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Network screening for specific collision types at urban signalized intersections - conventional and spatial methods

Wai Kei Felix Wong
Ryerson University

NETWORK SCREENING FOR SPECIFIC COLLISION TYPES AT URBAN SIGNALIZED INTERSECTIONS – CONVENTIONAL AND SPATIAL METHODS

by

Wai Kei Felix Wong, B.Eng., Ryerson, 2003

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Master of Applied Science, 2005

By Wai Kei Felix Wong

Department of Civil Engineering

Ryerson University

Abstract

Transportation authorities are always looking for ways to improve road safety since vehicle collisions cost Canada 25 billion dollars of capital loss and around 2800 deaths each year. An important step in improving road safety is to sieve out the problem sites through network screening processes. Screening for specific accident types is discussed in this thesis, using signalized intersections in Toronto in an illustrative application. Each such collision type is associated with corresponding countermeasures, which allows the engineer to rank the entities with specific remedies in mind. In this way, the effectiveness of road network screening can improved through targeted treatments. Three different screening methods are introduced and compared; procedures for selecting entities from screening results by different methods are also presented.

A process for ranking jurisdictions by regions is proposed. This is a method which combines the conventional network screening techniques with geographic information system (GIS) tools. The geographic information system can integrate the spatial information of a selected area with the conventional accident and road characteristic data and facilitate network screening by region.

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Dedication

For my parents.

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List of Acronyms

AADT	Annual Average Daily Traffic
CURE	CUmulative REsiduals
DES	Detailed Engineering Study
EB	Empirical Bayes
FI	Fatal and Injury
GIS	Geographic Information System
GLM	Generalized Linear Model
GOF	Goodness-of-Fit
GTA	Greater Toronto Area
MAD	Mean Absolute Deviation
ML	Maximum Likelihood
MPB	Mean Prediction Bias
NB	Negative Binomial
PDO	Property Damage Only
PDM	Property Data Map
PSI	Potential for Safety Improvement
Q_{major}	Major AADT
Q_{minor}	Minor AADT
$Q_{totalenter}$	Total Entering AADT
SPF	Safety Performance Function
TSIP	Traffic Safety Improvement Program

Chapter 1 Introduction

There are 19 million vehicles driven on more than 900,000 kilometres of roads in Canada. With that many vehicles travelling on the roadways, a large number of accidents are expected. Approximately 2778 traffic fatalities were reported during year 2001 and around 25 billion dollars of capital loss was listed per year according to a report from Health Canada and Transport Canada (*1*). Life losses and economic burdens require incessant work on improving road safety. Then improving the roadway is one way to reduce traffic accidents, as an alternate to improving drivers or vehicles.

As it is impossible to improve the safety of all the roads in a jurisdiction at one time, some sort of the screening mechanism is needed for flagging and ranking hazardous locations. Until recently, the screening process mostly relied on accident counts. Road safety analysts are now aware that this is problematic because accident counts fluctuate over time, and high accident counts are likely to decrease with time. This can result in an inefficient selection of hazardous locations. Recently, expected accident frequencies have been used instead of accident counts in road network screening. Expected accident frequency is estimated by applying the Empirical Bayes (EB) Approach to merge the observed frequency with that expected at similar sites. The observed information is extracted from accident record, whereas the expected value originates from a mathematical model called Safety Performance Function (SPF). Contrasting with the use of accident counts, researchers find that expected accident frequencies are more accurate in presenting the 'true' situation and can improve efficiency in screening. Detailed information about SPF and EB approach will be provided in Chapter 2.

Efficient screening can improve the cost-effectiveness of any road safety improvement program. One way of advancing the accuracy of screening is by looking at the spatial relationship among highly ranked accident locations from network screening. Accidents are usually not evenly spread over the transportation system, since they tend to form clusters. The level of accident clustering can affect the establishment of road improvement plans. Nicholson (*2*) stated 'a high level of accident clustering indicates that "black-spot" program is the most appropriate and, as the level of clustering reduces, a "black-route" program becomes more appropriate, with a "black-area" program becoming the most appropriate when there is a very low level of clustering'. Detailed discussion on accident clustering will be presented in Chapter 6.

Road network screening can be run at different levels, such as flagging the hazardous locations at the municipal level, city level, or even provincial level. When the screening is targeted to deal with a large area, the location of 'top-ranked' sites is expected from discrete regions. In order to increase the efficiency and lower the budget, the authority may want to upgrade road safety at some flagged locations in one area, instead of some flagged locations spread out in different areas. Procedures for ranking the hazardous 'regions' with the assistance of Geographic Information System (GIS) will be introduced in Chapter 6.

Road network screening usually ends up with a list of locations that reflects which sites have the largest potential for road safety to be improved. It is not easy to decide where the 'top-ranked' sites are located or how far the 'top-ranked' sites sit from each other, unless the person is very familiar with the jurisdiction. This paper is based on 5 years of collision data at more than 1700 signalized intersections in Greater Toronto Area (GTA). It investigates the feasibility of combining both traditional network screening methods and spatial analysis with the help of GIS. In so doing, it also tests the ability of

GIS in improving road network screening.

