Collision risk analysis and evaluation of countermeasures at highway-railway grade crossings

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Dedication

I would like to dedicate this research paper to my parents from China who unconditionally supported and encouraged me in my life despite of time and place, and especially through the difficult times during my education in Canada. I will continue to be a good son, I love you.

Acknowledgement

With deepest and sincere appreciations, I would like to thank my supervisor, Professor Luis Miranda-Moreno, who generously supported and encouraged me at all times during my undergraduate and graduate study, especially in the last few months for paper correcting and editing despite sickness.

Also, I own my deep gratitude to Professor Liping, Fu at University of Waterloo, my co-supervisor for this project, whose excellent guidance and support from beginning to end making the completion of the project possible.

And, I would like to thank Prof. Naveen Eluru who kindly served as another examiner for evaluating my paper during his vacation time.

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Last but not least, I would like to thank all the professors and classmates in department of civil engineering where I pursued my Bachelor's and Master's degrees as your patience and kindness light my heart and my way to the future.

Sincerely yours,
Rui Jiang

Abstract

Vehicle-train collisions at highway-railway grade crossings are a major concern for railway industry and government authorities in Canada. Motor vehicle-train collisions represent over half of railway accidents that occur every year in this country. In response to this concern, railway and government authorities have been looking for solutions to this problem through the implementation of safety engineering countermeasures and the systematic improvement of highway-railway crossings, in particular those classified as public highway-railway intersections. This reports aims at 1) upgrading a safety analysis tool refereed as "gradex" and 2) evaluating the safety benefits of different countermeasures in the Canadian environment. For this purpose, collision occurrence and injury severity datasets are built. Using statistical regression methods, collision frequency and injury severity models are developed. The link between collision risk and crossing-level attributes is then established. Among the group of attributes are the road and railway geometry characteristics, speed limits, train and vehicular traffic volumes as well as warning devices. This analysis is carried on using historical vehicle-train collision data from the years 2002 to 2010. In a second step, using the developed models as well as past studies and expert opinions, collision modification factors for countermeasures at highway-railway crossings are established. The most effective countermeasures are identified. Also, their safety benefits are quantified. This work is expected to help in the identification of cost-effective countermeasures.

Résumé

Les collisions entre trains et véhicules aux croisements de voies ferrées étant au même niveau de routes canadiennes (aux passages à niveau) sont une préoccupation majeure pour l'industrie ferroviaire et pour les autorités gouvernementales au Canada. Les collisions entre trains et véhicules représentent plus de la moitié des accidents ferroviaires à chaque année au Canada. En vue d'adresser ce problème, les autorités gouvernementales et haut-dirigeants de l'industrie ferroviaire travaillent à trouver des solutions à ce problème qui portent sur l'implantation de mesures préventives en matière de sécurité et sur l'amélioration systématique des passages à niveau, en particulier ceux qui sont classées comme étant intersections de voies ferrées et autoroutes publiques. Ce rapport vise à 1) mettre à jour un outil d'analyse de sécurité que l'on appelle «gradex» et 2) évaluer les bénéfices en matière de sécurité en considérant les différentes mesures préventives sur le territoire canadien. Pour accomplir ceci, des ensembles de données se reliant aux instances de collisions et gravité de blessures, sont construits. En utilisant des méthodes statistiques de régression, des modèles sur la fréquence des collisions et sur la gravité des blessures sont développés. Le lien entre le risque de collision et les caractéristiques physiques des passages à niveau est alors établi. Les caractéristiques physiques comprennent la géométrie des routes et voies ferrées, les limites de vitesse, le volume de circulation des véhicules et des trains, et les dispositifs d'avertissement. Cette analyse est effectuée en utilisant les données historiques sur les collisions entre véhicules et trains entre les années 2002 et 2010. Par la suite, des facteurs de modification/détermination de collisions pour mesures préventives aux passages à niveau sont établis en utilisant les modèles développés, études antérieures et conseils d'experts dans le domaine. Les mesures préventives les plus efficaces sont identifiées. Leurs avantages en matière de sécurité sont également quantifiés. Ce travail est destiné à aider dans la détermination de mesures préventives étant également rentables par rapport aux coûts.

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Introduction

1.1 Highway Railway Safety

Highway-rail grade crossings are intersections of adjacently connected railway tracks and highways. Interactions between vehicles and trains at grade crossings are of high complexity, where serious collisions with greater injuries and fatalities occur. The resulting damage is more than in any other type of traffic accidents, due to the substantial mass difference between trains and vehicles. At present, over half of railway fatalities and injuries in Canada occur at grade crossings, as a result of vehicle-train collisions, realignments or trespassers. In this context, safety at highway rail crossings has become a major concern for transportation authorities and the railway industry in North America. In response to this concern, the Canadian and US governments have endeavored to reduce collisions, through programs on improvements of cost-effective countermeasures and railway safety standards at grade crossings. Some examples include: the Direction 2006 and Grade Crossing Improvement Program (GCIP) in Canada, as well as the Rail-Highway Crossing Safety Action Plan implemented by USDOT (U.S. Department of Transportation) Federal Railroad Administration. This last program has already demonstrated some benefits. For instance Horton (2009) reported that collisions at highway rail crossings have declined by 41.2% in the period 1994-2003, and by 44.7% in 2004-2007.

This issue has also attracted attention in transportation safety research literature. Several recent research studies have proposed alternative methods to identify hotspots and assess the suitability of countermeasures, with highest safety rewards at grade crossings.

Chapter 1

Introduction

1.1 Highway Building Safety

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[illegible]

Accident occurrence at highway rail crossings has been associated with various factors, which include human actions, vehicles/trains conditions, geometric design, safety facilities and environmental conditions. Various past studies have quantified the effect of specific factors on collision probability or frequency; such as traffic control devices, warning devices and geometry design at crossings (Lee et al, 2004). In a report by Transport Canada, the primary accident contributors have been classified into six categories in literature reviews and databases analysis. These are: unsafe actions, individual characteristics, train visibility, passive signs and markings, active warning systems and geometric constraints.(J.K. Caird, et al, 2002)

Given the uncertainty and randomness associated with unmeasured contributing factors such as weather and human operational errors, most of the studies tend to apply statistical modeling techniques with random effect (such as mixed Poisson models and Statistical modeling techniques). This is to identify the observed factors associated with collision occurrence and assess cost-effective countermeasures for safety enhancement at grade crossings. For statistical modeling calibration, historic car-train accident records and site-specific characteristics at each crossing are the main source of information.

Over the years, researchers have developed and applied different accident prediction models and methodologies for safety evaluation and improvement of highway rail crossings. In some cases, only frequency models are developed. In other cases, total risk is considered in which both collision frequency and collision severity are incorporated into the analysis (Jutaek Oh, 2005). Collision frequency and severity models have been considered simultaneously in order to make correct assessments of risk at grade crossings. These models are important to identify key factors contributing to the likelihood and influences of traffic accidents and provide parameters and references on future application of cost-effective countermeasures. In addition, some studies have evaluated the effectiveness of countermeasures implemented with the aim of reducing the likelihood and impact of accidents risk

for a literature review; refer to section 2.

Despite the available literature, there are still several unresolved issues. Firstly, the US Federal Railroad Administration (FRA) unsuitably employed a/the cross-sectional model to evaluate the effectiveness of countermeasures, because there are many unresolved statistical elements in the model, such as input co-linearity, misspecification, and failure to consider higher order interaction effects. (Sacoomanno and Lai, 2005). Secondly, Park and Sccomanno (2006) have found Empirical Bayesian in before-after analysis, which is not well suitable to Canadian grade crossing dataset, due to excessive "zero" collisions in the collision dataset. As discussed by Lord (2006) Park and Saccomanno (2006), it is possible to produce unreliable and biased results when collisions are extremely rare. Also, it is difficult to evaluate combined effects of countermeasures using before-after analysis. Moreover, the average effectiveness of countermeasures cannot explain individual scenarios, as it is unrealistic and non-applicable to assess individual countermeasures for specific crossings due to excessive time and money. (Saccomanno, L. Fu, 2006)

1.2 Objective

The objective of this paper is to evaluate the impact of Canadian grade crossing programs, after cost-effective countermeasures are implemented at grade crossings for improving crossing standards. In more detail, four major components are carried out to achieve this goal:

- Develop collision frequency and severity models to identify crossings with unacceptable high risks;
- Review effectiveness of countermeasures through literature for estimating Collision Modification Factors (CMF) via combination of cross-sectional models and Empirical Bayesian before and after analysis;
- Evaluate the potential safety benefits, in terms of expected collision reduction rates, at sites in which countermeasures could be applied; and

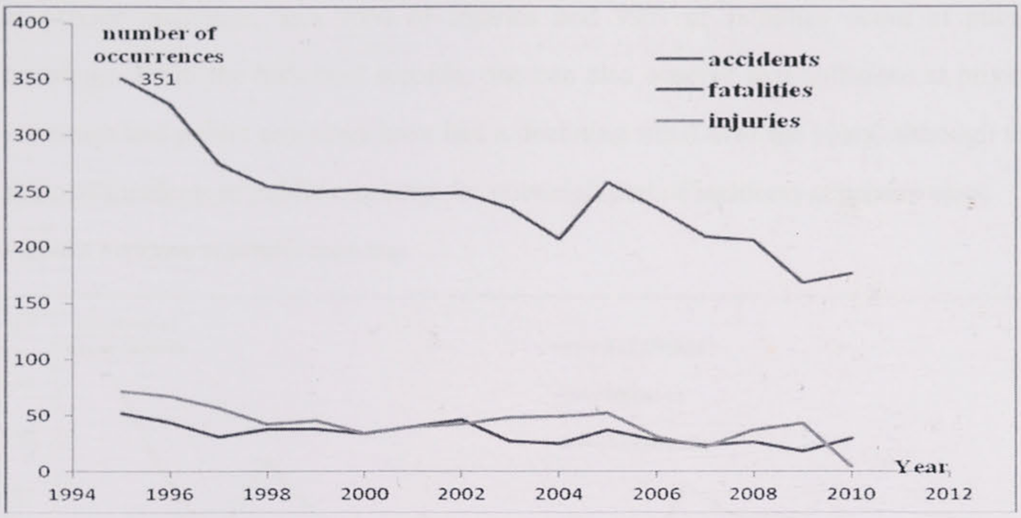
- Carry out cost benefit analysis after implementing countermeasures at grade crossings.

In this work, a decision-support tool developed by the University of Waterloo is used. This tool integrates the overall process for safety improvement at grade crossings through hotspots identification, safety ranking evaluation, mathematical models development and countermeasures design and implementation. This tool integrates RODS (Rail Occurrence Database System) and IRIS (Integrated Rail Information System) datasets provided by Transport Canada, in the nine-year period from 1993 to 2001 (Saccromanno F. and Liping. Fu, 2003). This paper, followed by previous risk modeling work, will apply RODS and IRIS datasets for next consecutive 9 years from 2002 to 2010, and update the parameters used in GradeX application.

1.3 Current Situation in Canada

According to the collisions at grade crossings recorded by Transport Canada from 1995 to July 2011, there were a total of 4,002 collisions with 549 fatalities and 700 serious injuries. The most fatalities in this period happened in 1995, where accidents occurred due to behindhand technologies and ineffective countermeasures. On a yearly basis, approximately 242 collisions with 33 fatalities and 42 serious injuries occurred. Thanks to the long-term effect of safety improvement, there has been a decrease in tendency of accident frequency and severity has been displayed. For instance, accident occurrences from 1995 to 2010 have dramatically reduced from 351 to 177 with a decreasing rate of 50%, and fatality reduction from 52 deaths in 1995 to 29 in 2010 with a decreasing rate of 44%. Comparing fatality and injury occurrences in collisions over years, the number of annual injuries are slightly higher than that of annual fatalities. Furthermore, it is promising to observe that the reduction rate of fatalities is faster than the reduction of injuries in collisions annually. Figure 1 depicts the summary of annual accidents at Canadian grade crossings from 1995 to 2011 July.

Figure 1 Annual accidents at Canadian grade crossings 1995 to 2010



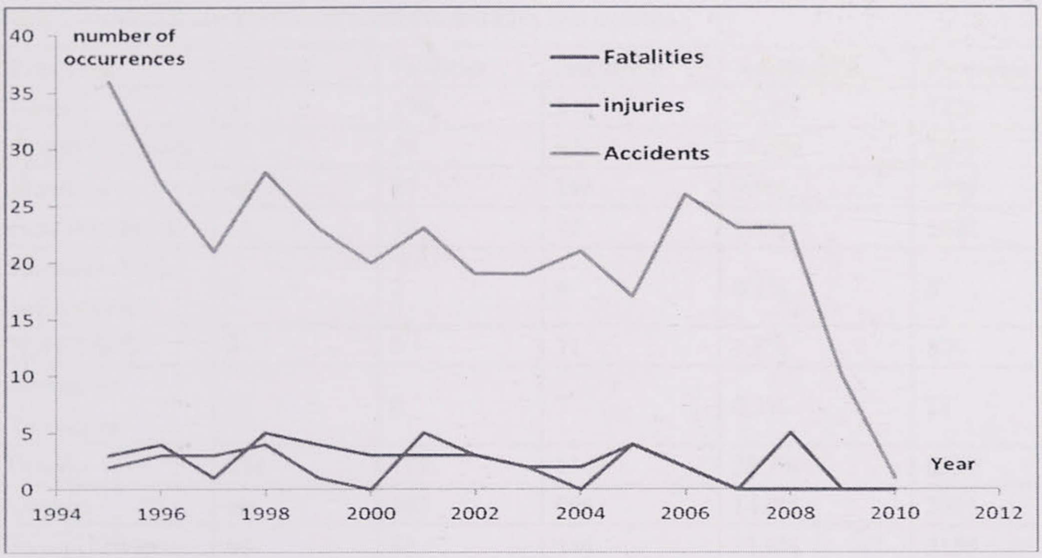
Source: RODS and IRIS datasets, 1995 to 2010, Transport Canada

Safety estimates, design and evaluation are critical issues at highway-rail crossings, where more than half of crossings are public and under three typical warning devices such as signs, gates and flashing lights (Wanat, 1998). Canadian grade crossings are comprised of public crossings and private crossings. A public crossing involves the intersected road that is owned and maintained by a road authority for public use, and public crossings are subdivided into active public crossings and passive public crossings (crossings without actuated flashing lights or gates). While a private crossing involves the intersected road that is not opened or maintained for public use, private crossings contain the types of farm crossings, industrial plant crossings, residential access crossings and temporary crossings. Public crossings are weighted 72% of overall grade crossings in Canada, and collisions at public crossings have a far higher level of frequency and severity as a result of heavy road vehicle volumes and frequent interactions between vehicles and trains.

