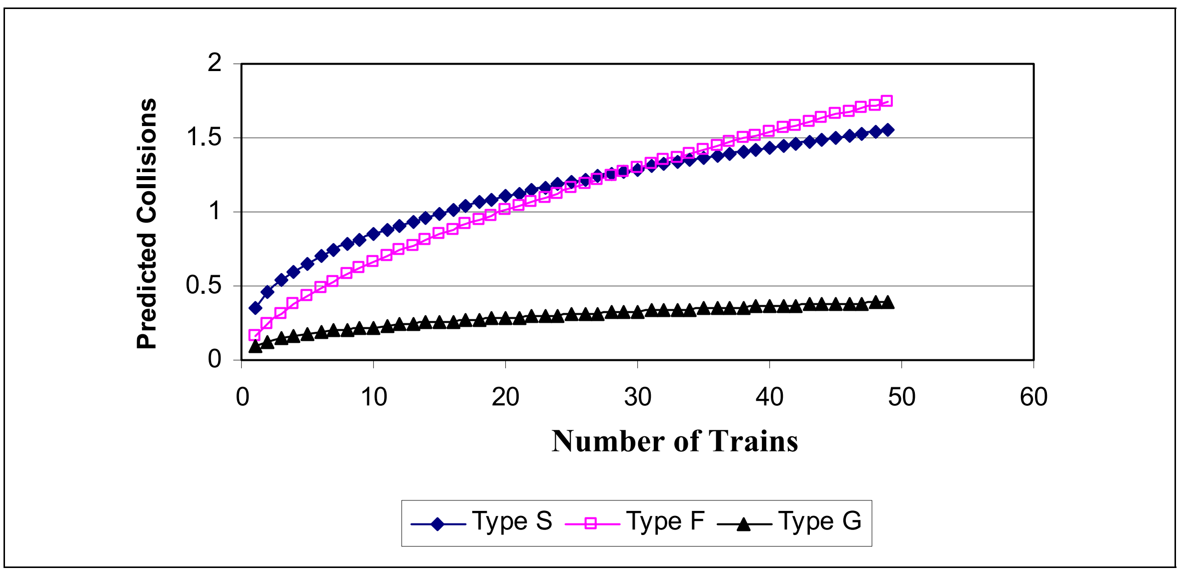

Figure 4.5(2) Relationship between collisions and number of trains for three types of warning devices (controlled by AADT = 8000 vehicle/day, train speed = 30 mph, road speed = 50 km/h, number of tracks = 2, and surface width = 12 ft)

4.4.4 Summary of Collision Prediction Results

A systematic safety improvement program for highway-railway grade crossings relies on models and tools that can be used to identify black spots (BS) where the risk of collision is unacceptably high and safety countermeasures are most warranted. This section presents a set of collision prediction models developed specifically for Canadian occurrence and exposure data. The US-DOT model was evaluated and found not to apply to Canadian data. Separate Poisson and Empirical Bayesian (EB) models were developed and evaluated for three different types of warning devices using crossing data for all the regions in Canada. Chi-square goodness-of-fit tests indicate that the Poisson model is best able to fit the observed data when crossings were grouped according to warning device, road and train volume (traffic exposure) and train speed. A sensitivity analysis using the calibrated models, lead to the following findings:

For the same crossing conditions (AADT, train speed, road speed and number of tracks), crossings equipped with signs experience the highest expected number of collisions per year among the three types of warning devices. This suggests that reduction in collisions can be expected if the warning devices at signed (passive devices) crossings are upgraded to flashing lights and gates (active devices).

While it is always beneficial to upgrade crossings from signs and flashing lights to gates, the relative effect of upgrading depends on road traffic volume, number of trains, train speed and surface width.

The expected number of collisions at crossings increases as road and train traffic volume increases. Traffic volume has a higher effect on expected collisions crossings with signs and flashing lights than at crossings equipped with gates.

Increased train speed has an adverse impact on the expected number of collisions at crossings with signs and flashing lights. For crossings equipped with gates, the effect is negligible.

We note that Canada has reported a noticeable reduction in collisions at grade crossings over the last 20 years. The above model indicates fewer collisions at crossings equipped with gates than crossings equipped with signs or flashing lights. This provides a possible explanation for the trend of collisions decreasing over time. That is, it could be due to an increasing number of crossings being upgraded to flashing lights and gates. However, this assertion needs further investigation, especially within the context of changing reporting thresholds.

5 PREDICTING COLLISION CONSEQUENCE

In this section we discuss: 1) an application of the US-DOT consequence model to Canadian data, and 2) the calibration and validation of the consequence model for the Canadian data.

5.1 US-DOT Consequence Model Applied to the Canadian Data

The transferability of the US-DOT consequence model was examined when applied to the collisions reported in the Canadian data. The resulting estimates at each crossing were subsequently aggregated according to three types of warning device, three types of train speed, and two types of traffic exposure. The predicted consequences differed significantly from the observed values, suggesting that the US-DOT model does not adequately reflect the Canadian data. This proved to be especially true in the case of casualty collisions. As a result, a new prediction model based on the Canadian collision consequence data was attempted. There are three basic reasons why a separate consequence model needs to be developed for the Canadian data as distinct from the US-DOT model: 1) poor goodness-of-fit results for the US DOT model applied to the Canadian data; 2) weak statistical basis of US DOT model and 3) inadequate treatment of correlation between fatality and casualty in the US-DOT model.

5.2 Canadian Collision Consequence Model

5.2.1 Establishing a Consequence Score

Fatalities and personal injuries were observed to be a very small subset of total crossing collisions in the Canadian data. Rather than developing separate models for each type of casualty as per the US-DOT approach, we adopted a combined model that reflects the total consequence of a given collision. The total consequence is expressed in terms of a collision "severity score", defined as the weighted sum of different types of consequence. This approach has several advantages: 1) it considers both fatalities and injuries in single expression rendering that is easier to use in black spot identification, 2) it makes better use of crossing data; all crossing with collisions are considered, not just those with casualties or fatalities, and 3) it accounts for co-linearity between fatalities and personal injuries, so that nesting the models is not required, as in US-DOT expressions.

Since fatalities, injuries, and property damage contribute disproportionately to collision severity, each of these consequences was weighted according to their reported costs. These costs form a uniform value or "yardstick" by which we can compare different collision consequences, such as severity of fatalities, personal injuries and vehicle/property damage. The weighted sum of collision consequences yields a "consequence score". This score can be related statistically to a number of crossing characteristics, control factors and measures of exposure to yield an estimate of expected consequences (or severity) at each crossing.

The weights assigned to fatalities and personal injuries were based on 1995 United States National Safety Council (NSC) cost estimates (California Life-cycle Benefit/Cost Analysis Model, California Department of Transportation, 1999). For property damage, weights were obtained from estimates provided by US Federal Railroad Administration (FRA) using a willingness-to-pay approach.

The average cost of different collision consequences were reported by the FRA in US$1995 as:

Fatality:	$2,710,000/Fatality
Injuries:	$65,590/Injury
Average Property damage:	$61,950/Train collision

The weight for property damage was set equal to 1.0 and scaled accordingly for other consequences to yield a collision consequence score (CS_i) of the form:

$$CS_i = 44 \times NF_i + 1 \times NI_i + 1 \times PD_i \qquad \textbf{(5.1)}$$

NF_i = number of fatalities
NI_i = number of injuries
PD_i = property damage

This score reflects the severity of collisions at grade crossings based on the number of fatalities, injuries and property damage.

Collision severity data was obtained from Canadian Transportation Safety Board (TSB). In this database, property damage is reported according to 12 categories of property type (including vehicle type) and four levels of damage. The value equivalence was assigned based on average values for each type of property according to published values. The four levels of damage in the RODS/IRIS database include: totally destroyed, major damage (80 percent destroyed), minor damage (30 percent destroyed) and no damage. Percentage values were assigned in this study using best judgment.

5.2.2 Data Splitting

Due to lack of information in the RODS/IRIS database, some crossings were deleted from the analysis. The final data set used for the calibrated consequence model contains 826 collisions on 720 crossings Canada-wide for the period 1997 to 2001. The consequence variable was expressed as a score based on reported fatalities, personal injuries and property damage. The explanatory risk factors in the data consisted of train speed, road speed, number of tracks, track angle, surface width, AADT, number of train daily, and occupants of all road vehicles involved in a given collision.

The data was split randomly for calibration and validation as per Figure 5.1, 413 collisions for calibration and 413 collisions for validation.

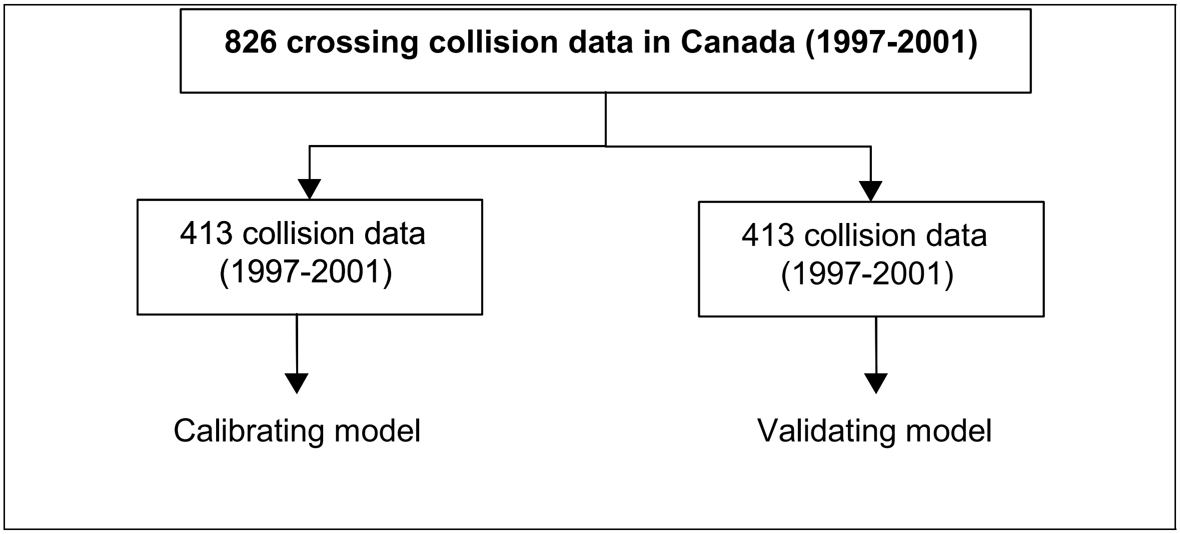

Figure 5.1 Data split for consequence model

5.2.3 Calibration of Canadian Collision Consequence Model

Initially, a Poisson model was fitted using the collision consequence score. The consequence score was summed over all collisions at each crossing and then divided by the number of crossing collisions. This yielded a crossing consequence score per collision as the dependent variable in the collision consequence model. The total number of persons involved in each collision was obtained by multiplying the number of vehicles involved in the collision by the number of occupants for all road vehicles involved. This variable was treated as a non-linear independent offset in consequence model.

