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Identifying at Highway-Rail Grade Crossing Hotspots in Canada

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A B S T R A C T

This research presents a risk-based Hotspots identification model at highway-rail grade crossings in Canada. Two sets of models were developed to predict collision frequency and consequence at individual crossings. A two–dimensional graphic approach was adopted to combine these two models together to predict the risk at each crossing. Hotspots based on collision history tended to be widespread in Canada, while the Hotspot list based on model prediction tended to cluster in the Prairie Region of the country for frequency and the eastern provinces of Ontario and Quebec for consequence. Most Hotspots identified based on collision frequency are located in urban areas with high AADT, while the Hotspots by collision consequence are mostly located in rural areas with high train speed.

1. Introduction

Highway-rail grade crossing collisions are a source of concern to railway authorities and the public-at-large. From 1992 to 2001, each year, an average of 47 people lose their lives as a direct result of grade-crossing collisions in Canada (Transportation Safety Board of Canada, 2001). In response to safety concerns at grade crossings, Transport Canada established a safety management program called "Direction 2006". The goal of Direction 2006 is to reduce collisions in Canada by at least 50% by the year 2006. Based on the success of Direction 2006, a new Direction 2010 was mandated with further collision reduction targets. The question that needs to be addressed is how can these safety targets best be achieved?

It would be prohibitively expensive and impractical to improve safety at all grade crossings to a uniform standard. A recent report prepared by the Transport Research Laboratory (TRL) for the World Bank concluded that a reduction in grade crossing collisions is best achieved by directing appropriate countermeasures to Hotspot locations. Hotspots refers to crossings with an unacceptably high collision risk. The TRL report suggests that when we attempt to allocate funds to all problem areas, lack of funds and poor maintenance capability often results in the most dangerous problems being left untreated. Targeting Hotspots ensures that this issue is less likely to be a problem [1-3].

In this paper, it is asserted that Hotspots cannot be established solely with reference to the historical collision experience for a given period of time. Collisions are rare random events that vary significantly over time and space. A longer term view of collision risk is needed to reflect potential risks involved over any period of time. Such estimates can only be obtained using accurate and reliable collision frequency and consequence models.

Furthermore, Hotspots identification based solely on collision potential fails to provide a

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complete view of the "collision risk" at grade crossings. Collision risk consists of two components: frequency and severity or consequence. Ignoring collision severity would lead to exclusion of some crossings that have low collision occurrence but high consequence in Hotspots list. When analyzing the collision risk at grade crossings, it should not only consider collision frequency but also the related severity. A risk-based model is needed to identify Hotspots at the grade crossings in Canada.

This paper is organized into three main sections: 1) development of a collision prediction model using the Canadian data, 2) development of a collision consequence model using the Canadian data, and 3) identification of Hotspots at highway-rail grade crossings in Canada based on the above models.

2. Data Sources

The study used the RODS/TSB database [4], provided by Transport Canada to calibrate the collision frequency and consequence models. This database contains an inventory of 29,507 grade crossings for all regions in Canada and includes information on highway and rail geometric characteristics, traffic volumes and selected train operating features. A second data table includes information on collision occurrence at these crossings for the period 1993-2001 [5]. The inventory and occurrence data share a common reference number that permits linkage of each collision occurrence to the specific crossing where it took place. A number of crossings were found to be poorly specified for the said purposes of this research, that is, they did not include variables needed in the models, and these were removed from the database in the analysis. As a result, the data set used in this study includes collision history and inventory information for 10,381 crossings in Canada for the period of 1993 to 2001.

3. Collision Frequency Model

Before developing a new collision prediction model for the Canadian crossings, the RODS/TSB data were split into two random samples, one consisting of 5,194 crossings for model calibration and the other consisting of 5,187 crossings for model validation.

A variety of collision prediction models were attempted based on different model structures (e.g. considering type of warning devices as a independent variable vs. different expressions for crossings with different types of warning devices) and different assumptions on the distribution of collision frequency (Poisson, Negative Binomial and Empirical Bayesian method) [6]. Three separate Poisson models, each for one of the three types of warning devices (Type S for crossings with signs, Type F for crossings with flashing lights and Type G for crossings with gates), were found the best to represent the observed pattern [7, 8].