There are a total of 27,882 Canadian grade crossings correctly recorded in terms of valid location ID by Transport Canada. Besides 71.9% of public crossings, farm crossings and private crossings account for 17.5%. About 10.6% of grade crossings are unidentified or unrecorded of crossing types. In addition, usable Crossings used in statistical analysis later in this report are 26,882; 96.4% of overall crossings. On

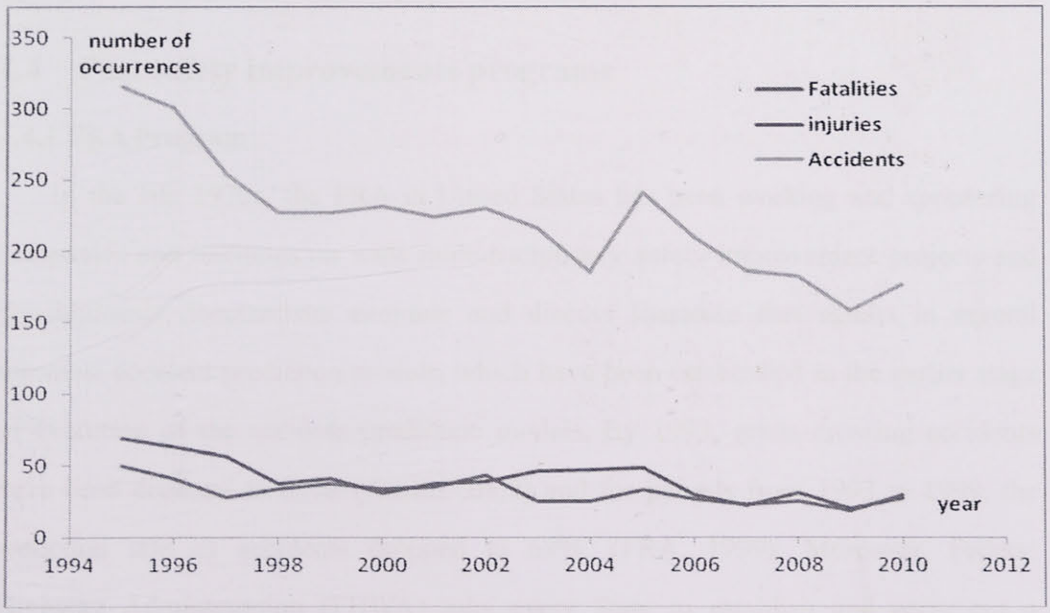
average, the annual collisions at public crossing are 11 times higher than the collisions at private crossings, and 95% of injuries and 99% of fatalities occur at public crossings. From the historical records, one can also observe that collisions at private crossings and public crossings have had a declining trend over the years, although the scale of incidents at public crossings far outweigh that of incidents at private ones.

Figure 2 Accidents in private crossings



Source: RODS and IRIS datasets, 1995 to 2010, Transport Canada

Figure 3 Accidents in public crossings



Source: RODS and IRIS datasets, 1995 to 2010, Transport Canada

Provincially, accidents at highway rail grade crossings during 1995 to 2011 are comparatively different due to various attributes: such as population size, economic development, industry growths and number of tracks. From table 1, not surprisingly, Ontario has the highest number of severe hotspots with 1149 collisions (29% of total) from 1995, followed by Alberta and Quebec, with 818 (20% of total) and 596 collisions (15% of total).

Table 1 Provincial comparison of accidents, fatalities and injuries

Provinces	Injuries	Fatalities	Accidents	Accidents%	Crossings
Alberta	81	170	818	20.4%	3426
British Columbia	40	56	423	10.6%	3097
Manitoba	44	67	398	9.9%	2509
New Brunswick	11	13	72	1.8%	1222
Newfoundland and Labrador	0	2	4	0.1%	8
Nova Scotia	5	9	71	1.8%	876
Northwest Territories	0	0	7	0.2%	28
Ontario	214	199	1149	28.7%	6559
Quebec	90	103	596	14.9%	3926
Saskatchewan	64	81	464	11.6%	5158
Others	N/A	N/A	N/A	N/A	73
Total	549	700	4002	100%	26882

1.4 Past safety improvements programs

1.4.1 FRA Program

In the late 1970s, the FRA in United States has been working and sponsoring companies and institutes on wide multidisciplinary safety improvement projects and developments. Researchers examine and discuss literature that results in several foremost accident prediction models, which have been established in the earlier stage of evolution of the accident prediction models. By 1993, grade crossing accidents have been declined to 64%. (Austin, 2002) and for periods from 1993 to 1999, the reduction rate of accidents dropped to 69%. (FRA, 1999). Moreover, Federal Highway Administration (FHWA) asks every State to establish and carry out a highway safety-improvement program (HSIP), involving three main components:

planning, implementation and evaluation. The FHWA developed regulated methodology to identify and explicate hazard indices and formulas for highest potential risks of grade crossings. Furthermore, in the past two decades, strong efforts on improved warning devices are frequently being studied to reduce collisions. A large volume of literature focused on education, enforcement and improvement in grade crossing systems.

1.4.2 Direction 2006 Canada: highway-rail crossing research program

On June 1st, 1999, the roles and responsibilities of the Railway Safety Act (RSA) were redefined for the purpose of safety insurance at railway road crossings, which emphasized the importance of safety as the top priority issue over other calls such as intelligence, strategy and sustainability. Specifically, a Safety and Security Strategic Plan was also carried out for detailed implementations.

The Highway-rail crossing research program, which was initiated in 1999, later was part of Direction 2006. This program focused on discovering key factors that significantly impacted grade crossing collisions and trespassing incidents for seeking effective countermeasures. This was able to estimate national grade crossings and railway trespassing collisions for over 10 years by 2006. The goal of this program is to enhance the safety of grade crossings and implement cost-effective countermeasures via technological, operational and human factors research.

Moreover, this research program consist of eight divisions concerning possible aspects of enhancements at grade crossings, including program and research development, risk mitigation methodologies, driver, pedestrian, vehicle behavior, enforcement technologies, active-warning crossings, passive warning crossings, signal lights and structures and train-based warning systems.

This program brought $1.3 million as a base budget contribution from all

program partners including Transport Canada, Canadian Railway and provincial road authorities. The research aimed to apply new technologies and improve the existing systems from the perspectives of technological, operational and human factors.

Most importantly, there are five expected results of this research program, which are the initiative of this project. Citing from Transport Canada, Table 2 depicts these results in a positive sequence

	Expected Results
1	*An integrated and accessible database of railway crossing collisions and trespassing incidents*
2	*A methodology for risk analysis and evaluation of risk mitigation measures applicable to railway crossings*
3	*Identification of factors associated with technological and design elements of crossings and warning systems, railway operations, human factors, and road user characteristics that contribute to grade crossing collisions and trespassing incidents*
4	*Cost-effective countermeasures to the primary contributing causes of collisions and incidents and , where these are not feasible or cost-effective, identification of the reasons and of any further research required: risk mitigation measures should address issues associated with rail, road, and pedestrian users*
5	*Prototype equipment, concept systems, design standards, specifications, and methodologies.*

Table 2 Expected results in grade crossing research program of Direction 2006

* italics are directly cited from Transport Canada research program overview.

1.4.3 Grade Crossing Improvement Program (GCIP)

The Grade Crossing Improvement Program is another Canadian grade crossing program, in addition to the Direction 2006 program. This program strives to provide financial support to various public crossing improvement projects, under federal jurisdiction for the sake of reducing collisions at public grade crossings in Canada. In this program, over 80 percent of crossing improvement cost would be covered and funded under section 12 of RSA (Railway Safety Act), and there are over $100 million funded by Transport Canada for crossing improvements projects from 1995 to

2006. Table 3 lists the most-recent grade crossing improvement program funding projects among provinces in Canada from 2011 to 2012.

Table 3 2011-2012 grade crossing improvement program funding projects

Province/Territory	Projects	Contribution
British Columbia	43	$1,170,481.00
Yukon	0	$0.00
Northwest Territories	0	$0.00
Alberta	76	$1,370,220.00
Saskatchewan	14	$493,400
Manitoba	11	$1,652,155.00
Ontario	399	$5,568,319.00
Quebec	199	$2,605,580.00
New Brunswick	48	$725,040.00
Newfoundland and Labrador	0	$0.00
Nova Scotia	20	$118,800.00
TOTAL	**810**	**$13,703,995.00**

source: http://www.tc.gc.ca/eng/railsafety/publications-46.htm#identifying_projects

Funded crossings are those which are prioritized over other crossings due to unacceptably high collision risks. Transport Canada has carefully selected most risky/dangerous crossings which need indispensable improvements to reduce number of collisions. A report prepared by Transport Canada in 2008 showed that between 1990 and 2007, annual fatality rate for GCIP-funded public crossings was 1.25%, which far outweighs 0.14% for non-funded crossings.

During the years of 1989 and 2004, there were about 1,389 public grade crossings funded by GCIP, which is 6% of overall population (totally 23150 public crossings). For the next consecutive years, by 2008, funding was kept consistent while 425 grade crossings were enhanced.

Table 4 describes the past funding for the number of crossings from 1989 to 2008 and the expected funding for the number of crossings in 20 years

Table 4 Funded Crossings

Years	Annual Funding (millions)	Funded Crossings per year	Av. Project Cost (thousands)	CPI
1989-2004	$7.5	86.81	$86.39	2.44%
2004-2008	$7.5	85.00	$88.24	2.10%
2009	$11.1	127.46	$87.44	-0.90%
2010	$11.1	126.20	$88.32	1.00%
2011	$12.4	138.27	$89.64	1.50%
2012	$12.9	141.73	$90.98	1.50%
2013	$12.9	139.63	$92.35	1.50%
2014	$12.9	137.57	$93.73	1.50%
2015	$12.9	135.54	$95.14	1.50%
2016	$12.9	132.88	$97.04	2.00%
2017	$12.9	130.27	$98.98	2.00%
2018	$12.9	127.72	$100.96	2.00%
2019	$12.9	125.21	$102.98	2.00%
2020	$12.9	122.76	$105.04	2.00%
2021	$12.9	120.35	$107.14	2.00%
2022	$12.9	117.99	$109.29	2.00%
2023	$12.9	115.68	$111.47	2.00%
2024	$12.9	113.41	$113.70	2.00%
2025	$12.9	111.19	$115.98	2.00%
2026	$12.9	109.01	$118.30	2.00%
2027	$12.9	106.87	$120.66	2.00%
2028	$12.9	104.77	$123.07	2.00%
2029	$12.9	102.72	$125.54	2.00%

(Source: Transport Canada. Railway safety, Project No. 521-0604)

Grade Crossing Improvement Program (GCIP), which is designated to improve the safety level of all grade crossings, has the ultimate objective of ensuring that all grade crossings are improved to meet current safety standards. Over the last decade, from figure 1, thanks to GCIP, accident occurrences during 1995 to 2010 have dramatically reduced from 351 to 177 with a decreasing rate of 50%, and fatality reduction from 52 deaths in 1995 to 29 in 2010 with a decreasing rate of 44%.

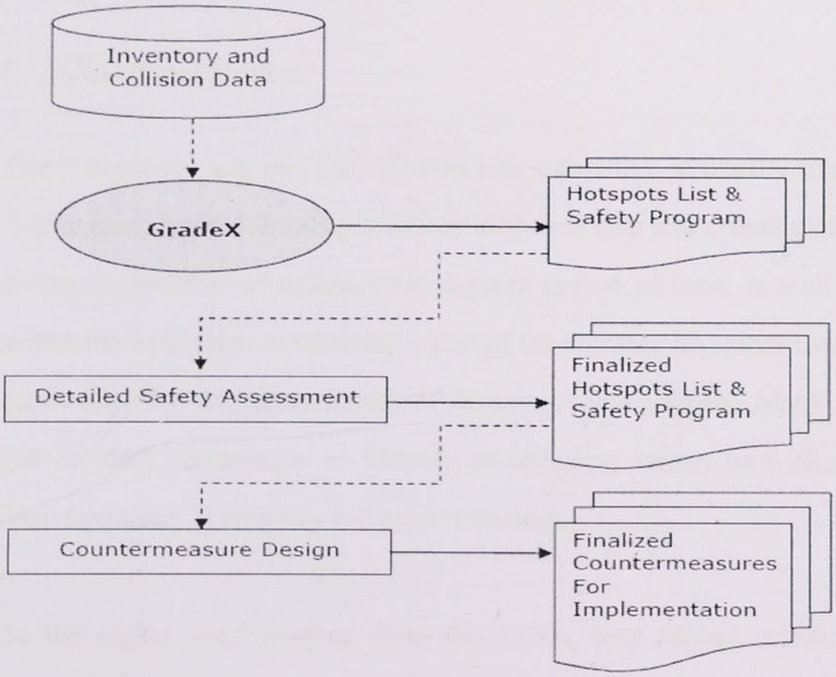
1.5 GradeX Program Overview

Motivated by the Highway rail research program as described earlier, in August 2003, the department of civil engineering at the University of Waterloo provided a detailed statistical report on hotspots identification of highway-rail grade crossing by

using Canadian collision occurrences datasets from year 1993 to 2001. This was to develop collision frequency and collision consequence models for fulfilling (Frank Saccomanno, August 2003). And GradeX was established as the condition required, for integrating all aspects of expected results into one simple but comprehensive decision-making tool for assisting Transport Canada and railway engineers to fulfill the objectives of grade crossing research program.

Four primary functions in GradeX are carried out, which are identifying potential individual hotspots with high risk collisions: evaluating safety ranking of targeted grade crossings, developing and evaluating mathematical models in terms of historic collision frequency and consequence analysis, and finally design countermeasure plans and implement cost-effective countermeasures. (Liping F, Saccomano, 2007). Figure 4 illustrates the primary functions of GradeX application.

Figure 4 GradeX application of Grade Crossing Safety Management Program



Source:(Liping F, Saccomano, 2006)

CHAPTER 2

Literature Review

Studies at highway-railway crossings can be classified in two categories: cross sectional studies and before-and-after studies. Firstly, cross sectional studies make use of statistical models that are fitted to a collision database with one observation over time (cross sectional data). These are then used to evaluate the effect of contributing factors or potential countermeasures, such as the presence (installation) of warning devices or geometry factors. Secondly, observational before-and-after analysis is a more formal and well accepted method to evaluate the effectiveness of countermeasures, where in most of the cases, a set of treated and non-treated sites is used. Data (collision and traffic) is collected in the before and after period. A brief introduction and literature review for each of these two approaches is presented as follows:

2.1 Cross-Sectional Studies

Cross-Sectional analysis for collision risk estimation is usually implemented to develop regression models using collision historical data and crossing characteristics. Observing the number of collisions in a given period of time, as well as geometry characteristics and traffic conditions, is part of the crossing inventory that is needed as the input data for the development of cross-sectional models. Many studies have studied accident occurrences to identify contributing factors as well as to predict collision frequency at highway rail grade crossings.