The Poisson consequence model is of the form:

$$E(C/C) = e^{(-0.4818 + 0.0718 * PI - 0.2433 * TN + 0.0051 * TA + 0.0253 * TSPD)} \quad \textbf{(5.2)}$$

Where: *E(C/C)* = expected consequence/collision
PI = number of persons involved
TN = number of railway tracks (both directions)
TA = track angle
TSPD = maximum train speed (mph)

Although the type of warning device was found to have a significant effect on collision frequency, it did not indicate any significant effect on severity. This result is consistent with that obtained in the US-DOT consequence model.

The statistical results for the Poisson model are summarized in Table 5-1.

Table 5-1 Poisson consequence model SAS results

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	408	7229.2396	17.7187
Scaled Deviance	408	7229.2396	17.7187
Pearson Chi-Square	408	15622.9745	38.2916
Scaled Pearson X2	408	15622.9745	38.2916
Log Likelihood		3066.6410	

Algorithm converged.

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence	Limits	Chi-Square	Pr > ChiSq
Intercept	1	0.4818	0.0982	0.2894	0.6742	24.10	<.0001
Person_inv.	1	0.0718	0.0108	0.0506	0.0930	44.15	<.0001
track_no	1	-0.2433	0.0322	-0.3064	-0.1802	57.12	<.0001
tangl	1	0.0051	0.0011	0.0030	0.0072	21.84	<.0001
tspeed	1	0.0252	0.0008	0.0236	0.0269	890.89	<.0001
Scale	0	1.0000	0.0000	1.0000	1.0000		

NOTE: The scale parameter was held fixed.

The results in Table 5-1 suggest that all input variables in the model are statistically significant at the 5 percent level. The Scaled Deviance and Pearson Chi-square values were both found to be greater than one, indicating the presence of Poisson over-dispersion in the data. To overcome this problem, we next attempted a Negative Binomial (NB) model fit.

The resultant NB Consequence model is of the form:

$$E(C_q/C) = e^{(0.3426 * PI - 0.2262 * TN + 0.0069 * TA + 0.0250 * TSPD)} \quad \textbf{(5.3)}$$

Where:

$E(C_q/C)$	=	expected consequence/collision
PI	=	number of persons involved
TN	=	number of railway tracks (both directions)
TA	=	track angle
TSPD	=	maximum train speed (mph)

The statistical results for the NB model are summarized in Table 5-2.

Table 5-2 NB consequence model SAS results

Criteria For Assessing Goodness Of Fit

Criterion	DF	Value	Value/DF
Deviance	409	441.4557	1.0794
Scaled Deviance	409	441.4557	1.0794
Pearson Chi-Square	409	1157.3388	2.8297
Scaled Pearson X2	409	1157.3388	2.8297
Log Likelihood		6091.2497	

Algorithm converged.

Analysis Of Parameter Estimates

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence	Limits	Chi-Square	Pr > ChiSq
Intercept	0	0.0000	0.0000	0.0000	0.0000		
Person_inv.	1	0.3426	0.0865	0.1730	0.5121	15.68	<.0001
track_no	1	-0.2262	0.1106	-0.4430	-0.0094	4.18	0.0409
tangle	1	0.0069	0.0027	0.0015	0.0122	6.38	0.0115
tspeed	1	0.0250	0.0030	0.0191	0.0309	68.33	<.0001
Dispersion	1	1.9615	0.1262	1.7292	2.2250		

NOTE: The negative binomial dispersion parameter was estimated by maximum likelihood.

For this model, the Scaled Deviance and Pearson X^2 for the NB model were found to be close to one. This NB model accounts for much of the Poisson over-dispersion in the data. **As a result, the NB model was selected as the basis for predicting collision consequences at grade crossings for the Canadian data.**

5.2.4 Empirical Bayesian Adjustment for Consequence Model

We next attempted an Empirical Bayesian (EB) adjustment for the initial Poisson consequence model. The EB model includes both the historical data input and Poisson model estimates to provide a more accurate explanation of the historical pattern of collisions observed at each grade crossing.

To develop the EB model, we split the 720 crossings data “time-wise”, into two samples: 456 crossings for the period of 1997 to 1999 to calibrate the model (including calculation of K value and α value) and 264 crossings to validate the model. For the 264 crossings, we used the collision history for the period 1997-99 as an input in the EB expression. The historical input was the number of collisions per year for the three-year period (1997-1999). This was compared to reported collisions at these same crossings for the period 2000-2001. A K value of 2.15 was obtained from the EB iteration procedure. This was used to calculate crossing-specific α-factors.

All the crossings in the 264 crossing sample reported zero collisions for the period 1997-99. This means that the EB model relied exclusively on the α-adjusted Poisson model estimates, which we found to be over-dispersed. As such, the EB model was not pursued further in this study. Presumably, as more historical data becomes available for a longer time period, the EB approach can be revisited as the basis for predicting collision consequences at grade crossings.

6 BLACK SPOT IDENTIFICATION AND ANALYSIS

In this analysis two approaches were considered for identifying grade crossing black spots: 1) a two dimensional graphical approach, and 2) a combined risk-index approach. In the graphical approach, frequency and consequences are represented as separate axes in a two-dimensional plot (as illustrated in Figure 1.3). Critical thresholds values were superimposed on this plot to yield crossings with unacceptably high frequencies and/or consequence scores as predicted by the models. These crossings are referred to as black spots. Alternatively, we have also obtained a combined risk index for each crossing based on the product of expected collision frequency and consequences score (given a collision). This measure can also be compared to pre-set thresholds to determine whether such crossings should be considered for intervention.

The number of black spots targeted for intervention depends on underlying thresholds for predicted frequency, consequence and risk. Obviously as these thresholds are reduced, an increased number of crossings become black spots. With an increased number of black spots, the cost of intervention is expected to increase. Practicable thresholds can be established by considering the tradeoff between safety intervention and its cost. Without knowing both the safety benefits and cost of the intervention, we cannot obtain practicable thresholds for black spot identification, an exercise that is outside the scope of this report.

This section of the report briefly introduces the graphical and combined risk index approach for black spot identification, and discusses black spots resulting from varying thresholds. The basic features of a sample of black spot crossings from Canadian data are discussed.

6.1 Black Spot Identification - Graphical Method

A total of 10,797 highway-railway grade crossing observations were considered for black spot identification in all regions of Canada. For each crossing, collision frequency and consequence/collision were predicted using the above models for different crossing characteristics, AADT and speed. For frequency prediction we used the Poisson model shown in equations 4.2 - 4.4, while for consequence prediction we used the NB model given in equation 5.3.

Frequency and consequences at each crossing were plotted as shown in Figure 6.1. The distribution of crossings by risk/year (expressed as the product of expected frequency and consequence score) is illustrated in Figure 6.2. In Figure 6.1, the horizontal axis represents predicted consequence/year for all collisions at each crossing, while the vertical axis reflects the expected collision frequency/year at these crossings. Three thresholds values were considered: crossings whose predicted collision frequency and/or consequence score is exceeded only 0.1 percent, 0.2 percent, and 0.5 percent of the time.

Figure 6.1 shows that crossings with high frequency differ from crossings with high consequence scores. This indicates that Backspots based solely on one criterion fail to provide an adequate representation of crossings that should be targeted for intervention. Clearly, it should not be using frequency or consequence in isolation to establish black spots, but rather use both criteria to provide a more complete picture of the underlying risks.

Figure 6.2 provides additional insight into black spot identification where a combined risk measure is used. Note that over 97 percent of crossings have expected risks/year the 0.1 percent threshold (frequency times consequence score). A total of 269 crossings have predicted risks greater than 0.1 percent. If a combined risk measure is adopted, it is tempting to designate these crossings as black spots.