3.1. Type S Crossings

The Poisson model for crossings with signs only is:

$$E(mP)=Exp(-11.6778+0.01\times\boldsymbol{train\_speed}+0.3973\times\boldsymbol{\ln(exposure)}) \quad (1)$$

where: *train speed* = maximum train speed (mile/h)

exposure = a product of AADT and number of trains daily

A Chi-square goodness-of-fit test comparing observed and predicted collisions for different train speeds and traffic exposure was applied. The Chi-square (9.69) of the model is less than critical ($\chi^2_{0.05,5}$= 11.07) at the 5% level of significance, suggesting the model is statistically significant at aggregate level.

3.2. Type F Crossings

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

$$E(mF) = Exp(-14.9060 + 0.0091\times\boldsymbol{train\_speed} - 0.0077\times\boldsymbol{road\_speed} + 0.0312\times\boldsymbol{surface\_width} + 0.5161\times\boldsymbol{\ln(exposure)}) \quad (2)$$

where: *surface_width* = road surface width (m)

road_ speed = posted road speed (km/h)

This expression contains four statistically significant explanatory variables. The Chi-square value (16.09) was found to be slightly greater than critical (11.07), indicating a relatively good model fit for crossings with flashing lights.

3.3. Type G Crossings

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

$$E(mG) = Exp(-8.7407-0.1428\times\boldsymbol{track\_no}+0.258\times\boldsymbol{\ln(exposure)}) \quad (3)$$

where: *track_no* = number of railway tracks (both directions)

The Chi-square goodness-of-fit test also yielded good results, when crossings were classified by train speed and traffic exposure. Chi-square value (2.82) is less than the critical at 5% level, indicating a good match to the observed data.

4. Collision Consequence Models

A collision may result in a variety of consequence, such as fatalities, serious injuries and property damage. In this research, a collision consequence score to combine the different types of consequence is used. Since fatalities, injuries, and property damage contribute disproportionately to collision severity, it was necessary to first weigh each of these consequences according to their reported costs. In this study, the weights assigned to fatality and person injuries were based on the WTP approach [2].

The weight for property damages (PD) was set to 1.0 and scaled accordingly for other consequences to yield a consequence score (CS) expression shown in Equation (4).

$$CS=44.0\times\textbf{Number of Fatalities}+1.0\times\textbf{Number of Injuries}+1.0\times\textbf{PD} \quad (4)$$

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

The final data set used to calibrated consequence model contains 826-collisions on 720 crossings Canada-wide for the period 1997 to 2001. The collision occurrence data were split into two samples, one to calibrate the consequence model (413 collisions) and the other to validate the model (413 collisions).

The consequence score was summed over all collisions at each crossing during the five-year period and then divided by the number of crossing collisions. This yielded a crossing consequence score per collision, which is served as the dependent variable in the collision consequence model. The explanatory risk factors in the data consisted of train speed, road speed, number of tracks, track angle, surface width, AADT, number of train daily, and number of persons involved in a given collision [9].

Again, several models were attempted and a Negative Binomial (NB) model was found to be the best to fit the data. The resultant NB consequence model is of the form:

$$E(\textbf{Consequence Score/Collision})=Exp(0.3426\times\boldsymbol{persons\_involved}-0.2262\times\boldsymbol{track\_no}+0.0069\times\boldsymbol{track\_angle}+0.0250\times\boldsymbol{train\_speed}) \quad (5)$$

where: *persons_involved* = number of persons involved in a collision

track_angle = the angle between track and road

5. Hotspots Identification

Two Hotspot identification approaches were considered based on the crossing collision prediction models: 1) a two dimensional graphical approach, and 2) a combined risk-based approach [10]. In the graphical approach, collision frequency and consequences are represented by separate axis in a two-dimensional plot. Crossings with unacceptably high frequencies and/or consequence scores as predicted by collision models are identified on the basis of either a critical frequency value or consequence value. The second approach is based directly on risk measure, that is, the product of collision frequency and consequences at specific crossings. The predicted risk at a crossing is then compared to pre-set threshold to determine whether or not this crossing should be designated as Hotspots and then considered for intervention [11].