In the earlier years starting from the 1970s, four central collision prediction models of highway-rail crossings were proposed. These were: Peabody Dimmick Formula, New Hampshire Index, National Cooperative Highway Research Program (NCHRP) Hazard Index and the United States Department of Transportation

(US-DOT) accident prediction formula. For a literature review, one can refer to Austin, R.D. 2000. Peabody Dimmick Formula (Federal Highway Administration, 1986) merged highway-rail crossings resources with AADT and average daily train traffic and warning devices coefficients for crossing collision conditions from rural highway-rail crossings in 1941. Due to insufficient explainable variables, the New Hampshire Index has significantly modified the previous formula with better accuracy prediction on collision frequencies and included large number of collision casual factors. As the number of accidents occurred more frequently, the National Cooperative Highway Research Program Hazard Index took into consideration a treatment of a series of protection factors from various attributes in the formula. However, but certain protection factors were approximated in terms of interpretation which would be potentially lacking consistency and misleading the outcomes of collision models (Hu, S.R. 2009). The US-DOT model was developed from solving the shortcomings of previous models such as inaccuracy, inconsistency and lack of descriptive contents, which is thus far the most widely accepted methodology for contributing to a crossings' level of safety. (Federal Highway Administration, 1986).

The development of a collision model is mainly from two perspectives: absolute collision risk and relative collision risk. Absolute collision models, which were developed by Coleman-Stewart (1976) and Farr (1987) explore the predicted number of collisions at given crossings, whereas, relative collision models, which were developed by a series of alternative methods compare the differences of risk frequency or severity among crossings. Especially the US-DOT model is pivotal and standard methodology for absolute collision frequency/consequences predictions for highway-rail crossings. A three-stage formula is involved in this: basic statistical model, subjective external adjustment for historical observations and subjective external adjustment for three typical types of warning devices which are Type S (Signs), Type F (signs with flashing lights), and Type G (signs + flashing lights + Gates) (Saccomanno et al. 2003). The US-DOT collision frequency model treats the

number of collisions with either fatality or casualty as a function of crossing characteristics such as highway, railway and warning devices at crossings. While the US-DOT collision consequence model treats three typical levels of collision severity, which are non-injury, injury and fatality, as the function of collision-occurrence related variables involving speed, vehicle and train information and driver characteristics. The US-DOT model has been successfully applied to Canadian crossings with IRIS and RODS databases. Relative models, known as hazard index, are mostly developed in the US before the development of absolute collision models, such as Ohio formula (1959) and City of Detroit formula (1971). Due to the lack of cost-effective estimate of collision risks, the relative risks model is limited for the use of black spot identification and analysis.

Negative Binominal models and their extensions are the most common linear models used to calibrate count data. They are count regression modeling techniques, which are very popular in road safety (Joshua and Garber, 1990). The Negative Binomial models are also able to deal with the problem of over-dispersion. This indicates that normally the variance of collision datasets is larger than the mean and the estimated parameters are most often inaccurate and biased. The Negative Binominal model is more suitable for calibrating collision frequency datasets primarily because it is able to overcome the problem of over-dispersed collision datasets better than Poisson distribution. (Miaou, S-P, 1994). The model introduces an error term that is Gamma distributed. This is not restricted to the mean being equal to the variance. Other extensions of the NB model that have been applied to train-car collision data at highway-railway crossings are zero-inflated negative binomial and Negative Binomial with varying dispersion parameter.

2. 2 Observational Before-After methods

The primary reason why before and after methods are used, is to estimate the effectiveness of countermeasures. Using historical collision data for the group of treated crossings and control group, the accident reduction is estimated.

Treatment group refers to the target sites with countermeasures where collisions are counted and assessed before and after the implementation of countermeasures. Control group refers to the targeted sites without implementing countermeasures, where collisions are assessed before and after the same countermeasures of the treatment group. In safety literature, the three most popular methods for before-and-after studies are: Naïve Before-and-After studies, Before-and-After Studies with comparison group, and Before-and-After Empirical Bayesian (EB) studies. Selecting target sites is the first step which greatly influences the accuracy and reliability of outcomes in the before and after analysis. Bias by selection refers to the fact that locations are not selected randomly. This generates the problem known as regression to the mean. Note that target locations are usually hotspots which are unrepresentative locations of the entire population. The use of hotpots as treated sites can either over or underestimate the effectiveness of a countermeasure. To deal with this problem, the use of observational studies with a control group or EB is recommended.

2.2.1 Naïve Before-and-After studies

This is the simplest method to assess treatment effects by comparing the differences of crash counts and computing crash rate in the before and after period. The collision counts and rates in the before period are considered as expected. This method lacks the consideration of many factors, such as: random effect, trend effect, exposure effect and treatment effect (ITE, may 2009). The following are some general problems that this method is not available to correct.

Regression-to-mean(RTM)

Regression-to-the-mean is a common phenomenon at targeted sites with high collision frequencies for a given year. It is a bias because collision frequency would fluctuate annually and will finally drop back to the site's long-term average frequency, regardless of countermeasures implementations. Over-estimation of countermeasure treatments would exist due to this effect. Empirical Bayesian statistical analysis overcomes this problem by considering both crash numbers from predictions and observations.

Crash Migration

Boyle and Wright (1984) firstly pointed out the occurrence of "Crash Migration", which was the phenomenon that one treatment site would transfer the crashes to its surrounding sites due to the effect of the treatment. Pendleton (1992) used "crash migration" referring to it as "geographic crash migration." Safety assessments are suggested to use databases in wider regions than solely treatment sites for crash migration effects consideration (Mountain and Fawaz, 1989).

Maturation

Council et al (1980) has found general crash trends due to temporal changes of certain factors such as weather, traffic volume, flows and economy. He referred to this trend as "maturation" and raised the question that the decline in crashes at a treatment site with countermeasures would not be only associated to treatments (Council et al, 1980).

External Temporal Factors

The trend of complicated factors such as weather, economy and precipitation are not easily measured and understood, while the change of these temporal factors during the before and after periods may cause the change of treatment effect. (Hauer, 1997).

2.2.2 Before-and-After studies with comparison group

Due to the previous outlined problems, the Before-and-After studies with comparison groups are preferable. This method can correct the temporal trends and changes in traffic parameters. Mountaine et al (1992) has found that it produces more accurate estimates. Several different formulas of crash reduction factors (CRF) based on this method were created and estimated for crash reduction calculation (Hauner, 1997; Pendleton 1996; Griffin, 1982; Al-Masaeid 1997, Benekohal and Hashmi 1992). However, this method is still limited in use due to several constraints. Firstly, this method is not always able to find many treatment groups and comparison groups with same methods. Further, the counts of crashes in comparison groups needs be sufficient enough for comparison with that in treatment groups. (Hauer, 1997). More importantly, uncertainty is not considered in the analysis.

2.2.3 Before-and-After Empirical Bayesian studies

It has been observed in road safety studies that crash risk at targeted(hotspot) sites with high frequency of crashes can decrease even without treatment. Moreover, low crash-risk locations can increase towards the average risk value. This is known as "regression-to-the-mean bias". The Empirical Bayesian method is used to account for this effect. Typically, a Poisson/Gamma or Negative Binomial model is used for the analysis.

The fundamental concept of this method is to forecast expected collision in the treatment group, where the countermeasures are yet to be implemented in the after period. And this expected collision is calculated statistically as a result of changes in various attributes from the before period. Additionally, actual crash counts in reference sites without countermeasures are also used for the estimate. Based on the Poisson-Gamma or the NB model, the EB estimator or the posterior, expected crash frequency can be determined as follows (Gan, et al 2005):

Expected collision counts in a treatment site (if treatment would not be applied) = weight x (Expected number of crashes using safety performance function) + (1-weight) x Registered crashes at treatment sites in the before period.

Later, the EB approach is applied to calculate expected collision reduction at highway rail crossings; it integrates the collision history and collision models simultaneously for hotspot identification (Hauer, 1997).

2.3 Summary of countermeasure effectiveness

In addition to the available methods, the effectiveness of typical highway-railway systems is documented in this subsection.

Crash Reduction Factors (CRFs) are developed by the two approaches described above: cross-section analysis and before-and-after analysis. While the latter one is applied more often for CRFs. The difference between these two approaches was well explained by Tarko et al (1998):

"*the key difference between before-and-after analysis and cross-sectional analysis is not in the difference methods used to analyze the data but rather in the different concept of how to investigate the safety effects. In before-and-after study, the idea is to investigate these locations where a given improvement has been applied within the period of analysis, while for the cross-sectional analysis, the investigated locations do not experience any major changes with the period of analysis. Thus, the before-and-after study focuses on the changes in safety over time, while the cross-sectional analysis focuses on the differences in safety between locations.*"

Table 5 summarizes the countermeasures at highway-railway crossings and their effects obtained from literature reviews:

Table 5 Summary of countermeasures from literatures and their effects

Major Countermeasures	Number of sources	Countermeasure effects (Collision reduction %)
Lighting	6	10% - 52%
Sign to flashing lights	7	28% -75%
Sign to gates	8	45% - 77%
Flashing lights to 2Q gates	5	75% - 77%
Lights gates + flashing lights	3	44% - 88%
Stop signs	4	25% - 58%
Yield signs	2	25% to 45%
4Q gate system	2	86%
Sight distance to the crossing	1	56.2%
Sight distance at crossings	4	30% - 56.2%
Sight distance improve	2	30%
Safety advisory warning system	3	16%-19%
X-box marking	4	25% - 36%
Pavement condition	2	20%
Speed humps	3	40%
Post speed limits	2	20% -25%
Crossing closure	2	100%
Eliminate while prohibition	1	26%
Median barrier	1	77%
Buckeye crossbuck	1	22.3%

Appendix C has summarized the list of past studies in greater detail on collision reductions at highway-rail crossings from various perspectives, such as traffic control devices, geometry, pavement marking and enforcements.

Collision/Crash Modification Factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. CMF is defined as the ratio of expected collision frequency with countermeasures to expected collision frequency without countermeasures. (Highway Safety Improvement Program Manual, FHWA).

CMF = Et / Ea

Where:

CMF = CMF under specific condition with treatment implemented.

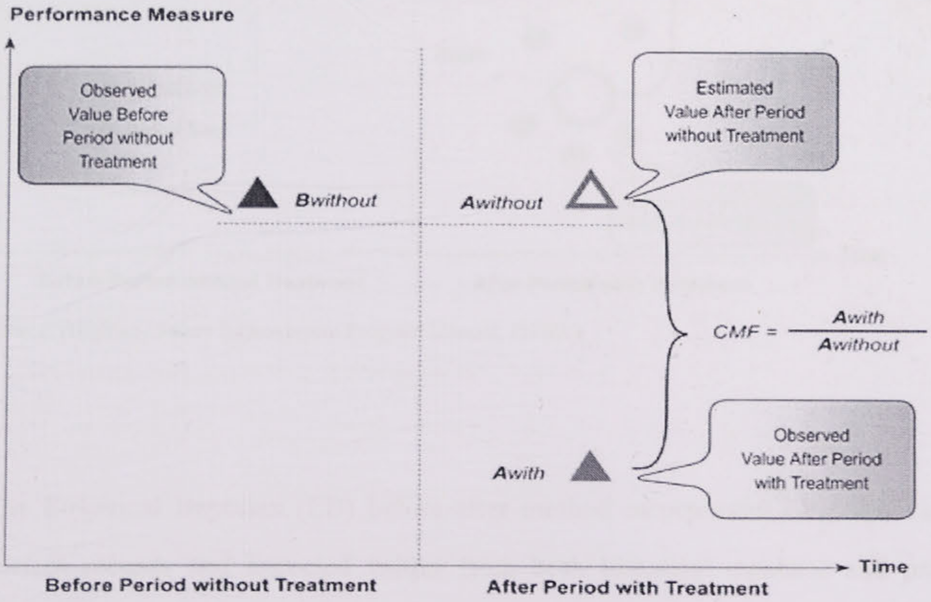
Et = expected collision frequency with countermeasure implementation;

Ea = expected collision frequency without treatment under identical conditions.

CMFs definitions in before-after methods

In the Naïve before-and-after method, crash frequency measurements are developed at all treatment sites in the after period, and CMFs can be calculated by taking the ratio of observational values with treatment to estimated value without treatment in the after periods (Figure 5).

Figure 5 CMF in Naïve before-and-after method

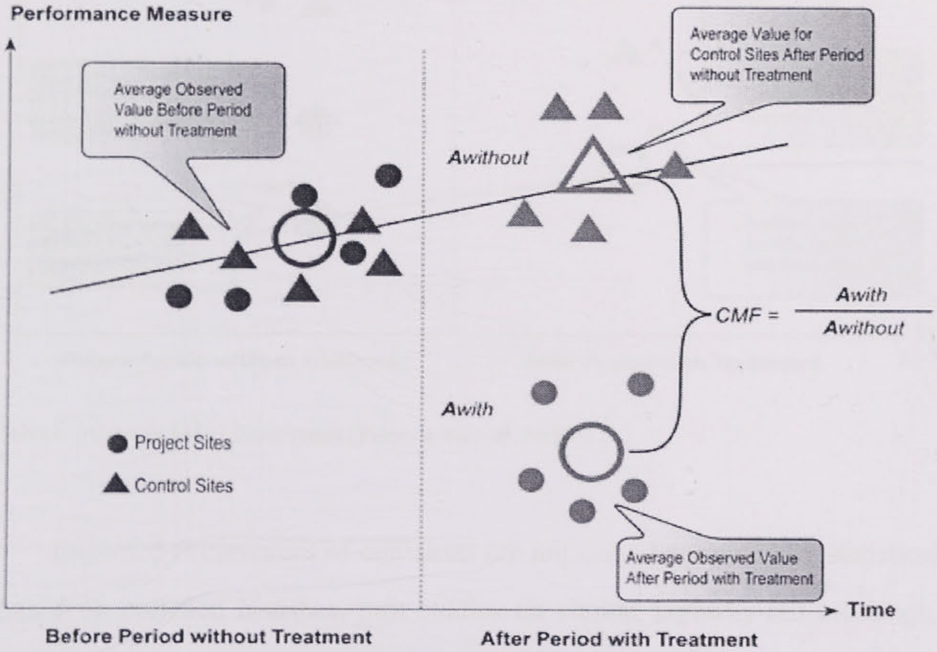


Source: (Highway Safety Improvement Program Manual, FHWA)

In Figure 5, 6 and 7, the X-axis represents the incremental period of performance measurements (monthly, quarterly, annually). The Y-axis represents the value of performance measurements such as crash frequency, fatality numbers, etc.