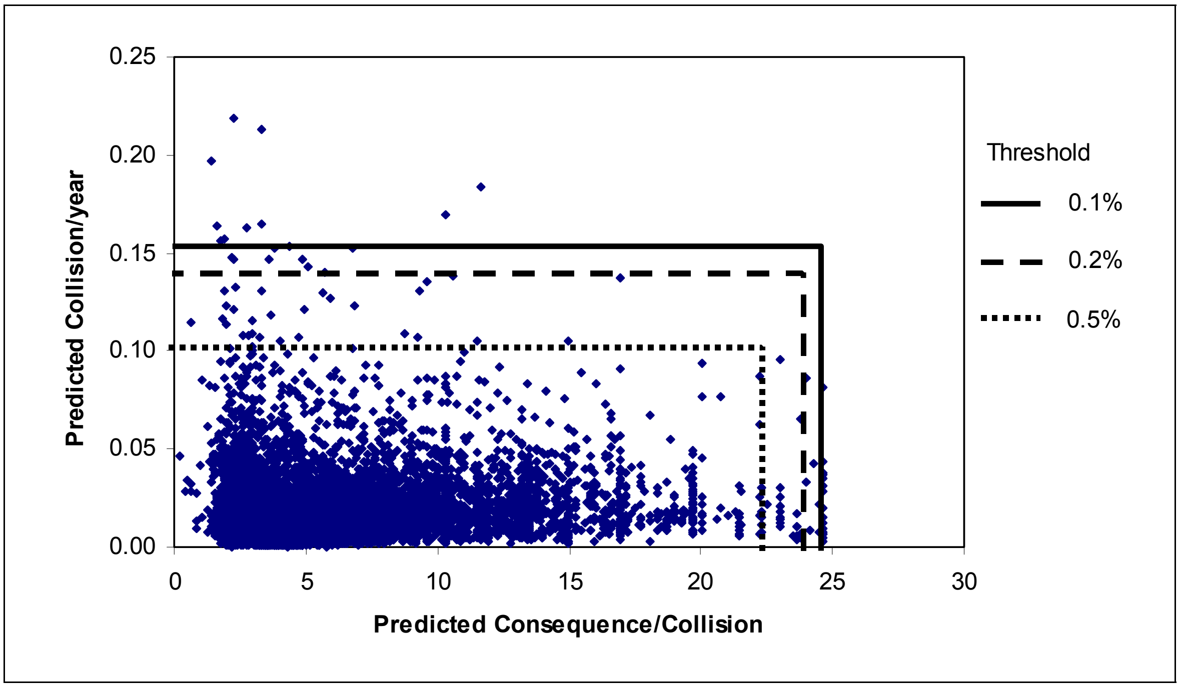

Figure 6.1 Black spot identification (graphical method – frequency and consequence/collision)

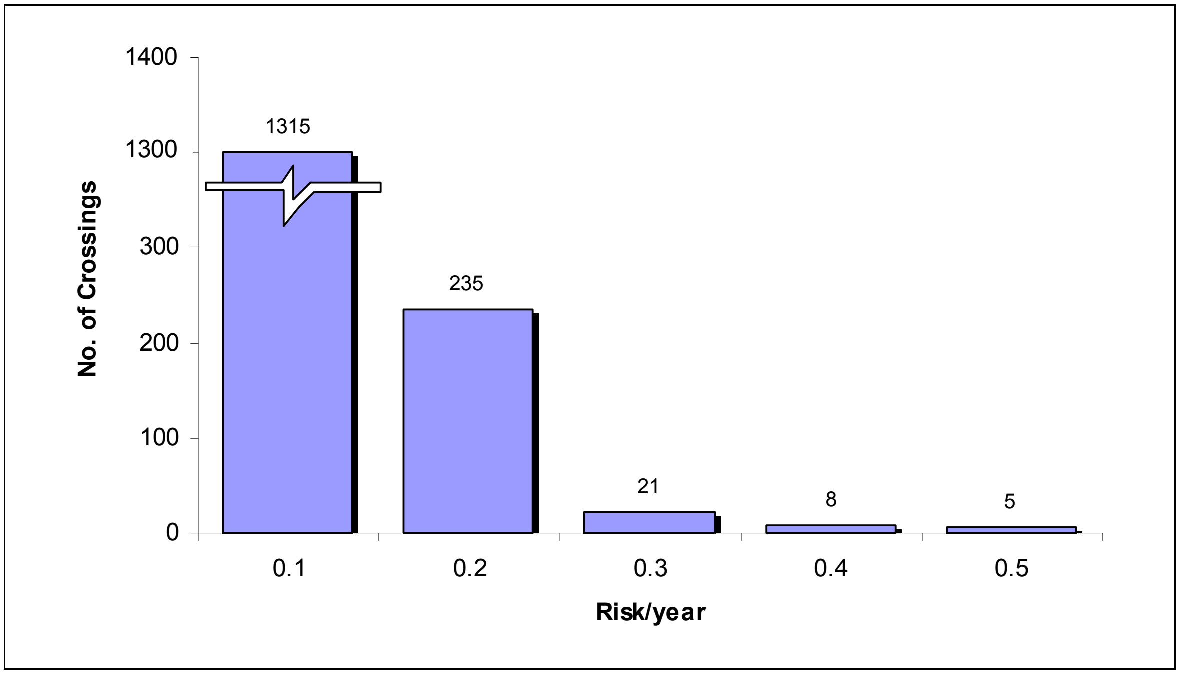

Figure 6.2 Black spot identification (combined risk index)

In this study we adopted a graphical frequency versus consequence approach for identifying black spots. There are essentially two reasons for this: 1) If frequency and consequences are combined in a single risk index, high frequency/low consequence and high consequence/low frequency crossings could result in a low risk index and be excluded from intervention. 2) Furthermore, high frequency/low consequence, low frequency/high consequence risk could reflect a similar index although different intervention strategies are required. If risk index alone is used, it is more difficult to tailor intervention strategies to specific safety problems at each crossing. Counter-measures tailored to reduce frequency are very likely to differ from counter-measures tailored to reduce the collision consequences.

6.2 Choice of Threshold

It is noted that the number of black spots depends on the chosen threshold. If 0.5 percent threshold is selected, a total of 104 crossings are identified, with frequency and/or consequence scores exceeding the threshold. The number of black spot crossings drops to 42 for a threshold of 0.20 percent and to 22 for a threshold of 0.10 percent. The relationship between the risk threshold and the number of black spots is summarized in Table 6-1 for seven threshold values, from 0.9 percent to 0.1 percent.

The basic question that needs to be addressed is: Which threshold to choose, so that safety is enhanced at the lowest intervention cost?

Table 6-1 Number of black spots (based on frequency and consequence)

Threshold Percentage	Number of black spots
0.9%	188
0.8%	166
0.7%	146
0.6%	126
0.50%	104
0.20%	42
0.10%	22

6.2.1 Investigating Threshold Percentiles

An optimal threshold can be determined based on a thorough cost-benefit analysis of the various intervention countermeasures considered. In the absence of this type of analysis, we assume that the more crossings are identified as black spots, the higher the cost of intervention. The benefit can be viewed in terms of reductions in risk at these crossings (frequency and consequence) resulting from each countermeasure.

Figures 6.3, 6.4 and 6.5 illustrate the relationship between total frequency, consequence and risk in terms of number of black spots for different thresholds. We note from these Figures, that there is no “inflection” point where safety benefits occur at a decreasing rate with respect to thresholds. The relationship appears to be monotonically increasing. In the absence of such an inflection point, the more crossings that are designated black spots, the safer the system. This relationship needs further investigation with respect to increases taking place for different budgetary constraints. For demonstration purposes, in this report we have adopted a threshold value of 0.1 percent.

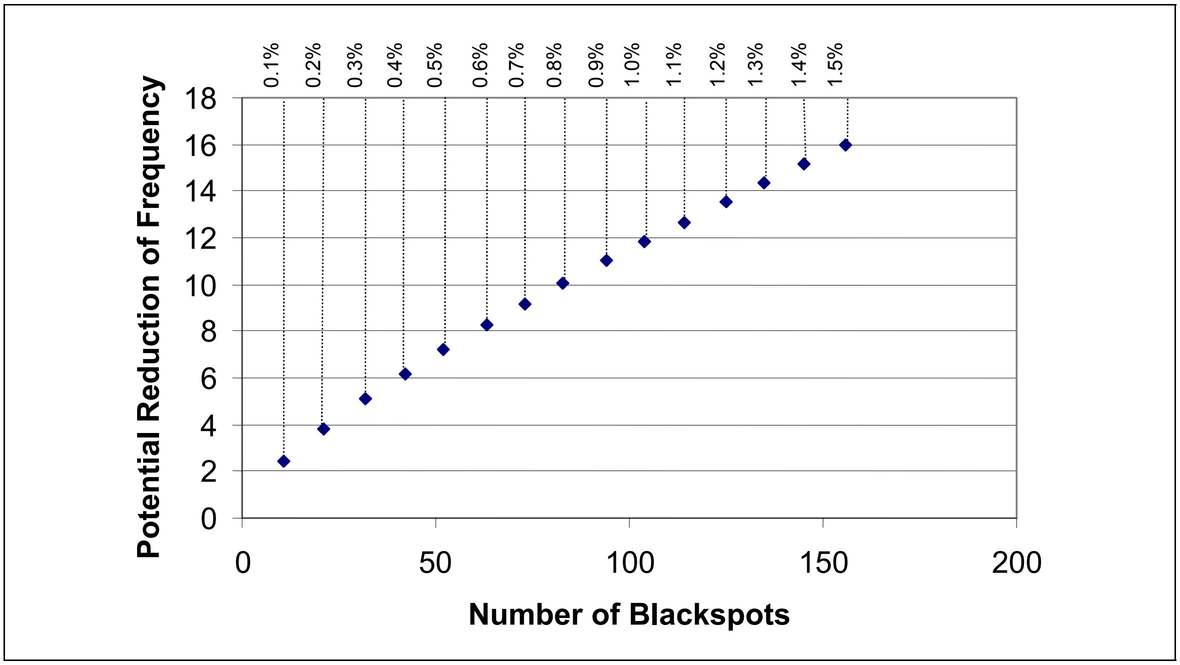

Figure 6.3 Cost-benefit comparison
(frequency per year v. number of black spots)