The number of Hotspots targeted for intervention depends on the underlying thresholds applied to predicted frequency, consequence and risk. Obviously as these thresholds are reduced, an increased number of crossings come under the Hotspot designation. With an increased number of Hotspots the cost of intervention is expected to increase as well. Practicable thresholds can be established by considering the tradeoff between safety improvements and the associated intervention costs.

5.1. Hotspots Identification- Graphical Method

A total of 10,336 highway-rail grade crossings were considered for Hotspot identification in all regions of Canada. These include both crossings that have experienced collisions over the period 1997-2001 period and those that have not [11].

For each crossing, collision frequency and consequence/collision were predicted using the above models for different crossing characteristics, AADT and speed. Model prediction rather than historical collision observation was adopted in Hotspots identification, because models can provide long-term, stable and reliable estimations. Notwithstanding the estimation of a combined risk measure, a graphical collision frequency versus consequence approach was adopted for identifying Hotspots. There are essentially two reasons for this: 1) If frequency and consequences are combined into a single risk measure, crossings with high frequency and low consequence or crossings with high consequence and low frequency may fall in low risk, and hence, be excluded from intervention. This can result in a possible misallocation of safety funds; and 2) if risk alone is used, it would be more difficult to tailor intervention strategies to the safety concerns at each crossing. Counter-measures that are tailored to reduce collision frequency could differ from countermeasures tailored to reduce their consequences.

Collision frequency and consequences at each crossing were plotted as shown in Figure 1. In this figure, the horizontal axis represents predicted consequence for all collisions at each crossing for the period 1997-2001, while the vertical axis reflects the predicted collision frequency at these crossings for the same period. This approach is crossing specific in order to be in line with this study objective: identify the unsafe crossings in the nation railway network.

Three thresholds values were considered: 0.1%, 0.2%, and 0.5%. Here threshold 0.1% is defined as crossings whose predicted collision frequency and/or consequence score is exceeded only 0.1% of the time, and in a similar fashion for 0.2% and 0.5% threshold value.

Figure 1 shows that crossings with high collision frequency differ from crossings with high consequence. This indicates that Backspots based solely on one criterion fails to provide an adequate representation of crossings that should be targeted for intervention. Clearly, collision frequency or consequences in isolation should not be used to establish Hotspots. Rather both criteria should be considered to provide a more complete picture of the underlying risk.

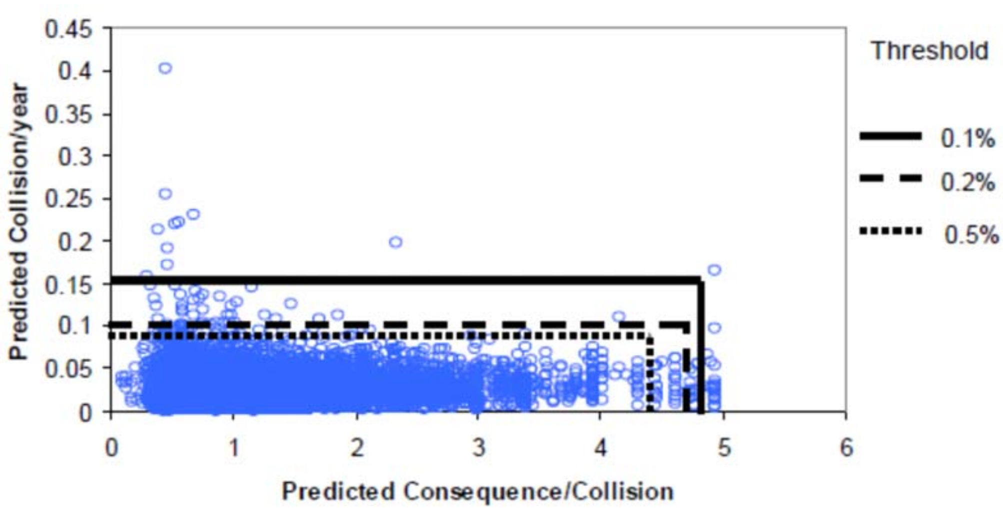

Figure 1. Graphical Identification of Hotspots (frequencies and consequences)

5.2. Choice of Threshold

In Hotspots identification, the basic question that needs to be addressed is: which threshold to choose, such that safety is enhanced at the lowest intervention cost.