In the before-after method with comparison group, it connected the non-treatment sites to evaluate CMFs by introducing comparison groups (controlled sites). Comparison groups in non-treatment sites normally have identical and comparable road characteristics and traffic volumes, to those in treatment sites before implementing countermeasures. CMFs are developed by taking the ratio of controlled group to the value in treatment sites in after period. (Figure 6

Figure 6 CMFs in before-after method with comparison group

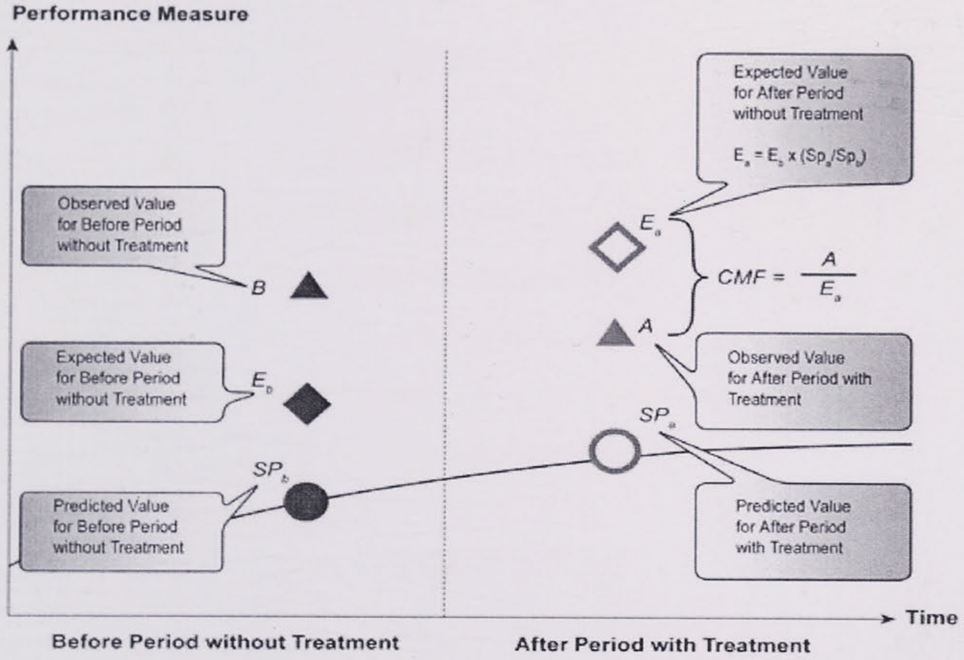


Source: (Highway Safety Improvement Program Manual, FHWA)

The Empirical Bayesian (EB) before-after method incorporates observed values on current records and expected values from both historical database and prediction

models. In figure 7, it illustrates associated variables and their definitions to calculate CMFs. Safety Performance Functions (SPF) are used to reduce the effects of the Regression to the Mean (RTM) in a/the targeted site's selection process. Expected values and predicted values are estimated from both the before and after periods. CMFs are obtained by taking the ratio of an observed value from the before period with treatment to the expected value for the after period without treatment (Figure 7).

Figure 7 CMFs in Empirical Bayesian (EB) before-after method



Source: (Highway Safety Improvement Program Manual, FHWA)

Expected occurrences of collisions are not only determined by statistical models based on collision histories, past studies on similar highway-rail crossings, but are also advisable and can be used as sources of references. Furthermore, adjustments and expectations of collision occurrences from expertise are mandatory to assist in making the final decision on the parameters of collision reductions. Many previous papers discovered collision reduction factors instead of CMF, and collision reduction factor is the compliment of Collision Modification Factors (CMF = 1- CRF)

Appendix G lists primary sources and parameter types of CMFs for specific main countermeasures from literatures. Appendix H summarizes the CMFs. Notice that some of CMFs are not directly given by reference paper; instead other parameters such as CRF or Elasticity are displayed. Certain assumptions and calculations as well as advices from transportation experts are consulted and discussed.

CHAPTER 3

Data and procedure for model development

Introduction

The car-train collision datasets used in this project were provided by Transport Canada. This includes 9 years (2002 to 2010) of data of all collisions at highway-rail grade crossings in Canada. This dataset is then combined with an inventory containing the geometry design and traffic control characteristics. This is described as follows: considering the continuation of previous risk modeling work in order to update the statistical changes on grade crossing collisions over the past decade, and more importantly, to be well prepared for identifying and upgrading highway-railway grade crossing hotspots and developing countermeasure cost-benefit analysis.

3.1 Datasets

Transport Canada has provided two datasets containing crossing and collision information. According to the Integrated Rail Information System Dictionary (IRIS), collected datasets are classified into 3 sub-sections: section A - Inspection Module, section B – Location and section C- Project Module; where section B is related to inventory characteristics and is the section of interest in this work. Section B provides crossing related characteristics, such as traffic volume, projects inspections at each crossing, traffic control devices information etc. The following are summaries of essential attributes in IRIS datasets.

Inventory Datasets

The inventory dataset contains 27,882 crossings in total (public crossings, private

crossings and farms). Of these 26,882 have a unique location ID and associated Transport Canada crossing file number for identification, which indicates location information by province, municipality and street. Comparing this with the IRIS dataset for period 1993 to 2001, there is about a 9% decrease on overall crossing locations of datasets. Table 6 has the details at the provincial level.

Table 6 Number of crossings comparison

Provinces	# of crossings used from 1993 to 2001	# of crossings used from 2002 to 2010	Percentage changed
Alberta	4074	3426	-16%
British Columbia	2185	3097	+42%
Manitoba	3161	2509	-21%
New Brunswick	1291	1222	-5%
Newfoundland	9	8	-11%
Nova Scotia	809	876	+8%
Northwest Territory	16	28	+75%
Ontario	7357	6559	-11%
Quebec	4127	3926	-5%
Saskatchewan	6469	5158	-20%
Yukon	13	6	-54%
Prince Edward Island	1	N/A	N/A
Total	29,507	26,882	-9%

Type of warning devices under Public Crossings

According to the previous works by Saccomanno, et al (2004), (who estimated collision frequency models at Canadian grade crossings through year 1993-1999), public crossings are typically divided into 3 types, according to the warning devices: crossings with flashing lights and gates (type G), crossings with flashing lights only (type F), and crossings only with signs (type S). For the classification of crossings according to the type of warning device, see Table 7. Table 8 presents the distribution of public crossings by type of warning device. Note that from the entire population of Canadian crossings (20,051) 17324 are classified as public crossings, from which 17,234 fall under one of the three typical warning devices mentioned above. The number of public crossings under flashing lights (Abbreviation FLB, type F), signs (abbreviation SRCS, type S), and gates (Abbreviation FLBG, type G) are 4,368,

10,637, and 2,229 respectively. These three types of warning devices overall represent 86% of all Canadian public crossings.

Table 7 Warning devices definition in IRIS dictionary

	Definition in database dictonary
FLB	Flashing lights and bell activated by railway equipment/employee.
FLBG	Flashing lights, bell and gate arms activated by railway equipment/employee.
GATED	Gates arms
SRCS	Standard reflectorized railway crossing sign
SRST	Railway Crossing sign and stop sign
GS	Grade separted crossing.
OTHERS	Other type of traffic control device.
Unknown	Impossible to determine.

Table 8 Crossings summary in terms of warning types

	Frequency	Percentage (%)
FLB (Type F)	4,368	21.78
FLBG (Type G)	2,225	11.1
GATED	4	0.02
SRCS (Type S)	9,283	46.3
SRST	1,354	6.75
GS	2,742	13.68
OTHERS	75	0.37

Inventory dataset contains many crossing characteristics such as highway geometry, railway geometry, warning devices, vehicles and traffic volume information. Unfortunately, almost half of the variables contain missing information. In order to

correctly and accurately analyze collision risks at each grade crossing, it is crucial to check the availability and completeness of dataset, eliminate those crossings with large portion of incomplete crossing information, and finally stratify comprehensive crossings with the most integrated crossing and collision occurrence information.

Collision datasets

Collision occurrence dataset involves four types of information as described from previous study (Frank Saccomanno, August 2003):

- Basic Collision data: This includes collision ID number, collision date and time, location, weather conditions, road conditions (wet or dry), road and rail geometry, traffic volume, train daily, etc;
- An involved driver and vehicle data: this includes information on driver characteristics (age and gender), driver maneuver action, visibility, etc;
- Involved "persondata": This data provides information on the number of persons and vehicles involved in the collisions;
- Severity consequence data: This data includes information on the number of fatalities, serious injuries and level of property damage level for each collision.

In the period of analysis, 1,826 collisions at highway-rail crossings were correctly recorded from the beginning of 2002 to June 2010 in Canada, where 1634 collisions (89.4%) occurred at public crossings under three types of warning devices, specifically: 581 under Flashing Lights, 508 under Gates, and 545 under signs. The collision occurrence is distributed equally among typical warning devices. Notice that collision datasets from 2002 to 2010 are reasonably clean and linked with IRIS datasets before developing collision frequency and collision consequence models. Attributes that have missing data are removed from the origin dataset. For significant variables with insufficient information, it is tested as an additional part after integrated collision consequence models are developed.

3.2 Procedures for Model estimation

Preparing data and Developing Collision Frequency model

For a collision frequency analysis, the crossing inventories and collision datasets are merged. Crossing inventories include around 400 attributes describing the characteristics around and at each grade crossing, and many of which are left in blanks. Collision datasets, with around 250 attributes describe the occurrence and situation of accidents at given crossings including crossing inventory, time and date, weather, severity information and traffic condition and so on.

Step 1- Merging Inventory and Collision Datasets

For the frequency analysis, the unit of analysis is the crossing from which the number of collisions during the period of analysis is the outcome of interest. For this purpose, the first step is to merge inventory and collision datasets to obtain crossing-level attributes that can be potentially related to collision occurrence. Using the collision ID, collisions belonging to the same crossing are grouped to obtain the number of collisions during the period of analysis. This outcome is then merged with the inventory containing crossing-level attributes (geometry, traffic conditions and controls). Table 9 shows the interrelationship of inventory and collision datasets. Unique crossing IDs, such as Location ID, and TC XNG_reference number, are two primary linkages connecting segregated components of each crossing with associated inventory and collision information.

Table 9 Merging explanation

	Joint links	Context
Inter-connected IDs in segaragted inventories	Unique Crossing ID (Location ID, and TCreference number)	Universal crossing information, latest Crossing information
	Collision ID	Collision information
	Project ID	Project information of given crossings

Step 2- Clearance of datasets errors

Inventory and collision datasets contain detailed crossing information from different perspectives such as highway geometry, railway geometry, warning devices, vehicle and traffic information. During merging process, two primary criteria are used to clean the data. The first criterion is the elimination of unmatched crossings (based on the ID), which are eliminated. There are a few dozen crossings with only report number or the inconsistency of location ID and TC_xng_number at the same crossing. The second criterion is the elimination of crossings with data entering errors. For example, unique crossing ID is wrongly and incompletely recorded, or a large portion of the information at a given crossing. In order to correctly and accurately analyze collision risks at each grade crossing, it is crucial to check the availability and completeness of dataset, eliminate those crossings with large portion of incomplete crossing information and finally stratify comprehensive crossings with most integrated crossing and collision occurrence information.

Step 3- Modifying Accidents Frequency Model from 2002 to 2010

After merging the inventory and collision history data, the next step is to develop an accident frequency model to establish the relationship between collision frequency and physical crossing characteristics. The outcome is the number of accidents occurring at each crossing during the period 2002-2010. In some cases, a crossing may appear more than once in the merged dataset, resulting from multiple accidents occurrences and updates of crossing inventory through projects. In these situations, repeated observations are eliminated. In addition, many crossings are updated and maintained through recorded projects over these periods, resulting in changes on inventory characteristics. At least, the inventory information that is used in this analysis corresponds to the last project update.

Step 4- Generating new variables

According to previous works (Sacommano et al. 2003), a set of variables are generated and tested to better reflect and predict the collision occurrence. The following are the main variables generated for the three types of public crossings classified according to the warning devices:

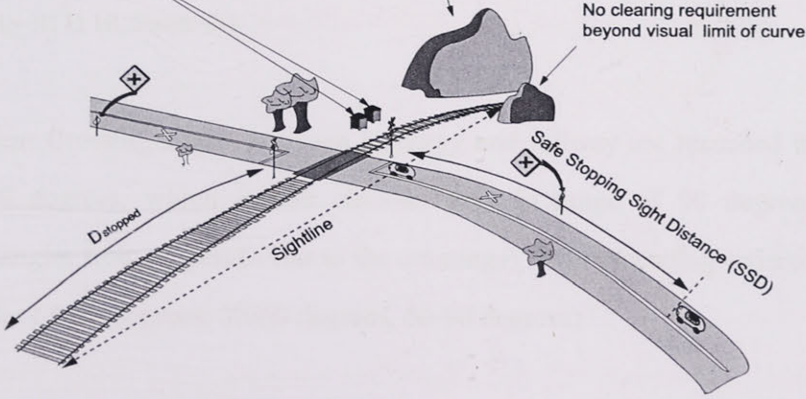
- Total Trains per day - number of freight daily trains + number of passenger daily trains + number of switching daily trains
- Max Train Speed - maximum value among freight, passenger or switching speed limits
- AADT = Average Annual Daily Traffic (road vehicles)
- Traffic exposure - Ln (total trains * AADT)
- Minimum Sightlines at grade crossings with warning systems are illustrates and defined in RDIMS-RTD-10(Road/Railway Grade Crossings Technical standards and inspections, testing and maintenance requirements.).

Figure 8 Minimum Sightlines at grade crossings with warning systems

No new communication signal housings, tool sheds, or any other buildings shall be erected closer than 9 m (30 ft.) from thetravelled way of the road nor within the sightlines of $D_{stopped}$ where it would obstruct sightlines.

No clearing requirement beyond natural and permanent visual barriers such as rock cuts and earthen embankments.

No clearing requirement beyond visual limit of curve.



Sightlines of a Railway Crossing Sign, and at least one set of front lights of the grade crossing warning system must not be obstructed within the SSD. Particular attention should be given to:

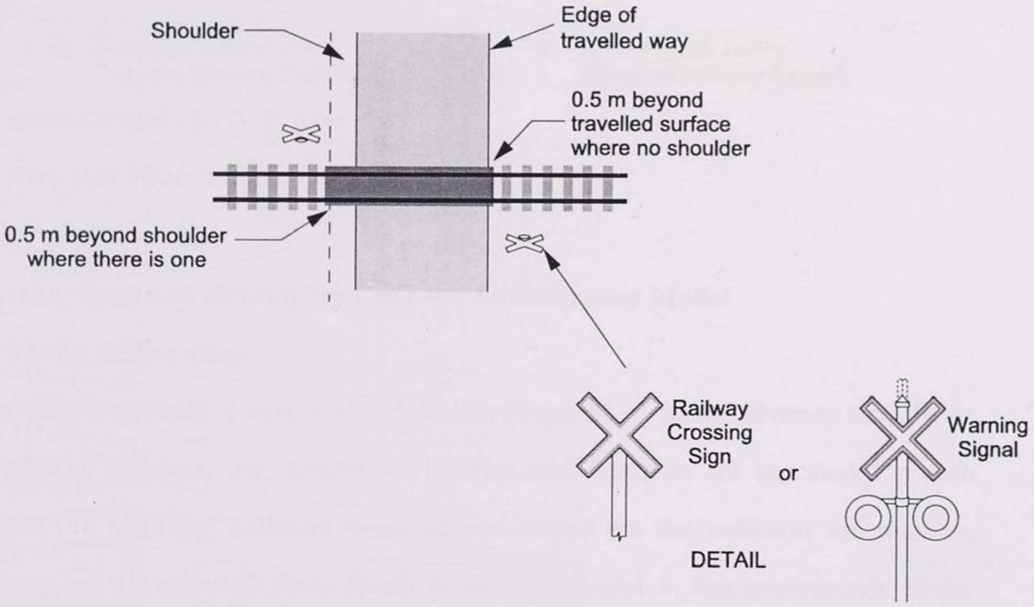
1. trees, brush, other vegetation, pole lines, signs, bus shelters or other roadside installations; and
2. parked vehicles, or buses loading or unloading passengers.