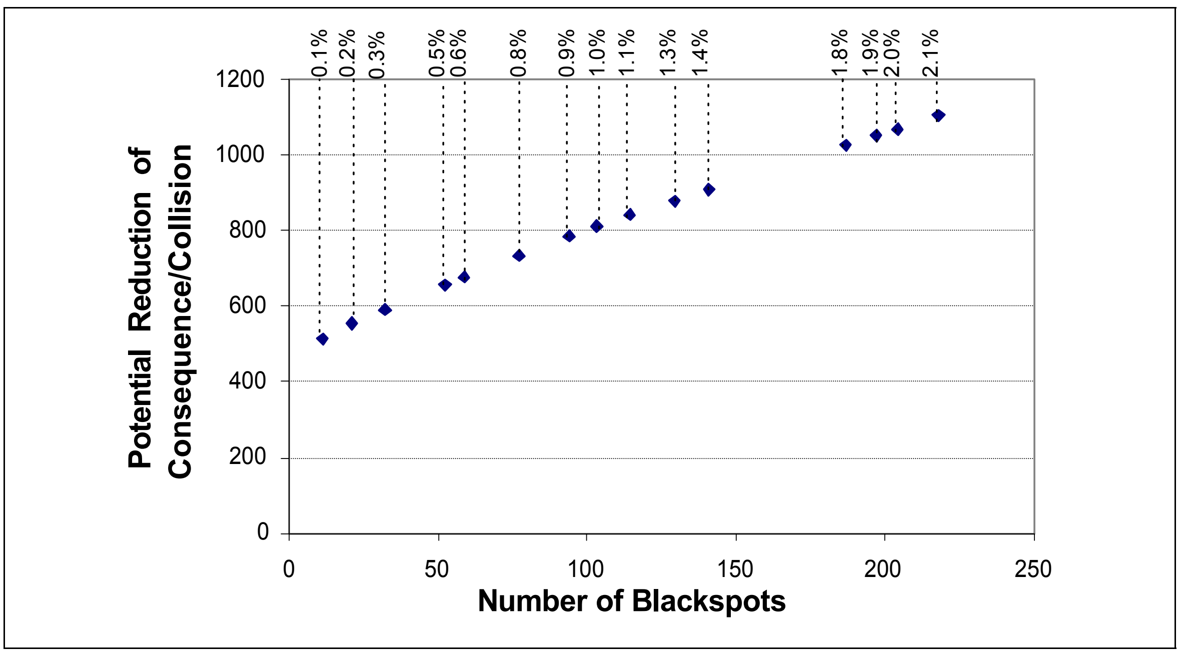

Figure 6.4 Cost-benefit comparison
(consequence per collision v. number of black spots)

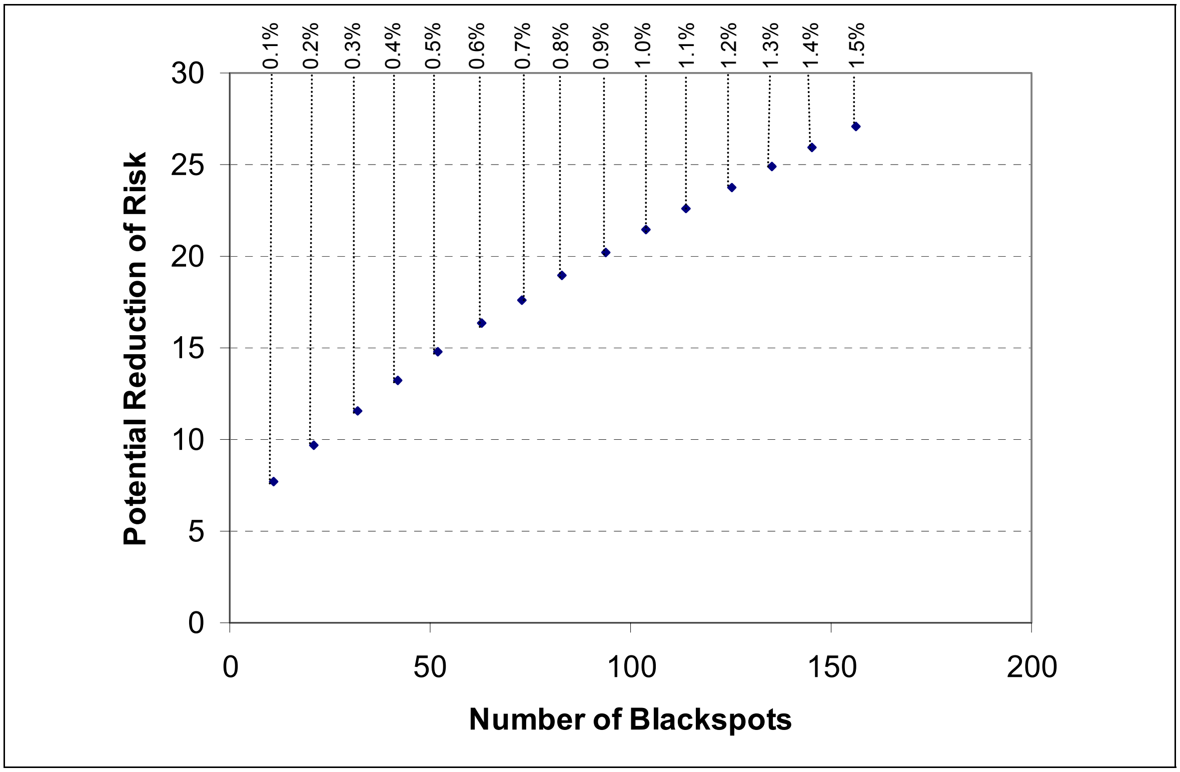

Figure 6.5 Cost-benefit comparison (risk per year v. number of black spots)

6.3 Average Attributes of Crossing black spots

A total of 100 crossings were selected randomly from the non-black spot sample and compared with the top 100 black spots (crossings with highest consequence scores and frequencies). Table 6-2 summarizes the mean values of selected factors for the top 100 black spot and non-black spot samples. On average, black spot crossings exhibit higher train speeds, more acute (from perpendicular) highway/track angles, higher road speeds, and higher road (AADT) and train volumes.

Table 6-2 Mean value for black spots and non-black spots

Mean Value	Black spots	Non-black spots
Train Speed (mph)	65.51	39.3
Road Speed (km/h)	64.20	60.65
Train Daily	32.04	7.58
AADT	10835.38	2717.42
Surface Width (ft)	15.71	11.33
Track Number	1.46	1.27
Track Angle	75.99	71.01

6.4 Discussion of Individual Crossing Black Spots

Based on the frequency and consequence threshold value of 0.10 percent, we obtained a list of 22 black spots (11 for frequency and 11 for consequence). The location of these crossings is documented in Tables 6-3 and 6-4 for frequency and consequence, respectively. These black spots are subsequently compared to the top 22 crossings with the highest historical collision frequency and consequence as reported in the 1997-2001 data. The results are summarized in Tables 6-5 and 6-6.

The top 22 crossings based on both historical frequency and consequence tend to be more spatially dispersed over regions in Canada, than the top 22 crossings designated black spots from the expected frequency and consequence as estimated from the models. The latter were found being more confined to a few regions of the country. From this analysis, we note that there are no crossings in common between the frequency and consequence black spot lists.

From historical frequency data, out of 11 top crossings with highest collision history, four are located in Saskatchewan, three in Manitoba, two in Ontario and two in Quebec. From the historical consequence data, out of the 11 crossings with the highest collision consequences, six are located in Ontario, three in Alberta, one in Saskatchewan and one in Quebec.

Based on the prediction models, of the top 11 expected collision frequency, six black spots are located in Saskatchewan, three in Ontario, one in Alberta, and one in New Brunswick. Five out of the top 11 black spot crossings for expected consequences are in Ontario and 6 in Quebec.

The top 11 crossings based on expected high frequency differ from the top 11 crossings based on expected high consequence, suggesting that the two criteria yield significantly different results. This underscores the importance of a black spot model that accounts for both frequency and consequence prediction.

The top 11 crossings with highest historical frequency and consequences tend to be widespread in Canada, while the top 11 crossings with highest expected frequency and consequences are clustered in Ontario and Saskatchewan. This suggests that a reliance on the historical data to identify black spots does not yield an accurate representation of the potential risks involved. Potential risk can only be obtained through the application of both expected frequency and consequence models.

Table 6-3 Black spots list based on expected frequency per year

TC_NO	Freq/Yr	Rank	Warning Device	Province	Municipality	Street Number
30438	0.219	1	F	SK	Saskatoon	22nd Street
12651	0.213	2	F	SK	Regina	Albert Street (Hwy 6)
12833	0.197	3	FS	SK	Regina	Pasqua Street
16972	0.184	4	F	SK	Corman Park Number 344	21-22-36-6
30951	0.169	5	F	ON	Tilbury East	Essex Road 22
12640	0.165	6	F	SK	Regina	Ring Road
8281	0.163	7		ON	Oshawa	Adelaide Street
28813	0.163	8	F	SK	Saskatoon	3rd Avenue North
30240	0.157	9	F	NB	Saint John	Main Street
20573	0.156	10	G	ON	Onaping Falls	Cartier Hy
24833	0.153	11		AB	Calgary	Heritage Drive

Table 6-4 Black spots list based on expected consequence/collision

TC_NO	Conseq./ Collision	Warning Device	Province	Municipality	Street Number
4843	24.65	G	QC	Saint-Cyrille-de-Wendover	Chemin du 3^e^ Rang
4863	24.65	G	QC	Saint-Simon	Rang St-Georges
4860	24.65	F	QC	Sainte-Hélène-de-Bagot	Chemin du 2^e^ Rang Est
36581	24.65	G	ON	Wolford	County Road 16
3261	24.65	G	ON	Maidstone	Rourke Line
4788	24.65	S	QC	Val-Alain	Route du 3^e^
4852	24.65	F	QC	Saint-Germain-de-Grantham	Chemin du 8^e^ Rang
4858	24.65	F	QC	Sainte-Hélène-de-Bagot	Rang St-Augustin
3258	24.65	G	ON	Belle River	Ducharme Road
19647	24.65	F	ON	Wolford	Kilmarnock Road
300759	24.65	G	ON	Tilbury North	Couture Road

Table 6-5 Black spots list based on collision frequency history (1997-2001)