The whole procedure of road network screening is introduced in Chapter 5 and the ability of spatial analysis for improving road network screening is discussed in Chapter 6. The theoretical background for screening methods is described in Chapter 2 and 3; while the descriptions of data used are provided in Chapter 4. Conclusions and suggestions of future work are presented in Chapter 7.

Chapter 2 Theoretical Background

This chapter reviews analytical methods in road safety, covering the very definition of road safety, the theory behind accident prediction model fitting, validation checks of prediction models, and the application of the Empirical Bayes theorem to adjust the model predicted value. All the above topics can be merged into a central idea – to estimate as best as possible, expected number of accidents at a site to get the most accurate ranking for sites with promise for safety improvement.

2.1 What is Road Safety?

It is a good idea to understand the definition of 'road safety' before studying how to improve road safety. In Hauer's (*3*) opinion, 'safety is not to be equated with the fluctuating accident counts'. Instead, safety should be 'an underlying stable property that has the nature of a long-term average'. Hauer (*4, 5*) demonstrated the fluctuation of accident counts and the regression to mean phenomenon by examining Ontario accident data whereby for systems with above-average accident counts in one period, a decrease in a later period is expected even without treatment; similarly, for systems with below-average accident counts in one period, an increase in a later period is expected. Hauer (*3*) also thought that safety should be measured by expected accident frequency and he described the safety of a single site as 'the number of accidents (crashes), or accident consequences, by kind and severity, expected to occur on the entity during a specified period'.

2.2 Safety Performance Function (Accident Prediction Models)

2.2.1 Introduction

As mentioned in last section, safety should be measured by a long-term mean of accident occurrence. In other words, one should find a way to extract the long-term mean accident from existing accident data. Accident prediction model or Safety Performance Function (SPF) is used in this process.

2.2.2 Model Structure

SPFs are statistical regression models for establishing the relationships between accident counts, traffic flows and other relevant information for similar entities. Thus, if one wants to estimate the accidents in a jurisdiction, several site-specific models are required (e.g., for three-legged signalized intersections and two-lane rural highways). In general an SPF can be represented by:

$$\kappa = f\left(X_1, X_2, X_3, \ldots, X_n,\ \beta_1, \beta_2, \beta_3, \ldots, \beta_m\right) \tag{2.1}$$

κ is the expected accident frequency for entities' characteristics ($X_1, X_2, X_3, \ldots, X_n$), and $\beta_1, \beta_2, \beta_3, \ldots, \beta_m$ are the parameters in some functional forms $f(\ )$.

Hauer (*6*) mentioned that not all the functional forms used previously fitted well. One such problematic form is the linear model of the form:

$$\kappa = (SegmentLength)\left(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_n\right) \tag{2.2}$$

where segment length is equal to 1 for intersections.

Consider the simplification of this form as:

$$\kappa = (SegmentLength)\left(\beta_0 + \beta_1 AADT\right) \tag{2.3}$$

The indication from this model is that a lot more accidents are expected with Annual Average Daily Traffic (AADT) of 24000 vehicles per day (vpd) than an AADT of 800 vpd. Clearly, the predicted values are contrary to the 'real' situation since the relationship between accidents and AADT is not linear. Thus, the linear model doesn't seem to be a proper choice for predicting accident frequency.

Multiplicative models were considered in later days and they seem to be more appropriate for describing the nature of accidents. They are represented as the following:

$$\kappa = (SegmentLength)\, \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots X_n^{\beta_m} \tag{2.4}$$

or

$$\kappa = (SegmentLength)\, \beta_0 e^{(\beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_m X_n)} \tag{2.5}$$

The models have the flexibility to calibrate accidents and traffic flows non-linearly and, because they can be linearized, are referred to as Generalized Linear Models (GLMs). GLMs were introduced in 1972 by Nelder and Wedderburn (*7*). These models enhance the ability of fitting some non-linear models (SPF), separating the distributional description of the data and modeling of the mean (*7*). In GLMs, the mean of a population (accident counts) is allowed to depend on a linear predictor through a nonlinear link function. The response probability distribution can be any member of an exponential family of distributions. They include binomial, inverse Gaussian, gamma, Poisson, Negative Binomial (NB), etc.

Hauer (*6*) suggested using the combined functions of additive components and multiplicative components in the prediction model. Additive components represent the influence of point hazards (e.g., number of mall entrances in segment), while multiplicative components correspond to the influence of factors that naturally apply to the road (e.g., lane width of segment). With both components considered in any functional form (βX , X^{β} or $e^{\beta X}$), the model equation will end up as

$$\begin{aligned}\kappa = &(\text{Sacle Parameter})(\text{SegmentLength})(\text{Multiplicative Component}) \\ &+(\text{Additive Component})\end{aligned} \quad (2.6)$$

An example of such a model would be

$$\text{Multiplicative Component} = f(\text{AADT}) \times g(\text{Lane Width})$$
$$\text{and Additive Component} = h(\text{AADT}, \text{\# of Mall Entance})$$

2.2.3 Statistical Distribution of Accidents Used in Developing SPFs

Understanding the nature and statistical distribution of accident counts is necessary before calibrating SPFs and estimating the long-term mean number of accidents at a site. Firstly, accident counts are discrete, and large numbers of sites with zero accident counts in a year can usually be found in road accident collision database. Because of these properties, the Poisson distribution has been used to model counts at a site over time.