Source: RDIMS-RTD 10, figure 8-2

Where in dataset, Sightline distances (in km) = (left-sided sightline distances + right-sided sightline distances) /1000

- Crossing width is defined as the widths of grade crossings for public road vehicles. The minimum of crossing width is 8m. (figure 6-1, RDIMS-RTD 10)
-

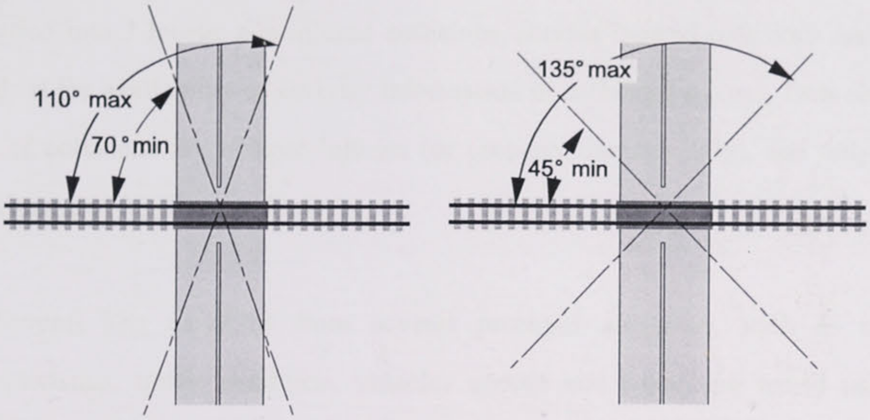
Figure 9 Grade crossing width for public road vehicles



Source: RDIMS-RTD 10, figure 6-1

- Crossing angles: Crossing angles between highway and railway are recorded in range of 180 degrees, which is less obvious than in range of 90 degrees (conversion angles from perpendicular to the crossings), or in ascending ordered range of angles (0-30 degrees, 30-60 degrees, 60-90 degrees)

Figure 10 Grade Crossing Angles



a) Crossings without Grade Crossing Warning System.

b) Crossing with Grade Crossing Warning System.

Source: RDIMS-RTD 10, figure 7-1

Note that other variables are defined later.

Preparing Data and Developing Collision Consequence Model

Step 1 Data preparation

A similar process is executed for the development of injury severity models. In the collision datasets, the number of injuries and fatalities are reported for each collision. To consider collision consequences based on the collision information, collisions are classified in three levels of severity. Level 3: this corresponds to the fatality level, wherever a collision involves one or more deaths. Level 2: this is the serious injury level, with collisions involving serious injuries. And Level 1: that corresponds to non-injured level or property damage only. For simplicity, Levels 1 to 3 follow in ascending order of increasing severity.

Step 2- Establish (Injury) Consequence Model

This is developed based on the 1,826 collisions registered during the period from January 2002 to June 2010. According to the three types of warning devices within public crossings, 1634 records are usable, including 581 collisions for flashing lights, 508 collisions for Gates, and 545 for Signs. Distribution of collisions among these warning devices reflects the equal chances of collision frequency occurrences no

matter the specific warning crossing types in general. Again, each collision is classified into 3 levels: non-injured collisions, serious injured collisions and fatality, based on the availability of severity information in collisions dataset. Data shows that 75% of collisions are without injuries (or property damage only), and only 10% of collisions are classified as fatal.

Several key variables from several potential attributes, such as inventory characteristics, traffic condition, vehicles speeds and types, are tested using both multinomial logistic model and order logistic model. After a series of trial and errors, an acceptable model with statistically significant variables is selected. For model selection, goodness-of-fit and correlation among explanatory variables are taken into account. Among the variables tested are those presented in Table 10.

Tables 10 and 11 present a summary statistics of the attributes used in collision frequency model and severity model.

Table 10 Statistical description of attributes used in collision frequency model

Variables	Unit	Mean	Std.Dev	Min	Max
Max Train Speed	Mph	39.77	21.0	5	100
Road Speed	km/h	63.71	20.8	5	110
Surface Width	Ft	10.91	594	5	134
Sightline Distance	Metters	3235.5	3514.6	5	9999
Urban	Categorical	0.133	0.339	0	1
Whistle prohibition	Categorical	0.0473	0.2122	0	1
Exposure		4.103	2.3	-4.605	11.513
Collisions	Jan 2002 to June 2010	0.12	0.41	0	5

Table 11 Statistical description of attributes used in collision severity model

Variable	Classification	observation	Mean	Std. Deviation	Min	Max
Severity	1= no-injuries 2= injuries 3= fatalities	1634	1.374541	0.6870247	1	3
Approximate train speed at crossing	mph (continuous)	1606	29.62391	19.15253	0	100
Crossing Environment: Urban area	0= no 1= yes	1628	0.531941	0.499132	0	1

Despite driver and vehicle characteristics, the frequency of collisions at highway-rail crossings are largely influenced by speed and crossing geometry. In a/the frequency model, train speed, vehicle speed, crossing surface width, sightline distances from both sides approaching to the track, urban surrounding environment, whistle prohibition as well as the traffic exposure are explored as they have significant contribution on the frequency of collisions under three typical warning devices.

The level of collision severity not only relates to the existing warning devices and crossing characteristics such as approximate travel width, track angle, crossing environment, manual flags and types of warning devices, but more importantly it also largely depends on many dynamic factors such as speed, vehicle conditions and driver characteristics. In our analysis, the significantly dynamic factors are approximate train speed, max daily train speed, number of trains at collisions, type of trains, type of vehicles(on road), derailment, driver gender, and vehicle impact. Be aware two train speeds are classified above: "Approximate train speed" is the train speed estimated involved in the accidents at that time. "Max Speed" is the top speed of three daily trains on rail: passenger trains, freight trains and switching trains.

Three severity levels of collisions are recorded and classified orderly as non-injuries, injuries and fatalities. In summary, 1634 collisions involve 1,216 non-injuries, 224 injuries and 194 fatalities. Train speed at crossings and urban environment are two statistically significant attributes discovered in datasets by analyzing both multinomial logistic regression and ordered logistic regression.

Chapter 4

Collision Frequency and Severity Models

Introduction

Using collision data and crossing inventory attributes, collision frequency and severity models are developed with statistical models that take into account observed and unobserved factors. According to the collision frequency literature, the most popular statistical modeling technique that is used is the Negative binominal (NB) regression model. Moreover, for the collision consequence model, multinomial logistic regression and ordered logistic regression are both applied in this work.

For selecting the best of models (collision frequency and severity), several statistical trials were attempted with different combination of explanatory variables. Model selection was done based on the compatibility with the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). As part of the statistical tests, over-dispersion was evaluated among good model candidates. This was done using the log-likelihood ratio (T_{LR}) test, which tests for equality of the mean and variance. The popular software STATA 12, known as integrated statistical package for data analysis, data management and data graphics, is applied for collision model analysis and calibration.

4.1 Collision Frequency model

Using the collision frequency dataset defined in the previous Chapter, different models are calibrated for each of the three crossing types. Standard Poisson and NB regression models are fitted for each crossing dataset with different set of explanatory variables and controlling for traffic exposure. Based on AIC and BIC, the best set of

models are selected; which criteria reveals that, the NB model is superior to the standard Poisson regression model. This confirms the presence of over-dispersion due to unobserved heterogeneity in the data. Table 12 shows the results of best frequency model with 5% confidence interval.

From this table, one can see that traffic exposure, defined as the product of daily vehicle traffic and daily trains at crossings, has a significantly positive impact on collision frequency over all three types of crossings. The parameters of traffic exposure are 0.45, 0.48 and 0.33 for signs, flashing lights and gates, respectively. In accordance with the literature, this shows the typical non-linear association between exposure and collision frequency. Moreover, from the model with "Signs" as warning devices, two factors are found to be statistically significant: train speed and urban crossing. These two factors have a positive sign, as intuitively expected. For the model with "Flashing lights", variables such as crossing surface width, urban crossing environment, whistle prohibition and train speed have positively influenced the collision frequency. Finally, for the model with "Gates", the set of contributing factors that are identified as statistically significant are road and train speed as well as sightline distance. According to the results, an increase in road and train speed will induce an increase in the frequency of collisions, while sightline distance has negative impacts on collision frequency for crossings with gates. This can be explained as the shorter sightline distances that drivers perceive have higher possibility of collision occurrences.

Table 12 Best NB models for crossings under three types of warning devices

	Warning Devices "Signs"			Warning Devices " Flashing Lights"			Warning Devices " Gates"		
Observations	9470 (91.6% datasets used)			3462 (79.3% datasets used)			1996 (89.5% datasets used)		
Variable	**Estimate**	**Std Error**	**P> IzI**	**Estimate**	**Std Error**	**P>IzI**	**Estimate**	**Std Error**	**P>IzI**
Intercept	-6.1202	0.1961	0.000	-6.9147	0.3512	0.000	-5.3818	0.4998	0.000
Road Speed							0.0069	0.0037	0.061
Surface Width				0.0206	0.0081	0.011			
Urban	0.4540	0.1541	0.003	0.2315	0.1087	0.033			
Whistle Prohibition				0.5499	0.1426	0.000			
Train Speed	0.0185	0.0025	0.000	0.01137	0.0029	0.000	0.0044	0.0023	0.057
Sightline Distance				-0.0452	0.01543	0.003	-0.055	0.01594	0.001
Exposure	0.4546	0.0283	0.000	0.4877	0.0373	0.000	0.333	0.0358	0.000
α	1.278	0.323		0.7054	0.1881		1.1732	0.2293	

	Warning Devices "Signs"				Warning Devices " Flashing Lights"				Warning Devices " Gates"			
Criterion	LR Chi2	T_{LR}	AIC	BIC	LR Chi2	T_{LR}	AIC	BIC	LR Chi2	T_{LR}	AIC	BIC
	446.64	32.4646	3354.085	3389.864	319.63	25.315	2707.44	2756.637	110.22	57.6382	2278.47	2312.063

Note that dispersion parameters for the three models are statistically significant, which confirms the presence of over-dispersion in the data. The parameters are 1.27, 0.7054 and 1.17, respectively.

Based on the T_{LR} the presence of over-dispersion is confirmed. For instance, for the "Flashing light" model, the log likelihood of Poisson model is -1358.3777 and the log likelihood of Negative binomial model is -1345.7202, resulting in a test statistics of (T_{LR}) 25.315. Note also that the header information on the right side shows the number of observations used in the analysis (e.g., 3462 for flashing lights), followed by the p-value for the chi-square. We can see P values are all smaller than 0.05, indicating that this model is statistically significant. And the Pseudo-R^2 is 0.1062. Also, note that the lower the AIC and BIC, the better the model fits.

4.2 Collision Severity model

For the collision severity analysis, a similar approach to the one described previously for the collision frequency analysis, is used. Since collision severity is a categorically dependent variable, multinomial logistic regression and ordered logistic regression techniques are used. As part of the procedure described in the previous Chapter, data is cleaned previous to the modeling analysis. Some observations with missing information are eliminated. Also, dummy variables are generated for categorical covariates. For modeling purposes, each collision is classified into three levels of severity: 1) non-injuries or property damage only, 2) minor and major injuries and 3) collisions with fatalities (one or more).

For model selection, the AIC is also used. Correlation among covariates is also verified using a correlation matrix to avoid co-linearity. Only statistically significant variables at the 5% level or less are retained in the final model. Different combinations of variables are attempted. The final outcome and best option reported in this work is the one presented in Table 13-1.

Note that dispersion parameters for the fitted models are statistically significant, which confirms the presence of over-dispersion in the data. The parameters are [illegible] ± 0.106 and [illegible], respectively.

Based on the χ^2, the presence of over-dispersion is confirmed. For example, for the "Flashing light" model, the log likelihood of Poisson model is [illegible] and the log likelihood of Negative binomial model is [illegible], resulting in a test statistic of [illegible]. Note also that the pseudo [illegible] and this shows the number of observations used in the analysis [illegible] followed by the [illegible]. The [illegible] F values [illegible] indicating that the model is statistically significant, with the P-value [illegible]. Also, note that the lower the AIC and BIC, the better the model fit.

4.2 Collision Severity model

For the collision severity outcome, [illegible] approach [illegible] for the collision severity analysis, [illegible] ordered logit, multinomial logistic regression and ordered Probit regression [illegible] analysis [illegible] dummy variables are generated [illegible] each collision is classified into three levels of [illegible] collisions with [illegible].

[illegible] Correlation among [illegible] statistically significant [illegible]. The final [illegible] are shown in table 13.

Table 13-1 Multinomial logistic regression(MLR) severity model

Mulitniminal logistic regression				Number of observations =		1605
				LR Chi 2(4)	=	154.22
Log likelihood = -1124.7413				Prob > chi2	=	0.0000
Severity	Coefficient	Std. Err	z	P >1z1	95% Confidential Interval	
1	(Base outcome)					
2						
Train Speed	0.0228847	0.0038898	5.88	0	0.0152608	0.0305086
Urban	0.3422376	0.1499109	2.28	0.022	0.484177	0.6360575
_Cons	-2.552547	0.1715337	-14.88	0	-2.888747	-2.216347
3						
Tran Speed	0.0454096	0.0041061	11.06	0	0.0373618	0.0534573
Urban	0.3233754	0.1669586	1.94	0.053	-0.003857	0.6506083
_Cons	-3.583064	0.2087064	-17.17	0	-3.992121	-3.174007

*Severity level 1 is non-injury collision, severity level 2 is injury collision and severity level 3 is fatalities collision.