TC_NO	Number of Collisions	Rank	Warning Device	Province	Municipality	Street Number
32379	6	1	F	ON	Niagara Falls	Reg Rd 102, Clifton
28813	5	2	F	SK	Saskatoon	3rd Avenue North
18061	4	3	F	QC	Saint-Jean-sur-Richelieu	Grand Bernier Road
23696	4	4	F	MB	Winnipeg	Kimberly Avenue
24123	3	5	G	SK	Regina	Ross Avenue
17073	3	6	S	SK	Senlac Number 411	Grid Road 675
7044	3	7	G	ON	Brampton	Torbram Road
13174	3	8	G	MB	Portage La Prairie	Third Street
23164	3	9	G	SK	Sherwood Number 159	Municipal Road
21521	3	10	G	MB	Winnipeg	Marion Street
10492	3	11	G	QC	Montreal	Rue De Courcelles

Table 6-6 Black spots list based on collision consequence history (1997-2001)

TC_NO	Total Fatality	Total Injuries	Rank	Warning Device	Province	Municipal	Street Number
6398	4	1	1	G	ON	Halton Hills	4th Line Road
5019	3	0	2	S	ON	Ingersoll	Mckeand Avenue
7091	2	0	3	G	ON	Halton Hills	Derry Road Reg. 25
32033	2	0	4	F	ON	Cambridge	Dolph Street
19657	2	0	5	G	ON	Elizabethtown	County #28
27477	2	0	6	S	AB	Mountain View County Number 17	Ns W15-33-1-5
35559	2	1	7	F	SK	Arlington Number 79	Yellowhead Hwy (16)
36755	2	0	8	S	AB	Leduc County Number 25	Range Road 245
713	2	1	9	F	ON	Whitchurch-Stouffville	Slater Road
21282	2	2	10	F	AB	Crowsnest Pass	9th Avenue
18061	1	1	11	F	QC	Saint-Jean-sur-Richelieu	Grand Bernier Road

The list of black spots given in Table 6-3 indicates that the top 11 high frequency crossings are located in urban areas, especially in Saskatchewan. The top 11 high consequence crossings are mostly located in rural areas, especially in Ontario. Black spots located in Ontario are shown in Figures 6.6 and 6.7.

One possible explanation for the concentration of high frequency black spots in urban areas is that these crossings are usually associated with higher traffic volumes, usually found in urban areas. In rural areas, on the other hand, both trains and road vehicles traverse each crossing at higher speeds, and collision consequence tends to be more severe.

Top 11 crossings with highest expected consequence per collision reflect crossings with higher train speeds as compared to the top 11 expected frequency crossings. The mean value of train speed for the top 11 consequence crossings is 95 mph, significantly higher than the average of 54 mph for the top high frequency crossings. This confirms that train speed has a more pronounced effect on collision severity than frequency.

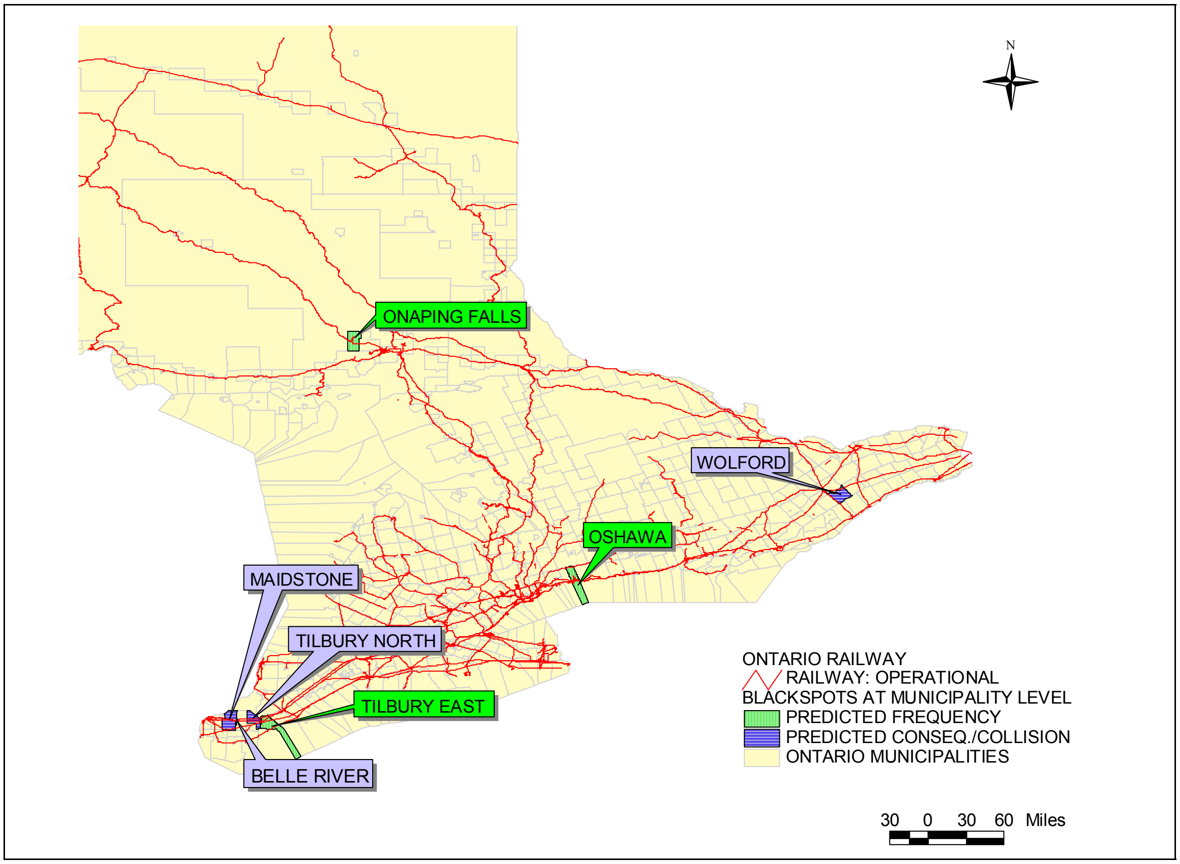

Figure 6.6 Black spots in Ontario at municipality level based on expected frequency per year and consequence/collision

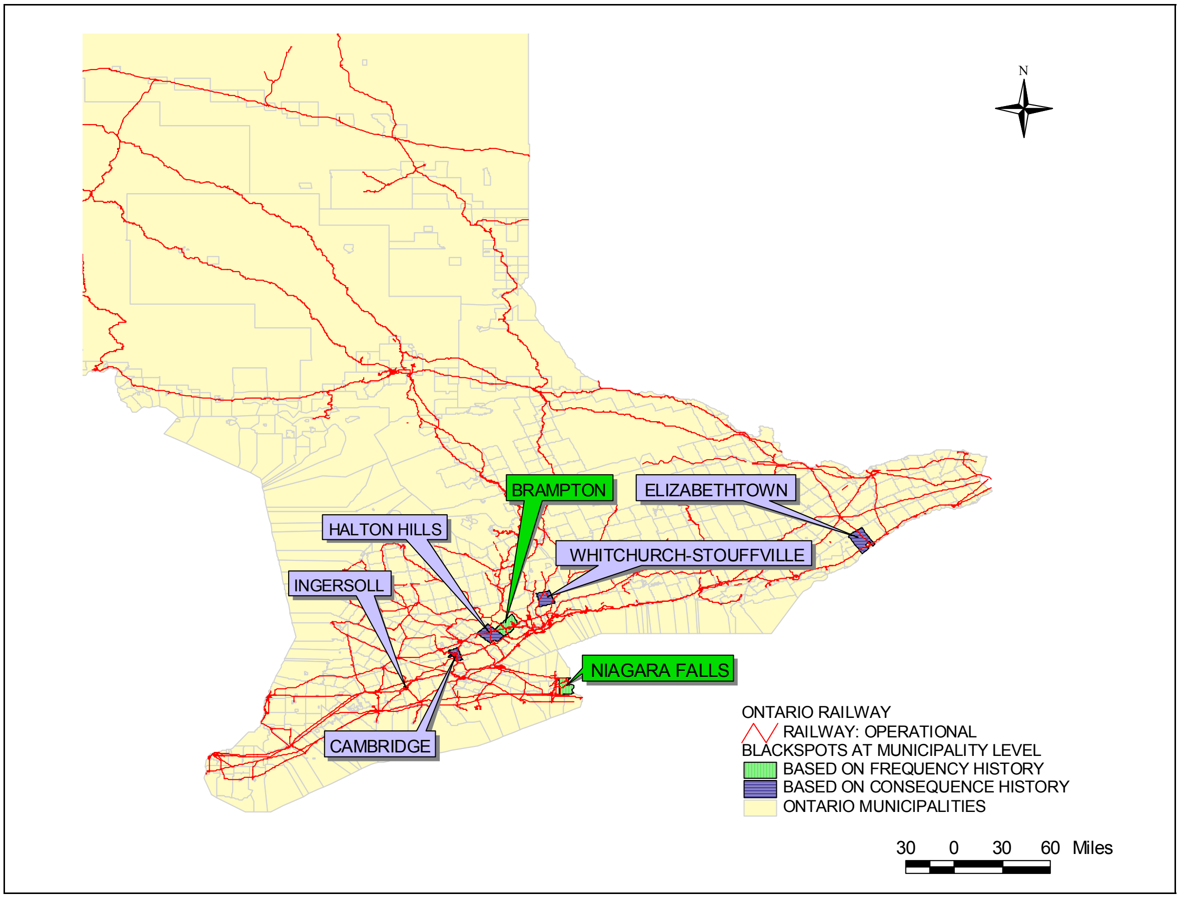

Figure 6.7 Black spots in Ontario at municipality level based on collision frequency and consequence history

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This research presents a risk-based methodology for identifying highway-railway grade crossing black spots in Canada. The main conclusions obtained from the research are summarized as follows.

Modelling collision frequency

1. A number of alternative models were investigated to predict collisions at grade crossings. It was found that Poisson distribution produced similar results when compared to Negative Binomial and Empirical Bayesian methods. Separate collision prediction models for each type of warning device were obtained. These models yielded better predictions than were obtained for a single expression with warning device included as an independent variable. These findings proved consistent with results obtained by the US-DOT for predicting collisions at grade crossings. From this analysis, we concluded that the expected collision frequency is best modelled using Poisson regression with separate expressions for different types of warning devices. In this case we used three classes of warning device: signs, flashing lights and gates.