An optimal threshold can be determined based on a thorough cost-benefit analysis of the intervention measures being considered. In the absence of this type of analysis, it was selected based on the relationship between number of Hotspots and potential reduction of collision risk. The more crossings identified as Hotspots the higher the cost. As more Hotspots are targeted, there is a greater possibility for risk reduction. In the absence of a more in-depth analysis of safety countermeasures and their benefits at individual crossings, it was assumed that benefits from countermeasures is equal to the total predicted frequency and consequences at Hotspot crossings.

Figures 2 illustrates the relationship between total frequency and consequences respectively, for different thresholds. From this figure it is noted no "inflection" point exists where improvements in safety increase at a decreasing rate with higher thresholds. In the absence of such an inflection point the more crossings are identified as Hotspots, the safer is the system. This needs to be investigated further with respect to increases that would take place in the intervention budget. In this study, 0.1% was selected for further analysis.

6. Hotspots in Canada

Based on the frequency and consequence thresholds of 0.10%, a list of 22 Hotspots was obtained across Canada, as an initial sample for further analysis [12]. The location of these crossings is given in Table 1 and 2 for collision frequency and consequences, respectively. The predicted Hotspot crossings are subsequently compared to the top 22 crossings with the highest historical collision frequency and consequence as reported in the data. The results are summarized in Table 3 and 4. Based on the models, the top five predicted frequency crossings are located in the Prairie Region province of Saskatchewan. Five out of eleven top crossings with highest consequence/collision are located in the Eastern Region province of Ontario and four crossings are located in the province of Quebec.

The top 11 predicted high frequency crossings differ from the top 11 predicted high consequence score crossings, suggesting that the two criteria yield significantly different results. This underscores the importance of a Hotspot model that accounts for both collision frequency and consequence prediction.

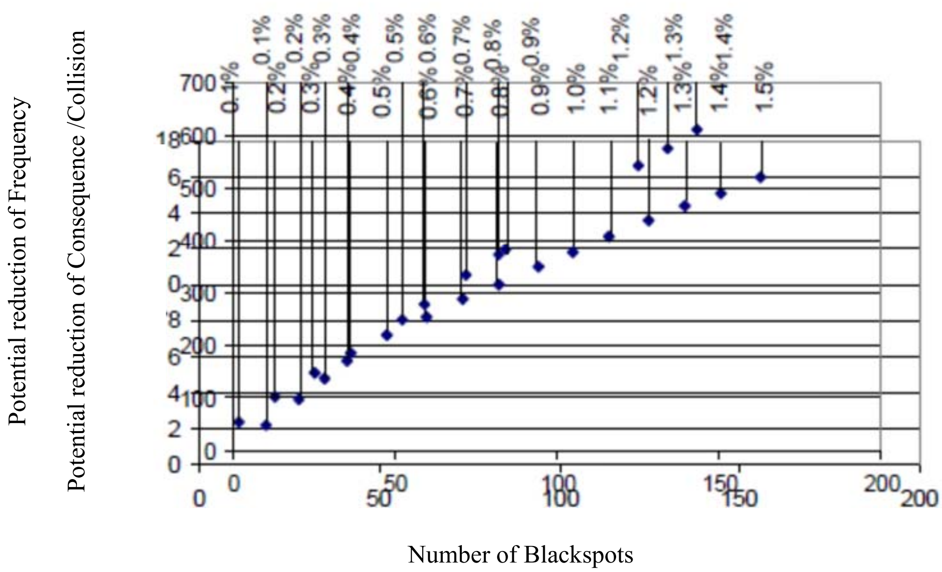

Figure 2. Reduction in Collision Frequency vs. Hotspots Treated
Reduction in Consequence vs Hotspots Treated

The top 11 crossings with highest historical frequency and consequence tend to be widespread in Canada, while the top 11 crossings with highest predicted frequency and consequence tend to be more clustered in Ontario and Saskatchewan. This suggests that a reliance on the historical data to identify Hotspots would not yield an accurate representation of the potential risk involved. Potential risk can only be obtained through the application of the frequency and consequence models.