Table 13-2 Ordered logistic regression (OLR) severity model

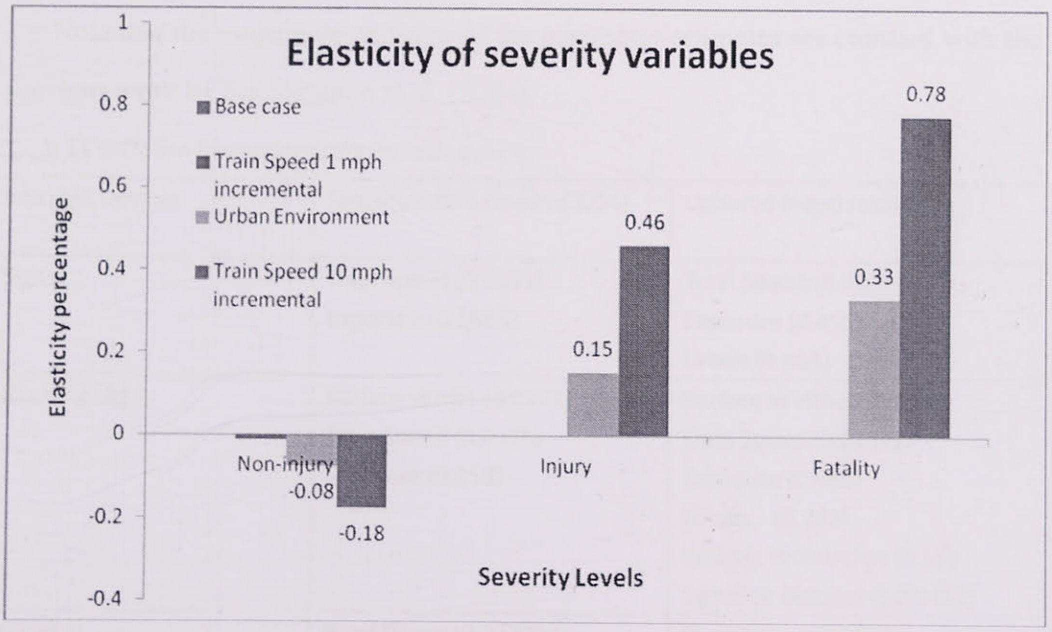
Ordered logistic regression				Number of observations	=	1605
				LR chi2 (2)	=	147.72
				Prob > chi2	=	0.0000
Log likelihood = -1127.9926				Pseudo R2	=	0.0615
Severity	Coefficient	Std. Err	Z	P >IzI	95% Confidential Interval	
Train Speed	0.0348282	0.0030382	11.46	0	0.0288734	0.040783
Urban	0.3226573	0.1188186	2.72	0.007	0.089772	0.555374
/cut 1	2.347957	0.1397045			2.074142	2.621773
/cut 2	3.375926	0.1556362			3.070884	3.680967

From the two techniques (MLR and OLR), consistent results are obtained. In the final model there are only two explainable variables significantly influencing the severity of collisions, which are train speed and urban crossing environment. As

train speed increases and crossing locates urban regions where more severe collisions would occur.

Finally, in order to illustrate how each single factor influences the level of collision severity, sensitivity analysis is applied to an ordered logistic model for estimating the percentage changes on collision severity in terms of changing single variable independently. This is also refereed as elasticity analysis. Base case overall scenario is created as a reference for different comparisons. The reference is defined as setting the mean value of all continuous variables and setting zero value of all dummy variables (note that a "0" value means no existence of corresponding variable and a "1" value means existence of corresponding variable). The way to change key variables is to increase one unit for continuous variable and change level from zero to one for a dummy variable. Figure 11 summarizes the elasticity for train speed and urban environment based on the ordered logistic technique.

Figure 11 Elasticity summary in percentage



According to the average train speed of 30 mph (base case), one can see that an increase of 1 mph is expected to be translated in a reduction of about 3% in only the non-injury collisions; while as train speed increases from 10mph to 40mph, the

negative impacts become obvious. Fatality and injury collisions increase intensely by 78% and 46% as shown in purple column; surrounded crossing environment, as a categorical variable, fluctuates markedly as well when it switches from non-urban to urban zones, which results in 15% and 33% increase in injury and fatality collisions.

4.3 Comparisons with previous studies

As part of the result validation, a simple comparison is carried on with respect to previous studies in Canada. In particular, the results are compared to those obtained by Saccomanno et al. (2004), using the same Canadian grade crossing inventory and accidents datasets from 1993 to 2001. A comparative analysis is summarized in Table 14. Note that the developed models produce similar results. In most of the cases, the variables in each model are the same with some exceptions. For instance, in the model with signs, "urban" crossing location that resulted, were also significant in the new model. Also, for the "Flashing lights" model, whistle prohibition and sightline distance are statistically significant. For gates, sightline distance is also incorporated as a new variable.

. Note that the magnitude and sign of the parameter estimates are constant with the previous work by Saccomanno et al. (2004).

Table 14 Collision frequency estimate comparison

Warning Devices	Saccomanno's results (2004)*	Updated (new) results**
Signs	Train Speed (0.0131) Exposure (0.3883)	Train Speed (0.0185) Exposure (0.455) Urban (0.454)
Flashing Lights	Surface Width (0.0171) Train Speed (0.0115) Exposure (0.618)	Surface Width (0.0206) Train Speed (0.0114) Exposure (0.488) Urban (0.281) Whistle Prohibition (0.55) Sightline Distance((-0.0452)
Gates	Road Speed (0.0122) Number of Tracks (0.2029) Exposure (0.3737)	Road Speed (0.0069) Train Speed (0.0044) Exposure (0.333) Sightline Distance (-0.055)

* with coefficients in parenthesis

** results obtained in this research report

4.4 Chapter summary

Collision frequency/consequences models at Highway-rail crossing have been discovered by 20,051 Canadian public crossings with the number of 1,826 accidents from beginning of 2002 to June 2010. For the collision frequency model, traffic exposure is the most crucial factor on collision frequency for all three types of crossings and a few additional variables are explored explaining the impacts on collision frequency compared with previous findings. For collision consequence in terms of multinomial logistic regression and ordered logistic regression model, train speed and urban crossing environments are found to significantly influence collision severity levels. Furthermore, sensitivity analysis is carried out as well for comprehending the impact of individual factor on collision consequences. The results indicate increasing fatality and injury collision possibilities could be induced by high train speed and under urban environment.

CHAPTER 5

Countermeasures Analysis

Introduction

As all statistically significant parameters can be classified under three types of warning devices in collision frequency models, via Negative Binominal Distribution, they constitute essential estimates using an Empirical Bayesian method (before and after analysis) for the purpose of calculating collision reduction rates. Transport Canada has selected a group of grade crossings as hotspots in need of collision reduction, where specific countermeasures are listed in a so-called "national crossing sampling form." The main task of this chapter is then to estimate these collision reduction rates and carry out a cost benefit analysis for specific countermeasures at each crossing.

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5.1 National Sampling Public Crossings Information

Before estimating collision reductions at grade crossings, given that countermeasures are to be implemented at the most dangerous crossings, identification of those crossings is foremost. Transport Canada has provided a "Public and private unrestricted crossing form" to determine which crossings need safety upgrades (see Appendix E). On this form, there are 16 technical grade crossing standards to quantify the crash risk threshold as a function of three primary crossing characteristics, which are sightline distances, traffic control devices, and warning systems. These standards are correlated to RTD-10 (Road/Railway Grade Crossing Technical Standards and Inspection, Testing and Maintenance Requirements), and are also applicable to the MUTCD (Manual on Uniform Traffic Control Devices). Table 15 summarizes 1,004 national sampling crossings in terms of the three types of warning signs

Table 15 Crossings classification in terms of warning devices

	Frequency	Percentage
Flashing Lights	198	19.7
Gates	203	20.2
Signs	470	46.8
Signs and Stop Signs	129	12.8
OTHERS	4	0.4
Total	1004	

In a national sampling of public crossings, 16 basic countermeasures that greatly influence collision reductions at highway rail crossings are specified under three categories: sightlines, traffic control devices and warning systems. Each public crossing is examined with respect to whether or not it meets these basic standards, using binary notation, where "0" indicates that the crossing meets a particular standard and "1" denotes that a crossing requires improvement in the area of collision reduction. Therefore, crossings with more than one "1" would be considered to require improvement, while crossings with only "0" notation would be considered as satisfactory crossings not requiring collision reduction. Table 16 is a summary of yet-improving and improved crossings for each crossing type. It shows that 845 out of 1,004 crossings need improvements, which indicates that collision reductions could possibly be accomplished after certain countermeasures are implemented at yet-improved crossings.

Table 16 Summary of yet-improving and improved crossings

Crossing Type	# Crossings that met the basic standards	# Crossings that require improvement
Signs	48	418
Signs and Stop Signs	16	113
Flashing Lights	43	155
Gates	49	154
Others	4	5
All	160	845

Yet- improved crossings are required to calculate expected collision reductions wherever the standards are not met.

5.2 Empirical Bayesian Method for Estimating Collision Frequency

In order to estimate expected collision reduction, the popular approach, the Empirical Bayesian Method, is used. This takes into consideration both practical and theoretical perspectives to calculate expected collision frequency at each crossing based on collision frequency models and collision histories. Empirical Bayesian method is a weighted average estimate of the sample mean and the prior mean. Expected collision frequency at each crossing is a weighted average of observed collision frequency from the field and estimated collision frequency from model analysis. The general formula for Empirical Bayesian (EB) is as follows:

Expected collision frequency= $w \times \mu + (1 - w) \times y$

where,

$w = \frac{\emptyset}{\emptyset + \mu}$, and $\emptyset = 1/\alpha$, w = weighting ratio

y = observed collisions per year

μ= Estimated average collisions per yearobtained from collision frequency model

$\emptyset$= Inverse of dispersion parameter

α = Dispersion parameter from NB collision frequency model.

In addition, estimated average collision rate, μ, can be calculated as an exponential function of the product of model coefficients and associated independent variables which have been discovered previously, that is,

$\mu = \exp(\beta_0 + \beta_1 * V_1 + \beta_2 * V_2\beta + ... + \beta_n * V_n)/N$

where,

β_0 = Intercept, constant value obtained from model

$\beta_1 .. \beta_n$ = coefficient of independent variable from model

$V_1 .. V_n$ = associated independent variables

N = number of years of data used in the model calibration

The expected collision frequency of every yet-improved crossing is calculated in a similar manner; the parameters associated with each crossing are obtained from three NB collision frequency models categorized by types of warning devices. To clarify, an estimation example of a highway-railway crossing in Montreal, near BOULEVARD MONK, under SRCS SIGNS is presented as follows:

Table 17 Sample crossing in Montreal

Crossing:	Variable	Coefficient from model	Associated independent variables
SRCS SIGNS	Intercept	-6.1202	n/a
TC reference # 10520	Urban	0.454	0
	Train Speed	0.0185	10
Observed collision : 0.12	Exposure	0.4546	5.9915
	α	1.278	n/a

With this crossing information, the annual estimated collision from Jan 2002 to June 2010 is calculated as:

$\mu = \exp(-6.1202 + 0.454 \times 0 + 0.0185 \times 10 + 0.4546 \times 5.9915)/8.5$

$= 0.005$

Note that the denominator 8.5 is the total years estimated from Jan 2002 to June 2010. We obtained an annual observed collision frequency of 0.12, therefore, the expected collision frequency is calculated in terms of EB method:

$\emptyset = 1/\alpha = 1 / 1.278 = 0.782$

weighting ratio $w = 0.782/(0.782 + 0.005) = 0.994$

Expected collision frequency= $0.994 \times 0.005 + (1- 0.994) \times 0.12 =$ **0.006**

As weighting ratio is equal to 0.994, it is 99.4% dependent on model analysis, and only 0.6 % dependent on observed collision frequency.

5.3 CMFs adjustments

CMF collision modification factors from a sampling of 16 basic national standards are used to estimate the expected reduction or increase in collision frequency or severity after a change to highway railway crossings. CMF factors are sourced mainly from previous literature where similar circumstances are related to these standards. Crossings which do not meet any of the 16 basic standards are indispensable when taking CMFs into consideration. Multiple disqualifications of standards at any particular crossing can have a combined effect on collision reductions. A multiplication formula is applicable to these situations:

$$\text{CMFs (CMF of All)} = \text{CMF}_1 \text{ x } \text{CMF}_2 \text{ x } \ldots \text{ x } \text{CMF}_k$$

However, an adjustment of CMFs from a review of the literature is required to assess their accuracy and reliability. These adjustments on CMFs are carried out by experts in the transportation field.

Appendix G summarizes the main CMFs for general countermeasures. Table 18 shows the weighted average CMFs from Appendix G with respect to 16 technical standards requirements.

Table 18 Summary of CMFs used for 16 technical standards

	*Field #	CMF	CMF Mean	CMF Max	CMF Min
Sightlines	*1*	0.703	0.725		
	2				
	3	0.827		0.911	0.539
Traffic control Devices	*4*		0.719		
	5				
	6a	0.685			
	6b	0.72			
	7	0.68			
	8	0.71			
	9	0.75		0.933	0.505
Warning system	*10a*		0.63		
	10b				
	11				
	12a	0.68			
	12b				

	13a	0.81			
	13b	0.74			
	14	0.6			
	15				
	16			0.196	0.246

*Field # is the order of 16 basic national standards provided by Transport Canada for enhancements criteria in Canadian grade crossings sampling form (See Appendix E for details).

Through literature reviews, CMFs associated with a majority of standards have been found. Overall, 16 basic standards are grouped into three classifications, namely sightlines, traffic control devices, and warning systems. Within those classifications, mean estimates as well as maximum and minimum values of associated CMFs are summarized. After integrating expert opinions about recent adjustments of CMFs, the adjustments obtained are as follows in Appendix H.

However, many yet-improved crossings may require more than one categorical CMF from 3 categories (sightlines, traffic device controls and warning systems), Central Limit Theorem could be applied to calculate the combination effects of integrated CMFs, as CMFs in each category is independent with finite mean and variance under assumption of normal distribution. Table 19 shows results of possible combination effects in terms of a multiplication formula.

Table 19 CMFs after adjustments

	CMFs after adjustments			
Combined Categories	Mean	St.dev	Max	Min
1+2	0.521	0.104	0.317	0.726
1+3	0.457	0.154	0.155	0.759
2+3	0.453	0.157	0.146	0.760
1+2+3	0.328	0.122	0.090	0.567

5.4 Expected collision reduction

As CMFs are obtained from the literature and corrected according to expert knowledge, expected collision reduction rate after the improvements of certain standards at each crossing can be estimated,

Expected Collision Reduction = Expected Collision Frequency x (1- CMFs)

Let us continue by estimating expected collision reduction using the previous example to see how CMFs are applied.

CMFs for Crossing with TC reference # 10520:

Table 20 CMFs for one crossing in Montreal

Standards	Mean CMF	Min CMF	Max CMF
Sightlines(1-3)	0.725	0.7	0.83
Traffic Control (4-9)	0.719	0.68	0.75
Warning Devices (10-16)	1	1	1

CMF is a positive number with an interval from 0 to 1. Zero of CMF represents 0% reliability and accuracy of collision estimate which needs to be re-modified completely, 1 of CMF represents 100% of reliability of collision estimates, which do not need to be modified or improved.