2. The statistical analysis concluded that traffic exposure (AADT x number of trains daily) was the most important factor affecting collision frequency for all types of highway-railway grade crossings. The nature of this relationship in non-linear and is affected by type of warning device. For crossings with passive controls (e.g., signs only), train speed and exposure were found to provide a significant explanation for differences in the expected number of collisions per year. For active crossings equipped with flashing lights, the significant input factors were train speed, road surface width and exposure. For crossings equipped with gates, the input factors for frequency prediction were road speed, number of tracks and exposure. These findings were also reasonably consistent with those obtain in the US-DOT models.

The collision frequency expressions for each type of warning device are summarized as follows, in Figure 7-1:

Table 7-1 Collision frequency models

Warning device	Collision frequency models
Signs	$E(m_S) = e^{[-5.66 + 0.0128 * \text{TSPD} + 0.3791 * \ln(\text{EXPO})]}$
Flashing lights	$E(m_F) = e^{[-9.1620 + 0.0112 * \text{TSPD} + 0.0151 * \text{SW} + 0.6103 * \ln(\text{EXPO})]}$
Gates	$E(m_G) = e^{[-7.2304 + 0.0118 * \text{RSPD} + 0.1912 * \text{TN} + 0.3526 * \ln(\text{EXPO})]}$

Where: *TSPD* = Maximum train speed (mph)
EXPO = Cross product of AADT and number of trains daily
SW = Surface width (ft)
RSPD = Road speed (km/h)
TN = Number of railway tracks (both directions)

Modeling collision consequence

3. A consequence score was developed based on average costs associated with different levels of collision severity, including fatality, serious injury and property damage. By using a single consequence score, the full spectrum of consequences associated with each collision was represented and incorporated into the black spot identification process. As in the case for frequency, different prediction models were investigated for collision consequences. It was found that a Negative Binomial model yielded the best fit results for predicting consequence at grade crossings.

4. Unlike the collision frequency model, warning device type was not found to be statistically significant in explaining collision consequence (severity). Train speed, number of tracks, track angle, number of vehicles and involved persons were found to have a significant effect on the expected collision consequences at crossings. The consequence prediction model assumes a prior occurrence of a collision.

The consequence model recommended for the identification of black spots is:

$$E(C_q/C) = e^{(0.3426 * \mathrm{PI} - 0.2262 * \mathrm{TN} + 0.0069 * \mathrm{TA} + 0.0250 * \mathrm{TSPD})} \quad \textbf{(5.3)}$$

Where: $E(C_q/C)$ = Expected consequence/collision
PI = Number of persons involved
TN = Number of railway tracks (both directions)
TA = Track angle (degrees)
TSPD = Maximum train speed (mph)

Risk analysis and black spot identification

5. A two-dimensional graphic approach was adopted to compare the predicted risks (frequency and consequence) at individual grade crossings. The risk graph included predicted collision frequency on the Y axis and predicted collision consequence in X axis, with each point representing an individual crossing. By plotting all crossings on this graph, system-wide risk distribution patterns can be conveniently identified for high-risk crossings (black spots).

6. The frequency versus consequence risk graph was used to identify those crossings with unacceptable collision frequency and/or consequence, which should be treated as black spots. Ideally, black spots should be identified based on risk thresholds determined from a comprehensive and objective appreciation of societal preferences and risk tolerance. Potential reductions in risk could be compared to increased costs following the introduction of different countermeasures. Such an analysis, however, is outside the scope of this study. For the purpose of demonstrating the model, however, in this report we ranked the crossings in the RODS/IRIS database with respect to their expected collision frequency and consequence. Crossings with expected frequency or consequence that were exceeded 0.1 percent of the time were designated as black spots. The 0.1 percent threshold was set subjectively. In this exercise a number of different thresholds were considered (0.1 percent to 0.9 percent exceeding) for black spot identification. In practical terms, different percentage thresholds were found to potentially incur different costs or intervention budgets. It would cost more to meet the 0.9 percent threshold than the 0.1 percent threshold, since more black spots would be targeted for intervention.

Identifying highway-railway grade crossing black spots in Canada

7. A list of black spots was identified on the basis of expected collision frequency and consequence at individual crossings across Canada for the assumed 0.1 percent threshold. It was found that the identified black spots were clustered in Saskatchewan (due to high traffic frequency) and Ontario and Quebec (due to high consequence). Most black spots based on collision frequency were located in urban areas with high AADT. Black spots based on collision consequence were generally located in rural areas with high train speeds but not necessarily high AADT.

8. Canada has reported noticeable reductions in collisions at grade crossings over the past 20 years. The risk models developed in this research indicate fewer collisions at crossings equipped with flashing lights and gates than at crossings with signs. This finding provides one possible explanation for the decreasing trend in collisions over time, i.e. an increased number of crossings that have been upgraded from passive to active warning devices (in particular gates). However, this assertion needs to be investigated further, especially within the context of different collision reporting standards (severity thresholds) and at-grade crossing closures.

7.2 Recommendations

This research represents the first step towards the development of a comprehensive framework for managing risk at highway-railway grade crossings in Canada. To achieve the goal of improving safety at highway-railway grade crossings, considerable effort needs to be expended at improving risk prediction models and identifying black spots. For example, there is a need to better integrate the resultant risk prediction models with a practicable decision-support system (DSS) for developing and evaluating cost-effective countermeasures. The DSS systems should be GIS based for different levels of spatial aggregation (crossing-specific, municipality, province, national, etc.). The findings from this report indicate clearly that such a system is not only possible, but highly desirable. Specifically, the following areas are identified for future research:

1) ***Establish more accurate consequence weighting factors.*** The consequence model presented in this report is dependent on the weighting factors used for combining different levels of collision damage. A more thorough analysis is needed to obtain these factors on the basis of detailed breakdowns for various severity levels.

2) ***Combine collision frequency and consequence.*** The approach of combining collision frequency and consequence needs further investigation for more objective and accurate black spot identification. In the current approach, collision frequency and consequence are considered as of equal importance and thus assigned the same value. It is possible that more detailed analysis may support the need to weigh collision frequency and consequence differently when combining them into a single risk measure.

3) ***Establish objective risk thresholds.*** The risk threshold used to identify black spots reflects the number of crossings considered for safety intervention. Ideally, this threshold value should be decided on the basis of a comprehensive cost-effective analysis (expected risk reduction and cost of countermeasures) for different countermeasures. The suggested research methodology (which is based on the relationship between the number of crossings considered as black spots for safety intervention and the potential reduction in collision frequency and consequence) could be extended to consider the cost of implementing specific countermeasures.

4) ***Identify cost-effective countermeasures.*** Once black spot crossings are identified, a micro-level analysis of contributing factors is required to identify the most appropriate safety countermeasures for each black spot. Methodologies for evaluating the cost-effectiveness of individual countermeasures need development.

5) ***Develop a GIS-based decision support system for risk management at grade crossings.*** To capitalize on the black spot identification methodology and risk models developed in this work, a user-friendly software tool should be developed for use by various stakeholders, such as railway companies, provincial and municipal transportation agencies and safety organizations, to address safety-related issues arising in the planning, design and operations of highway-railway grade crossings. To facilitate this work, better specification and linkage of available inventory, collision occurrence and spatial referencing needs to be achieved.

6) ***Improve collision and inventory data.*** The proposed risk-based black spot identification method relies on a set of statistical models that are calibrated on the basis of observed collisions at crossings with varied characteristics. It is therefore of critical importance to have an accurate and complete database of crossing characteristics (inventory) and collision history. Our research indicates that the current RODS/IRIS database needs improvement in the following aspects:

- The quality of the data reported in the IRIS database needs improvement. In our statistical analysis, over half of the crossing records were removed because of missing or erroneous data items.
- A spatial referencing system for all crossings and collisions should be established as part of the database. Individual crossings and collision occurrences should be geo-coded for analysis at different levels of spatial aggregation.
- Better linkage between RODS and police-reported data for collisions at the regional, municipal and provincial levels should be established. This linkage will allow for cross-validation of data and access to more extensive collision data.
- Better information on traffic exposure at individual crossings should be collected. This includes average daily trains of different types, AADT, and time-of-day distribution of train and road traffic. These data should be collected and organized on a *yearly* basis.