The Hotspots list (Table 1 and 2) shows that the top 11 crossings with highest frequency are mostly located in urban area, especially in Saskatchewan. The top 11 with highest consequence are mostly located in rural area,

Table 1. Hotspots List Based on Predicted Frequency

Frequency/year	Province	Municipal	Street No
0.401	SK	Saskatoon	22nd Street
0.254	SK	Saskatoon	33rd Street
0.230	SK	Regina	Albert Street(Hwy 6)
0.223	SK	Saskatoon	3rd Avenue North
0.220	SK	Prince Albert	2nd Avenue West
0.214	NB	Saint John	Main Street (Highway100)
0.197	SK	Corman Park No. 344	21-22-36-6
0.191	ON	Brockville	Perth Street
0.172	SK	Regina	Winnipeg Street
0.165	**QC**	**St.-Cyrill-De-Wendover**	**Chemin Du 3e Rang**
0.157	SK	Regina	Pasqua Street

Table 2. Hotspots List Based on Predicted Consequence

Consequence /collision	Province	Municipal	Street No
4.93	**QC**	**Saint-cyrille-de-wendover**	**Chemin du 3e rang**
4.93	QC	Saint-simon	Rang st-georges
4.93	QC	Sainte-helene-de-bagot	Chemin 2e rang est
4.93	ON	Wolford	County rd16
4.93	ON	Maidstone	Rourke line
4.93	QC	Val-alain	Route du 3e
4.93	QC	Saint-germain-de-grantham	Chemin du 8e rang
4.93	QC	Sainte-helene-de-bagot	Rang st-augustin
4.93	ON	Belle river	Ducharme road
4.93	ON	Wolford	Kilmarnock rd
4.93	ON	Tilbury north	Couture road

especially in Ontario. One possible explanation to this phenomenon is that crossings located in urban areas usually have more traffic volume than rural areas, which leads to potential for more collisions. While in rural areas there are less traffic volume. The speeds at which trains traverse the crossing are also high. Train speed is a major factor contributing to collision consequence. Hence, once collision occurs, the consequence at rural crossings is expected to be more severe than the urban area.

Table 3. Hotspots List Based on Collision Frequency History (Number of Collisions) (1997-2001)

No of Collisions	Province	Municipal	Street No
6	ON	Niagara Falls	Reg Rd #102-Clifton
5	SK	Saskatoon	3rd Avenue North
4	QC	Saint-Jean-Sur-Richelieu	Grand Bernier Road
4	MB	Winnipeg	Kimberly Avenue
3	SK	Regina	Ross Avenue
3	SK	Senlac No. 411	Grid Road 675
3	ON	Brampton	Torbram Road
3	MB	Portage La Prairie	Third Street
3	SK	Sherwood No. 159	Municipal Road
3	MB	Winnipeg	Marion Street
3	QC	Montreal	Rue De Courcelles

Table 4. Hotspots List Based on Collision Consequence History (Consequence/Collision) (1997-2001)

Total Fatality	Total Serious Injuries	Province	Municipal	Street No
4	1	ON	Halton Hills	4th Line Road
3	0	ON	Ingersoll	Mckeand Ave.
2	0	ON	Halton Hills	Derry Road Reg. 25
2	0	ON	Cambridge	Dolph St
2	0	ON	Elizabethtown	County #28
2	0	AB	Mountain View County	Ns W15-33-1-5
2	1	SK	Arlington No. 79	Yellowhead Hwy
2	0	AB	Leduc County No. 25	Rge Rd 245
2	1	ON	Whitchurch-Stouffville	Slater Road
2	2	AB	Crowsnest Pass	9th Ave.
1	1	QC	St.-Jean-Sur-Richelieu	Grand Bernier Road

7. Conclusions

This research presents a risk-based Hotspots identification model at highway-rail grade crossings in Canada. Two sets of models were developed to predict collision frequency and consequence at individual crossings. A two–dimensional graphic approach was adopted to combine these two models together to predict the risk at each crossing.

A list of Hotspots were obtained based on both predicted collision frequency and consequence in all the regions of Canada and compared to the list on the basis of collision history. It was found that the Hotspots based on collision history tended to wide spread in Canada, while the list based on model prediction tended to cluster in Saskatchewan for frequency and Ontario and Quebec for consequence. Most Hotspots identified based on collision frequency are located in urban areas with high AADT, while the Hotspots by collision consequence are mostly located in rural areas with high train speed.

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