Applying the multiplication principal, integrated mean CMFs are calculated as,

CMFs = 0.725 x 0.719 x 1 = 0.521

Expected Collision Reduction = 0.006 x (1 -0.521) = 0.0028 = 0.3%

Therefore, expected collision reduction at crossing site #10520 under SRCS SIGNS is 0.3%

5.5 Collision reduction rates per crossing

As we are able to estimate the expected collision reduction of individual crossings with typical warning devices (Wi), such as FLB, FLBG, SRCS, and SRCS+STOP, total expected reduction and overall average collision reduction rates can be obtained,

$$\text{Total expected collision under Wi} = \sum \text{Expected collision reduction of individual crossing under Wi}$$

Total expected collision reduction

= Total expected collisions before improvements - Total expected collisions after improvements.

In addition,

$$\text{Annual Collision reduction per crossing under Wi}$$

$$= \frac{\text{Total expected collisions}}{\text{Ni}}$$

where,

Wi = type of warning devices at crossings

Ni = number of crossings under Wi

After applying this procedure, a summary of the total expected collision reductions and annual collision reductions per crossing of each warning type is calculated and shown in table 21.

Table 21 Total expected collision reduction

Crossing Type	**Total # Crossings Sampled**	**Total # of Crossings Considered in Benefit Estimation**	**Total Collision - Before**	**Total Collision - After**	**Total Expected Reduction**	**95% Low**	**95% High**	**Average Collision Reduction Rates (Collisions per Crossing)**
SRCS	466	466	4.5420	4.3437	0.1983	0.0885	0.3081	4.255E-04
SRCS+Stop	129	129	1.7532	1.6999	0.0533	0.0441	0.1100	4.131E-04
FL	198	130	4.9666	4.6601	0.3065	0.1356	0.4784	1.055E-02
FLBG	203	170	5.4452	4.9865	0.4587	0.1655	0.7535	9.569E-03
Others	9	0	0	0	0.000	0.000	0.000	0.000E+00
All	1005				1.017	0.434	1.650	0.00000

For instance, the number of public crossings under flashing lights (FL) in national sampling spreadsheets is 198, of which 130 crossings fall into the category of improvements required. Total expected reduction of all crossings under flashing lights is 30.65%. (4.9666-4.6601= 0.3065), and the average collision reduction rate per year is 1.05%

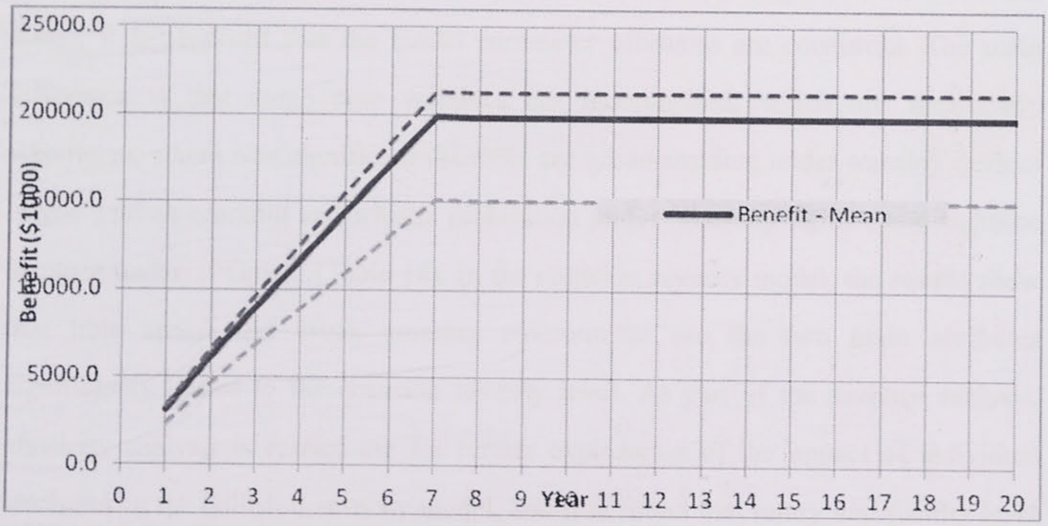
Finally a cost-benefit analysis is established. Table 22 lists seven detailed steps for evaluating the risk reduction benefits in Cost Benefit analysis for Grade Crossing Regulations. Also, Figure 12 is the overall risk reduction for a period of 20 years which Prof. Liping Fu (2011) has obtained for completion of this project.(Transport

Canada. Railway safety, Project No. 521-0604).

Table 22 Steps for risk reduction benefits

Steps	Risk reduction benefits
1	*Forecast the number of federally regulated public and private crossings*
2	*Forecast collision rates for collisions involving railway equipment (without the regulations)*
3	*Forecast collision rates for collisions involving railway equipment (with the regulations)*
4	*Forecast collision rates for collisions not involving railway equipment*
5	*Estimate the number of collisions*
6	*Estimate future number of fatalities, serious injuries, derailments, railway damage and other vehicle damage*
7	*Estimate future costs of collisions with railway equipment and other collisions*

Figure 12 Risk reduction benefits over 20 years



Conclusions

This work aims at upgrading the existing risk analysis tool for highway-railway grade crossings at Canada – this is referred as the GradeX tool. This tool is essential for identifying locations with potential for safety improvements (hotspot identification analysis) as well as the evaluation of countermeasures for improving safety standards.

For this purpose, collision frequency and injury severity models are first developed using a collision dataset from 2002 to 2010 (Table 12). For the frequency analysis, negative binominal modeling technique is used while for the severity analysis, multinomial and ordered logic regression techniques are implemented. Collision frequency models are established for each of three types of warning devices (signs, flashing lights and gates) (Table 13-1 and Table 13-2). The effect of geometry and traffic-related factors on collision occurrence and severity is investigated. Among other factors, traffic exposure, train speed, surface width, whistle prohibition, sightline distance and urban environment are found as the main contributing factors to the probability of collision. Compared with previous works (e.g., Saccomanno et al. 2003), it is observed that the model parameter estimates are consistent. The main difference is that some new variables are incorporated, which are statistically significant, where new significant variables are urban crossing under warning devices "signs", urban crossing and whistle prohibition under "flashing lights", and sightline distance under “Gates" (Table 14). In the collision severity model, the results show that train speed and urban crossing environment are the two main attributes significantly linked to the collision severity level. As part of the severity analysis, elasticity analysis is carried out for further explanation of the impact of individual attributes in the collision severity model, and it is found that injury and fatality level would increase substantially as either train speed increases or the crossing is within urban areas (Figure 5).

Secondly, an updated comprehensive literature review on main

countermeasures (table 5 and Appendix G) and their associated Collision Modification Factors (CMFs) (Appendix H) , at grade crossings are summarized. Also, cross-sectional studies and before-after studies (Naïve before-after studies, Before-after studies with comparison group, and before-after Empirical Bayesian studies) are methods which are/were introduced to evaluate the effectiveness of countermeasures.(Figure 5, 6, and 7) These CMFs represent empirical effectiveness of countermeasures over actual collision history.

As part of the third step, CMFs are updated by integrating historical records and expected estimates from statistical collision models, and applied in Empirical Bayesian before and after analysis for total collision reduction estimation. A national sampling of public crossings is employed to identify crossings in need of safety upgrades, known as hotspots, from 16 technical grade crossing standards (Appendix E), and CMFs are adjusted for each standard (table 18, table 19). Then, expected collision reductions at hotspots are calculated using before-after Empirical Bayesian analysis (Table 21). A cost-benefit analysis is carried out by Transport Canada in December 2011 using updated parameters, and the final estimation of risk reduction benefits over 20 years is presented (Figure 12).This paper provides valuable updates and references for cost-benefit analysis at Canadian grade crossings. Future research may continue to develop more suitable collision models to avoid potentially biased results, and define delicate techniques for CMFs estimation at individual crossing.

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7. Appendices

Appendix A NB regression models: Estimated parameters and associated statistic from 2002-2010

	Warning Devices "Signs"			Warning Devices " Flashing Lights"			Warning Devices " Gates"		
Observations	9470 (91.6% datasets used)			3462 (79.3% datasets used)			1996 (89.5% datasets used)		
Variable	Estimate	Std Error	P> IzI	Estimate	Std Error	P>Izi	Estimate	Std Error	P>IzI
Intercept	-6.1202	0.1961	0.000	-6.9147	0.3512	0.000	-5.3818	0.4998	0.000
Road Speed							0.0069	0.0037	0.061
Surface Width				0.0206	0.0081	0.011			
Urban	0.4540	0.1541	0.003	0.2315	0.1087	0.033			
Whistle Prohibition				0.5499	0.1426	0.000			
Train Speed	0.0185	0.0025	0.000	0.01137	0.0029	0.000	0.0044	0.0023	0.057
Sightline Distance				-0.0452	0.01543	0.003	-0.055	0.01594	0.001
Exposure	0.4546	0.0283	0.000	0.4877	0.0373	0.000	0.333	0.0358	0.000
α	1.278	0.323		0.7054	0.1881		1.1732	0.2293	

	Warning Devices "Signs"				Warning Devices " Flashing Lights"				Warning Devices " Gates"			
Criterion	LR Chi2	T_{LR}	AIC	BIC	LR Chi2	T_{LR}	AIC	BIC	LR Chi2	T_{LR}	AIC	BIC
	446.64	32.4646	3354.085	3389.864	319.63	25.315	2707.44	2756.637	110.22	57.6382	2278.47	2312.063

Appendix B Best STATA multinomial logistic regression severity model

```
Multinomial logistic regression                   Number of obs   =       1605
                                                   LR chi2(4)      =     154.22
                                                  Prob > chi2     =     0.0000
Log likelihood = -1124.7413                       Pseudo R2       =     0.0642

------------------------------------------------------------------------------
    severity |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
1            |  (base outcome)
-------------+----------------------------------------------------------------
2            |
Train Speed  |   .0228847   .0038898     5.88   0.000     .0152608    .0305086
Urban        |   .3422376   .1499109     2.28   0.022     .0484177    .6360575
       _cons |  -2.552547   .1715337   -14.88   0.000    -2.888747   -2.216347
-------------+----------------------------------------------------------------
3            |
Train Speed  |   .0454096   .0041061    11.06   0.000     .0373618    .0534573
Urban        |   .3233754   .1669586     1.94   0.053    -.0038574    .6506083
       _cons |  -3.583064   .2087064   -17.17   0.000    -3.992121   -3.174007
------------------------------------------------------------------------------
```

*Severity level 1 is non-injury collision, severity level 2 is injury collision and severity level 3 is fatalities collision.

Appendix C Summary of literature reviews on collision reduction at highway-rail crossings

Countermeasure		Reliability (Methodology , # of observations, datasets)	Effectiveness	Effectiveness on collision reductions	authors	sources
Traffic Control Devices	Lighting/ Illumination	before and after lighting (47 rural at-grade intersections in 3-year period) illumination of 34 crossings in 7 years Predictor, night-to-total-accident Ratio. (1967-1974 US HRC) CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.	2.illumination is effective low cost way for improving safety	1. 52% average night accidents reduction after lighting 4. 30% reduction in night accidents at crossings with illumination. 5. 28% reduction (range 23%-48%) 6. 10% reduction (range 0-17%)	*Walker & Roberts(1975) *Mather (1991) **Russel (2002) Wooldridge et al (2001) ***Gan et al (2005) ***Agent et al (1996)	6
	From sign to flashing light	Collision Prediction model (Canadian HRC dataset 1993-2001, 10449 public crossings) NB Collision prediction model (1993-2001)	7. 69% effectiveness on difference of train speed, crossing angle.	1. 58% reductions 2.28% reduction roughly, affected by other factors. 3. 75% reduction 4. 65 % reduction(range 30%-80%)	Saccomanno, et al(2005) Park, et al(2005) Gan et al (2005) Agent et al (1996) *Morrisey (1981) *Eck and Halkias (1985)	7

		CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements. 6. FRA database (1973-1976) 7. FRA database			*Hauer and Persaud (1987)	
	From sign to gate	Collision Prediction model (Canadian HRC dataset 1993-2001, 10449 public crossings) CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey)		63% reductions 90% reduction (CRF)	Saccomanno, et al (2005) Gan et al (2005)	2
	From Signs to 2Q gates	CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice		1. 45% reduction 2. 77% reduction (range (50%-99%)	Gan et al (2005) Agent et al (1996) *Morrisey (1981) *Eck and Halkias (1985)	6

		Survey) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.			* Farr and Hitz (1985) *Hauer and Persaud (1987)	
	From flashing light to gate	Collision Prediction model (Canadian HRC dataset 1993-2001, 10449 public crossings)		--13% reductions	Saccomanno, et al (2005)	1
	Eliminating whistle prohibition	Collision Prediction model (Canadian HRC dataset 1993-2001, 10449 public crossings)		26% reductions	Saccomanno, et al (2005)	1
	Flashing Lights	California1552 crossings 1960-1970 FRA database (1973-1976)		1. 64% Reduction 2. 83% Reduction 1.	Schulte (1975) Morrissey (1980)	2
	Lights & Gates + Flashing Lights	1. FRA Safety Report 1998 2. California1552 crossings 1960-1970 3.FRA database (1973-1976) 4. California (1960-1970)		1. 88% Reduction (Crossbucks Alone); 100% Reduction over Crossbucks 2.44% Reduction (Flashing Lights Alone) 4.70% reduction of train-vehicle accidents	NTSB (1998a) Schulte (1975) Morrissey (1980) Berg et al (1982)	3
	From Flashing	2.Survey of Sates and literature Review, follow cost-optimization		1. 75% reduction 2. 77% reduction (range	Gan et al (2005) Agent et al (1996)	5

	lights to 2Q gates	procedure to rank safety improvements.		65%-94%)	*Morrisey (1981) *Eck and Halkias (1985) Farr and Hitz (1985)	
	In-Vehicle Crossing Safety Advisory Warning Systems (ICSAWS)	1. FRA Safety Report 1998 2. ITS application at HRC (States, US) 3. Auditory warnings forward-collision avoidance, survey for driving simulator experiment.	2.16%-19% decrease in travel delay; 3. Recommend double-beep auditory icon for side-collision avoidance.		NTSB (1998a) Sikaras et al (2001) Hardner et al (2003)	3
	Constant Warning Time	Train Predictors application at HRC(2 months data)	Increase vehicle clearance time; reduce risky driver behavior.		Richard et al. (1989)	1
	Reflectorization			Deceleration rates reduction and looking behavior increased	**Russell Kent (1993)	1
	Reflective sheeting	Five configurations of retro reflective signs;	1. Enhancing conspicuity and uniformity;		Brich S.C. (1995)	1
	Stop Signs	FHWA in 1985 Zero-inflated collision frequency model (100 grade crossing in south korea) 4.Survey of Sates and literature Review,follow cost-optimization procedure to rank safety		35% reduction on collision 66.7% reduction 20% reduction(range 10% to 25%) Two way: 36% reduction (range 12%-50%); all way:	1. NTSB (1998a) 2. Lee et al (2004) 3. Gan et al (2005) 4. Agent et al (1996) 5. Farr and Hitz (1985)	4

		improvements. 5. DOT, FRA (1975-1978)		58% (range 35%-73%)		
	Yield Sign	CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.		1. 25% reduction 2. 45% reduction (range 20% to 59%)	Gan et al (2005) Agent et al (1996)	2
Geometry	Median Barriers	Traffic channelization devices, paddle delineators, concrete island meadian barrier.		77% Reduction	Carroll & Haines (2002a)	1
	Full road 2Q gate	13894 accidents 1990-2000 in Korea	Recommend ITS system installation.	10.2 % collision reductions	Kim et al (2002)	1
	Long Arm Gates (3/4 of roadway covered)	"Sealed Corridor"(improvements for HRC 1995-2000)		67 to 84% Reduction	Carroll & Haines (2002a)	1
	4-Quadrant Gate Systems	1994, combined 50 to 100-foot traffic channelization devices		1. 86% Reduction	Carroll & Haines (2002a) Heathington et al (1989)	2
	4-Quadrant Gate System + Median	"Sealed Corridor"(improvements for HRC 1995-2000)		92% Reduction	Carroll & Haines (2002a)	1