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APPENDIX A

SAMPLE DISTRIBUTION OF VARIABLES IN THE RODS/IRIS DATABASE

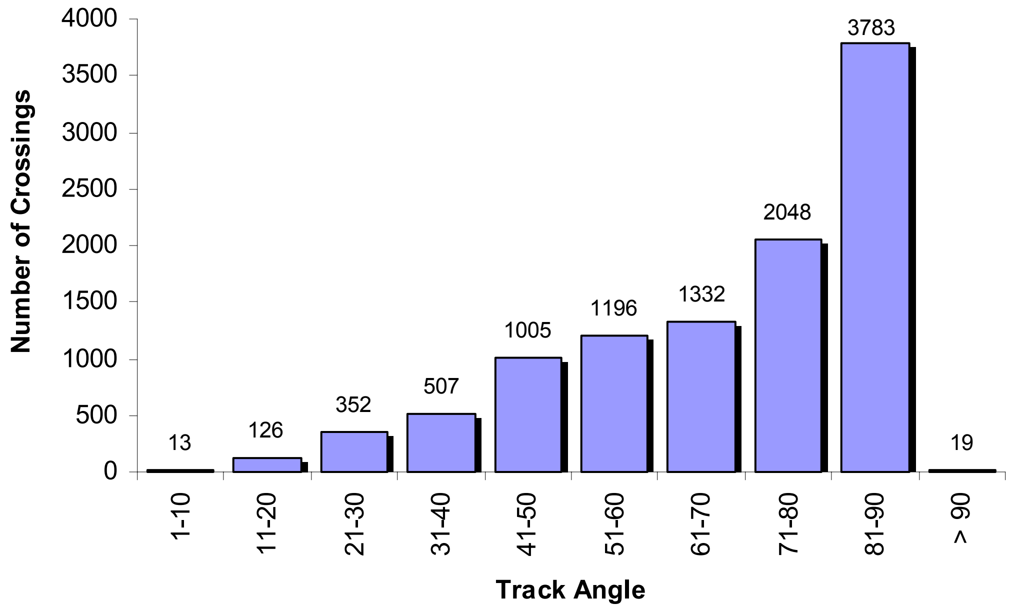

Figure A-1 Sample distribution of track angle

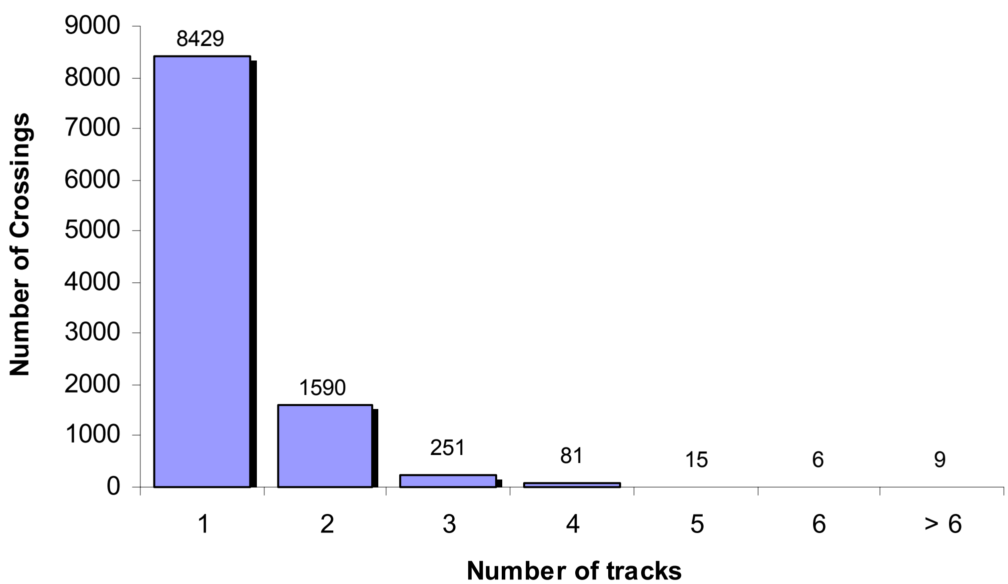

Figure A-2 Sample distribution of number of tracks

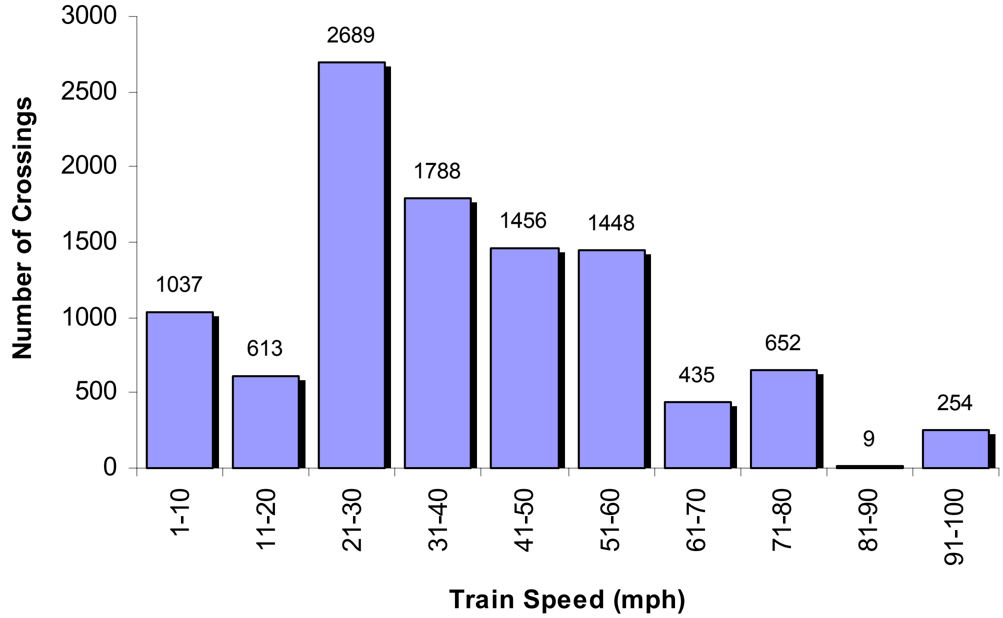

Figure A-3 Sample distribution of train speed

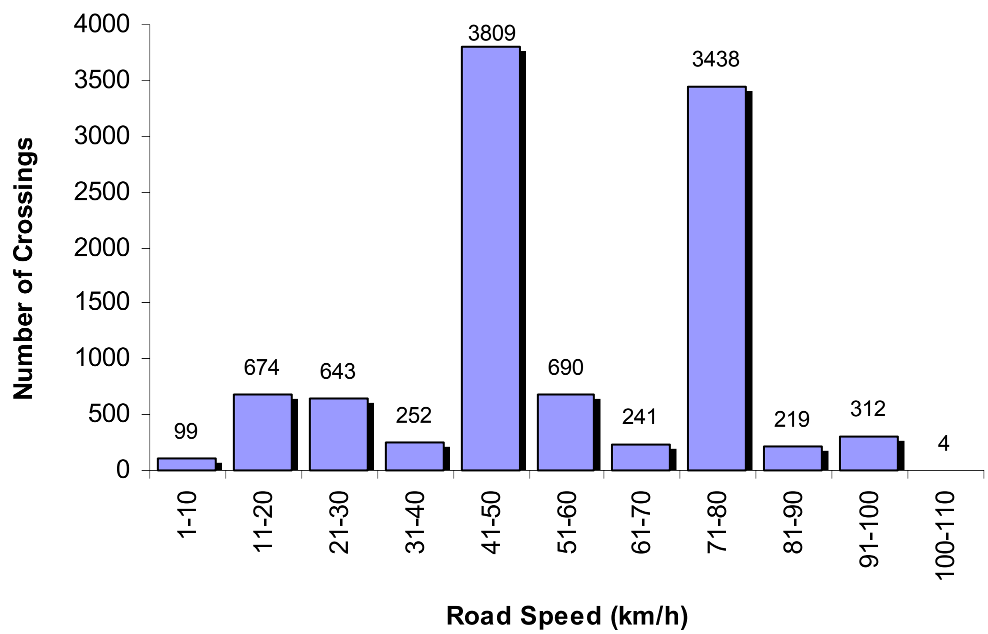

Figure A-4 Sample distribution of road speed

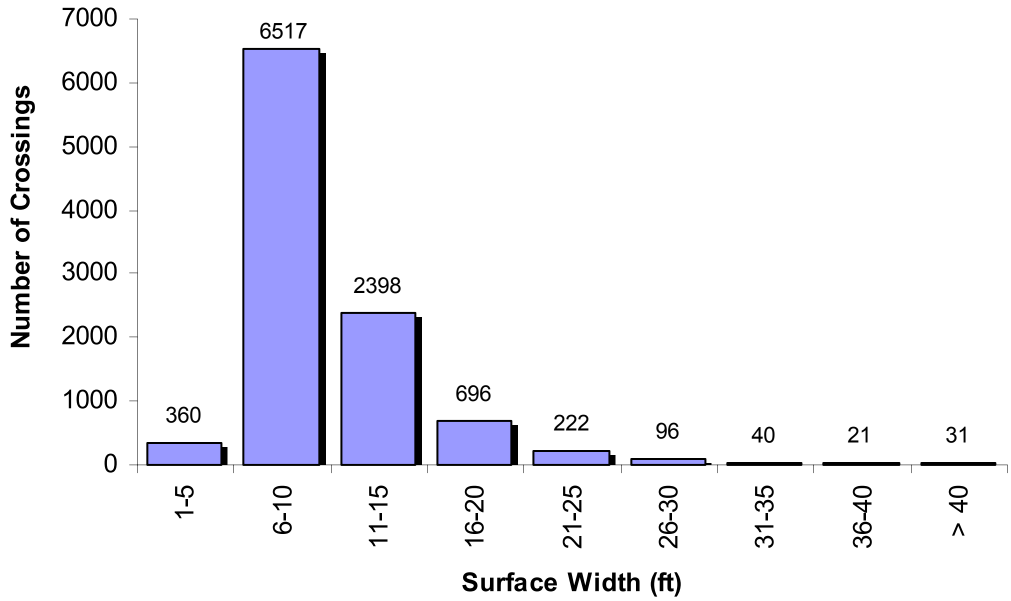

Figure A-5 Sample distribution of surface width

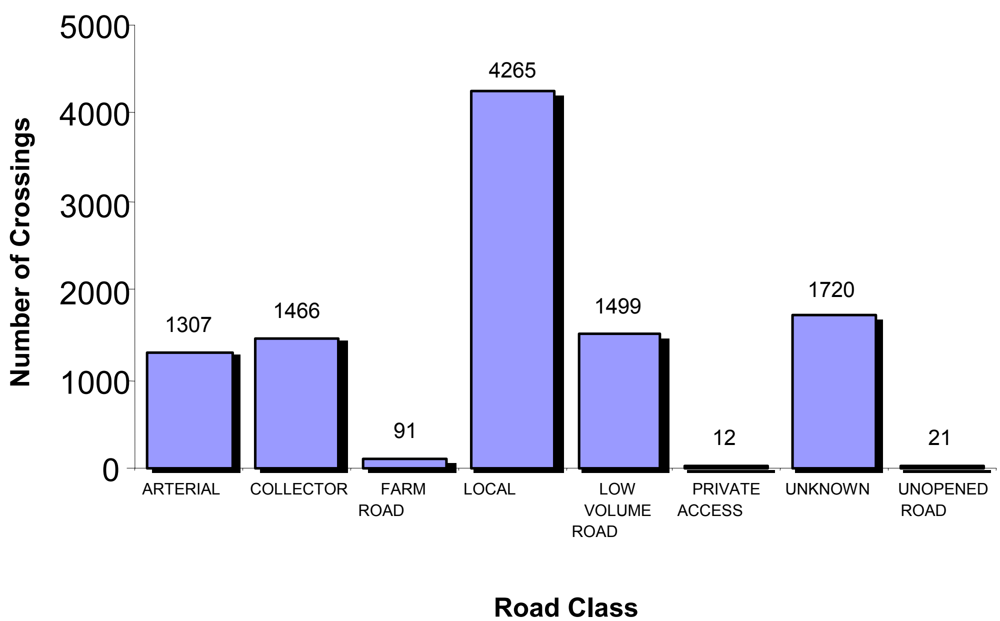

Figure A-6 Sample distribution of road class

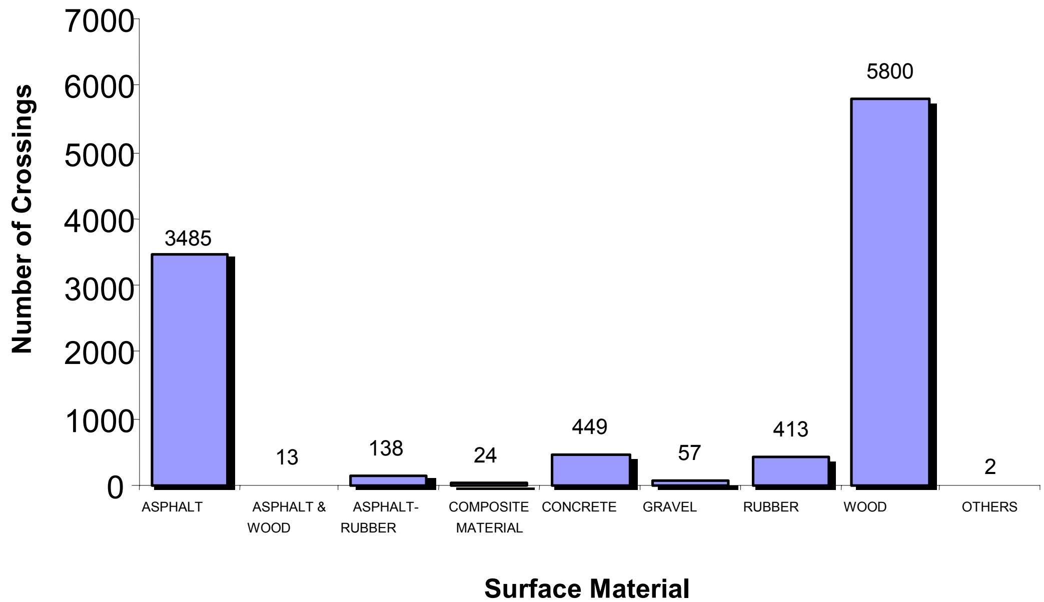

Figure A-7 Sample distribution of surface material

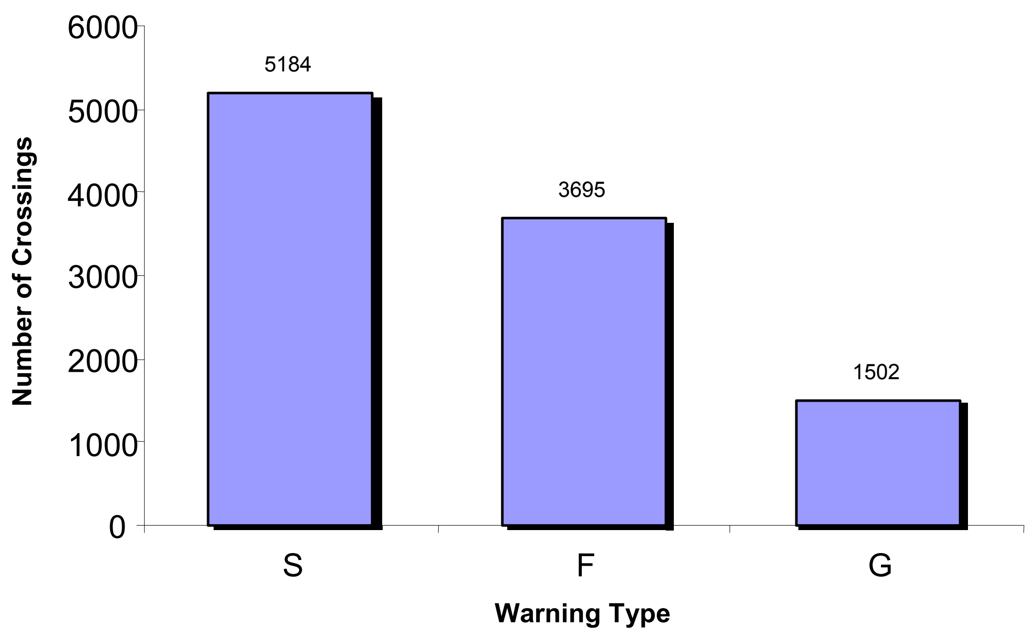

Figure A-8 Sample distribution of warning type (2001)

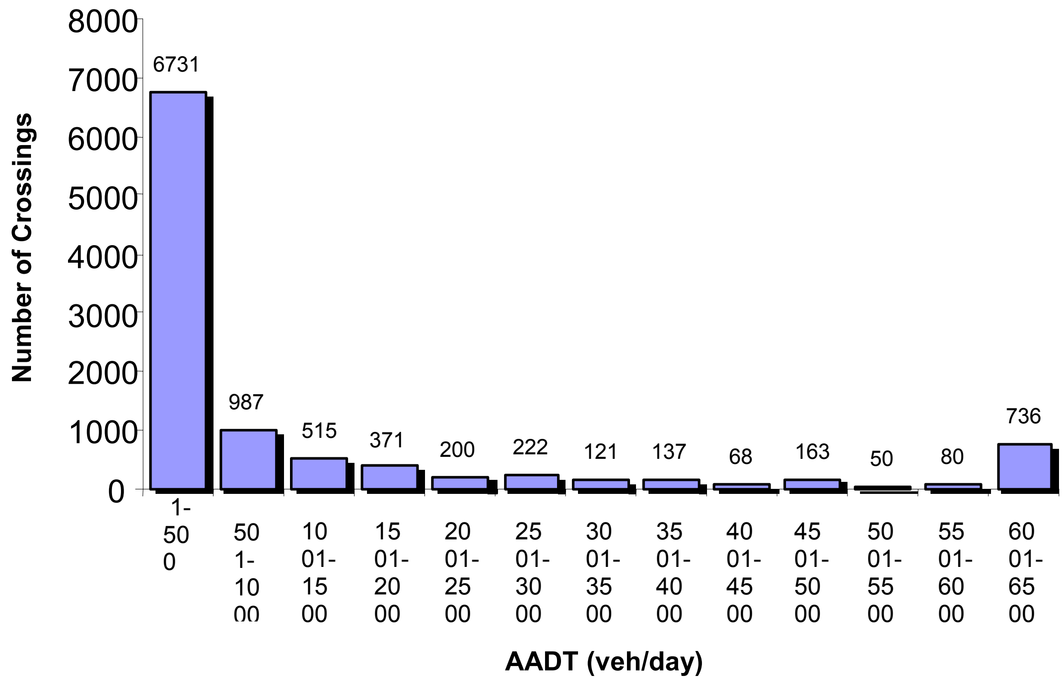

Figure A-9 Sample distribution of average annual daily traffic

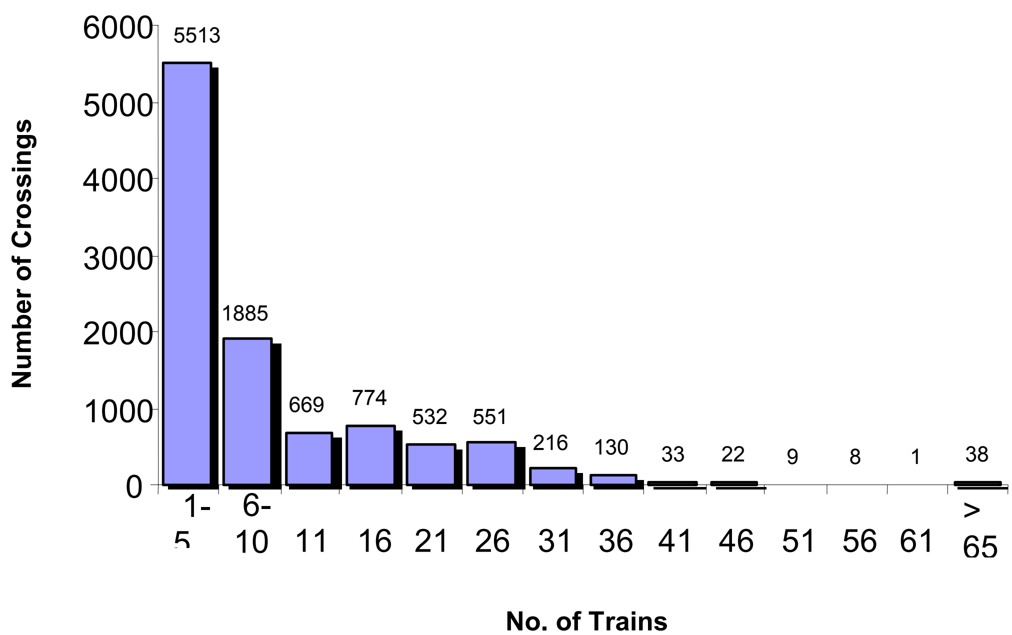

Figure A-10 Sample distribution of number of trains