	Barriers					
	Crossing Closure	“Sealed Corridor”(improvements for HRC 1995-2000), TSS (Traffic separation studies” 3. Eliminate all high speed crossings, 6 crossings closures.		100% Reduction 3. reduce to 0.23 fatality/year at 125mph	1. Carroll & Haines (2002a) Mironer et al (2000)	2
	Buckeye crossbuck	Evaluation of standard improved and buckeye crossbuck at HRC in Ohio.		1. 22.3% reductions	1. Zwahlen and Schnell (1997)	1
	Crossing Angle	Zero-inflated collision frequency model (100 grade crossing in south korea)		34.3% reduction	Lee et al (2004)	1
	Crossing Warning	Enhanced sign system at night driving conditions	13% speed reduction at 100-meter study location.		Noyce and Fambro (1998)	1
	Sight distance to the crossing	Zero-inflated collision frequency model (100 grade crossing in south korea)		1. 56.2 % reduction (elasticity)	Lee et al (2004) NTSB (1998)	2

	Sight distance at the crossing	Sensitivity analysis results compared between and current policy. Zero-inflated collision frequency model (100 grade crossing in south korea) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.		2. 56.2 % reduction (elasticity) 3. 30% reduction at crossing	*Fitzpatrick et al (1989) Lee et al (2004) Agent et al (1996)	3
	Improving Sight Distance	CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey) Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.		1. 25% reduction 2. 30% reduction	Gan et al (2005) Agent et al (1996)	2
	Gate Interval /Delay	Design method for gate delay and interval time at HRC in Illinois.	Provide optimal safe decision point for driver to cross.		Coleman and Moon (1996) Coleman and Moon (1997)	2
	Preemption	Model developed for determining time required to evacuate a queued vehicle off a track	This model adopt a high level of confidence to minimize the risk of accidents		Long (2003)	1
	Pedestrian gate	Five pedestrian treatments evaluated in Portland, Oregon.	1.Reduce the likelihood of pedestrians entering a crossing	90% reduction	Siques (2002) Agent et al (1996)	1

Pavement Markings	X-Box Markings	Two special X-box pavement marking tested in Florida. 3. Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.	60% reduction on stoppage rates	36% reduction. 25 % reduction	Stephens and Long (2003) Gan et al (2005) Agent et al (1996) Tarko and kanodia (2004)	4
	Improving Pavement Conditions	CRF development method, Before and After method(Simple and EB), Cross-sectional method (USDOT, State-of –the-practice Survey) Quality control method of an index of crash frequency is proposed.		1. 20% reduction	Gan et al (2005) Tarko and kanodia (2004)	2
Enforcement	Speed humps	1. Evaluate temporary speed hump and speed table on vehicle speeds. 2. Various models test crossing features using 1998-2002 dataset Korea. 3. Zero-inflated collision frequency model (100 grade crossing in south korea)	1. reduction on speed, volume. Accident frequency/ severity. 2. Speed hump decreases the crossing accidents (coef= -1.58 in Gamma estimation) 3. 41.8% reduction on accident frequency (elasticity)		Hallmark et al (2002) Oh et al (2005) Lee et al(2004)	3

	Post Speed Limit	2.Survey of Sates and literature Review, follow cost-optimization procedure to rank safety improvements.		20% reduction 25% reduction	Gan et al (2005) Agent et al (1996)	2
	Photo/Video Enforcement	Apply photo enforcement in public crossing, at six HRC in US.		34 to 94% Reduction in Violations	Carroll et al (2002b)	1
	Violation detecting	1998, six-track crossing, photo-based video enforcement methods combined with fine/penalty structure		72 % reduction in violations	Carroll et al (2002)	1

Appendix D STATA ordered logistic regression severity model

```
Ordered logistic regression                    Number of obs   =       1605
                                                LR chi2(2)      =     147.72
                                                Prob > chi2     =     0.0000
Log likelihood = -1127.9926                     Pseudo R2       =     0.0615

------------------------------------------------------------------------------
    Severity |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
Train speed  |   .0348282   .0030382    11.46   0.000     .0288734     .040783
Urban        |   .3226573   .1188186     2.72   0.007     .0897772    .5555374
-------------+----------------------------------------------------------------
       /cut1 |   2.347957   .1397045                      2.074142    2.621773
       /cut2 |   3.375926   .1556362                      3.070884    3.680967
```

Appendix E Public and private unrestricted crossing sampling form

Public and Private Unrestricted Crossing Sampling Form

Region ______________ RSI ______________

Subdivision ______________ Date ______________

Mileage ______________

							Field #	*Result*
ALL Crossings	Sightlines	Along RWY/Road ROW	Clear within 50 ft for 100ft along track? (RTD-10 Sec. 8.1 (a))		Yes	No	*1*	*1*
		Crossing Type	Passive	Clear within Rwy/Road ROW? (RTD-10 Fig. 8.1)	Yes	No	*2*	*0*
			Active	Clear within Rwy/Road ROW? (RTD-10 Fig. 8.2)	Yes	No	*3*	*1*
	Traffic control Devices	AADT > 100? (RTD-10 Sec. 9.3)	Yes	"RWY Crossing ahead" sign?	Yes	No	*4*	*0*
			No					*1*
		Traffic likely to encroach closer than 5m from crossing?	Yes	"Do not stop on Track" sign? (RTD-10 Sec. 9.5)	Yes	No	*5*	*0*
			No					*0*
		Road Surface Type (RTD-10 Sec. 9.6)	Paved	Pavement Markings According to applicable MUTCD?	Yes	No	6a	*0*
				Stop Lines applied within 8m of nearest rail?	Yes	No	6b	*0*
			Gravel					*0*
		Traffic forced to stop or slow down <15km/hr?	Yes	"Stop" sign? (RTD-10 Sec. 9.8)	Yes	No	7	*0*
			No					*1*
		Advisory speed tab? (RTD-10 Sec. 9.4)	Yes	According to applicable MUTCD ?	Yes	No	8	*0*
			No					*1*
		"Stop Ahead" sign? (RTD-10 Sec. 9.4.1)	Yes	According to applicable MUTCD?	Yes	No	9	*0*
			No					*1*

ACTIVE Crossings	Warning system		Cantilevered Light units? (RTD-10 Sec. 13.2)	Yes							1
				No	Distance between farthest edge of travelled way and signal mast >7.7m?			Yes	No	10a	0
					Front light units Visible?			Yes	No	10b	0
			Trains routinely stop, or railway cars left standing , within activating limits of a warning system (RTD-10 Sec. 20.5)	Yes	Cut Out?			Yes	No	11	0
				No							1
		Road Approach	Multi lane? (RTD-10 Sec. 13.6)	Yes	One set of front light units visible to drivers in each lane			Yes	No	12a	1
					Back lights visible to drivers in each lane?			Yes	No	12b	1
				No							0
			One way? (RTD-10 Sec. 13.7)	Yes	Backlights visible to drivers in each lane?			Yes	No	13a	0
					Sidewalk on both side of Road? (RTD-10 Sec. 13.8(b))	Yes	Front light units on both sides of road ?	Yes	No	13b	0
						No					0
				No							1
			Horizontal and Vertical Curve? (RTD-10 Sec. 13.4)	Yes	Complete coverage between primary front & back light units?			Yes	No	14	0
				No							1
			Road Intersection on Approach? (Sec. 13.5)	Yes	Adequate coverage for Drivers turning from intersection?			Yes	No	15	1
				No							0
			Sidewalks and paths? (RTD-10 Sec. 13.8(a))	Yes	Centerline >3.6m from signal mast?	Yes	Separate Light Units for sidewalk?	Yes	No	16	0
						No					0
				No							1

Appendix F Monetized Cost of Countermeasures for Improvements

Cost Element	Unit Cost	Crossing Type	Subset	Subset %	Estimated Current Compliance	Timing
Railway Costs - Public Crossings						
Sightlines						
clear sightlines	$330	FLBG			69%	annual, phased in over 5 years
clear sightlines	$1,000	passive			89%	annual, phased in over 5 years
clear sightlines	$1,000	FLB			77%	annual, phased in over 5 years
Other Basic Standards						
emergency notification sign	$500				0%	one-time over 3 yrs.
operational control circuits-cut-out	$50,000	active	trains routinely stop or railway cars are left standing within activating limits of warning system	18%	83%	one-time over 5 yrs.
operational control circuits-design approach warning time	$25,000	active			0%	one-time over 5 yrs.
additional light units-cantilevers	$75,000	active	no cantilever	69%	85%	one-time over 7 yrs.
additional front light units-multi-lane roads	$5,000	active	multi-lane road	41%	98%	one-time over 7 yrs.
additional back light units-multi-lane roads	$2,000	active	multi-lane road	41%	95%	one-time over 7 yrs.
additional back light units-one-way roads	$2,000	active	one-way road	4%	75%	one-time over 7 yrs.
additional front light units-one-way roads	$5,000	active	one-way road with sidewalks	4%	50%	one-time over 7 yrs.

additional light units-curve on road approach	$5,000	active	curve on road approach	36%	92%	one-time over 7 yrs.
additional light units-intersection road approach	$5,000	active	intersection on road approach	54%	95%	one-time over 7 yrs.
additional light units-sidewalks and paths	$20,000	active	with sidewalks & paths	2%	67%	one-time over 7 yrs.
Road Authority Costs-Public Crossings						
Sightlines						
clear sightlines	$2,000	passive			89%	annual, phased in over 5 years
clear sightlines	$2,000	FLB			77%	annual, phased in over 5 years
Basic Standards						
railway crossing ahead sign	$500		where AADT>100	51%	74%	one-time over 3 yrs.
do not stop on track sign	$350		where traffic may encroach closer than 5 m.	9%	18%	one-time over 3 yrs.
pavement markings	$365		paved road	41%	40%	one-time over 3 yrs.
stop line	$85		paved road	41%	47%	one-time over 3 yrs.
stop sign & stop ahead sign	$500	SRCS	where traffic forced to stop or slow to <15km/hr	17%	93%	one-time over 5 yrs.
stop ahead sign	$500	SRCS + stop			6%	one-time over 5 yrs.
Joint Costs-Public Crossings						
AAWS	$100,000	active	where front light visibility restricted	5%	0%	one-time over 7 yrs.

Appendix G Summary of main sources of CMFs

References #	**Author--Paper Name**	**Parameter Type**
1	Agent et al (1996) "Development of accident reduction factor"	Accidents Percentage Reduction
2	Gen et al (2005)	Crash Reudction factors (CRFs)
3	Saccomanno et al (2005)-- A model for evaluating countermeasures at highway-railway grade crossings	CMF
4	Park et al (2005a)	CMF
5	Lee (2004) -- Accident Frequency Model Using Zero Probability Process	Elasticity
6	Horton 2009-- SUCCESS FACTORS IN THE REDUCTION OF HIGHWAY-RAIL GRADE CROSSING INCIDENTS	Accidents Percentage Reduction
7	DongJoo 2005-- Analyzing the relationship between grade crossing elements and accidents	Model Coefficient of Right Clearing Sight Distance
8	Carlson (1995) - violations at gated highway-railroad grade crossings	Parameter values: Warning Time for Violations, Adequate Sight Distance
9	Carlson et al(1997) -- Traffic Violations at gated highway-railroad grade crossings	Regression stats for TEV prediction model: warning time
10	Marts (2007) -- Passive railroad-highway grade crossings -- > tables from washington and Oh (06)	CMF
11	Saccomanno et al (2006)	CMF

Appendix H Summary of Collision Modification Factors from literatures

References/CMFs	**Stop Signs**	**Stop Ahead Signs**	**Stop Line Sign**	**Pavement marking**	**Sightline**	**Advisory speed**	**Constant Warning Time**
1	0.81	0.75	0.75	0.75	0.75	0.8	0.72
2	0.5	0.7	0.75	0.44	0.93	0.8	0.592
3	0.65	0.51	0.66	0.9	0.68	0.8	0.564
4	0.65	0.85	0.72	0.9	0.65	0.64	0.408
5	0.47	0.65		0.85	0.7	0.7	
6	0.8			0.85	0.6		
7	0.65			0.85	0.7		
8	0.65			0.85	0.75		
9	0.62				0.62		
10	0.54				0.81		
11					0.79		
Mean	0.634	0.692	0.72	0.79875	0.72545455	0.748	0.571
Std.dev	0.112	0.125	0.0421	0.1524	0.095	0.074	0.128
# of Sources	10	5	4	8	10	5	3
Other parameters than CMF	CRF	CRF	CRF	CRF	Elasticity	CRF	
	0.35	0.15	0.28	0.15	-0.562	0.36	
	0.35	0.35			-0.611	0.3	
	0.38						
	0.46						

Appendix I CMFs used for yet-improved crossings

					95% Confidence Interval		Adjustment Factor	Adjusted CMF		
Field #		**AMF**	**AMF Mean**	**Stdev**	**AMF Max**	**AMF Min**		**Mean**	**Max**	**Min**
1	r1	0.703								
2	r2									
3	r3	0.827	0.725	0.095	0.911	0.539	100%	0.725	0.911	0.539
4	r4									
5	r5									
6a	r6a	0.685								
6b	r6b	0.72								
7	r7	0.68								
8	r8	0.71								
9	r9	0.75	0.719	0.109	0.933	0.505	100%	0.719	0.933	0.505
10a	r10a									
10b	r10b									
11	r11									
12a	r12a	0.68								
12b	r12b									
13a	r13a	0.81								
13b	r13b	0.74								
14	r14	0.6								
15	r15									
16	r16		0.63	0.196	1.000	0.246	100%	0.630	1.000	0.246