For the Poisson distribution the values of sample mean (μ) and sample variance (Var) are the same. However, accident counts in a given time period over a number of similar entities are overdispersed when compared to the data's mean (i.e., $Var(Y) > \mu$). In this case, over or underestimation of road accidents will take place if the Poisson distribution is applied to develop an accident prediction model using data for a given period for a set of such sites (*8*).

The Negative Binomial (NB) distribution can be used as an alternative to Poisson distribution when this overdispersion exists, i.e., when the value of the sample variance is larger than that of the sample mean. The NB distribution has a special parameter that accounts for overdispersion, namely the overdispersion parameter (k). This parameter has the ability to explain the unknown errors between the predicted values and the observed data. When applying this concept in an accident prediction model, the overdispersion parameter measures the effectiveness of the independent variables (e.g. AADT, lane width, etc) in explaining the dependent variable (e.g. accident counts or frequencies). If one is missing an important independent variable when calibrating the prediction model, a larger value of dispersion parameter is expected. As a result, the overdispersion parameter should be one of the factors to decide the fitness of the model. The variance in NB distribution is calculated as follows:

$$Var(Y) = \mu + k\mu^2 \tag{2.7}$$

where Y is the expected value of true mean (μ), and k is the overdispersion parameter. For a smaller value of k, a smaller variance is expected and a better model will result. From the expression above, the NB distribution will be approach a Poisson distribution when $k \to 0$.

2.2.4 Measure of Model Quality

In order to assess the performance of a model, a Goodness-of-Fit (GOF) test is necessary. Several of them are introduced in this section; they are Pearson's Product Moment Correlation Coefficients between Observed and Predicted Crash Frequencies (r), mean prediction bias (MPB) and Mean Absolute Deviation (MAD) These measures are similar to those used by Oh et al. (*9*).

2.2.4.1 Pearson's Product Moment Correlation Coefficients

The Pearson's product moment correlation coefficient (r) is a value that represents the linear relationship between two variables – the predicted values (Y_1) and the observed values (Y_2). If Y_1 perfectly matches with Y_2, a line plot can be sketched and the coefficient will end up as one; whereas a lack of linear correlation between both values will result to a coefficient of zero. The mathematical expression of r is the following:

$$r = \frac{\sum\left(Y_{i1} - \overline{Y}_1\right)\left(Y_{i2} - \overline{Y}_2\right)}{\sqrt{\sum\left(Y_{i1} - \overline{Y}_1\right)^2 \sum\left(Y_{i2} - \overline{Y}_2\right)^2}} \qquad (2.8)$$

where $\overline{Y}$ is the mean of Y_i, and the predicted (Y_1) and observed (Y_2) accidents are measured in accident frequencies.

2.2.4.2 Mean Prediction Bias

The mean prediction bias (MPB) is the ratio of sum of the differences between predicted and observed accident frequencies in a dataset to the sample size of the data. This statistical measurement provides two-dimensional checking of the validation of the model. The result can be positive or negative, and a zero value of bias will be the most desirable. When the MPB is positive, the predicted values are overestimated compared to the observed data; on the other hand, a negative MPB represents the underestimation of the predicted values. Finally, the value of MPB reveals the magnitude of average bias. The mathematical expression of MPB is the following:

$$MPB = \frac{\sum_{i=1}^{n}\left(Y_{i1} - Y_{i2}\right)}{n} \qquad (2.9)$$

where n is the sample size, while Y_1 and Y_2 are the predicted and observed accidents.

2.2.4.3 Mean Absolute Deviation

The mathematical form of mean absolute deviation (MAD) is very similar to mean prediction bias. The formula is:

$$MAD = \frac{\sum_{i=1}^{n} |Y_{i1} - Y_{i2}|}{n} \tag{2.10}$$

The only difference from MPB can be found in the numerator, where the sum of the differences between predicted and observed values in a dataset is replaced by the sum of the absolute values of the differences between predicted and observed values in a dataset. The values of MAD can only be positive, and a smaller value of MAD signifies a better model.

2.2.4.4 Cumulative Residuals – The CURE Method

The above mentioned GOF measurements are used to evaluate the overall fitness of the prediction model. However, it is important to get the predicted values (e.g. accident frequencies) well-fitted in the entire range of a variable (e.g. AADT), not just well-fitted overall. To examine this, Hauer (*10*) has suggested the CURE method.

The difference between predicted and observed accidents for an entity in certain time period is called a 'residual'. One can find out how good the model equation is and how fit the model is by inspecting the residuals. The normal plot of residuals of Fatal and Injury (FI) against AADT is shown in Figure 2.1. However, one can learn little besides the magnitude of the residuals.

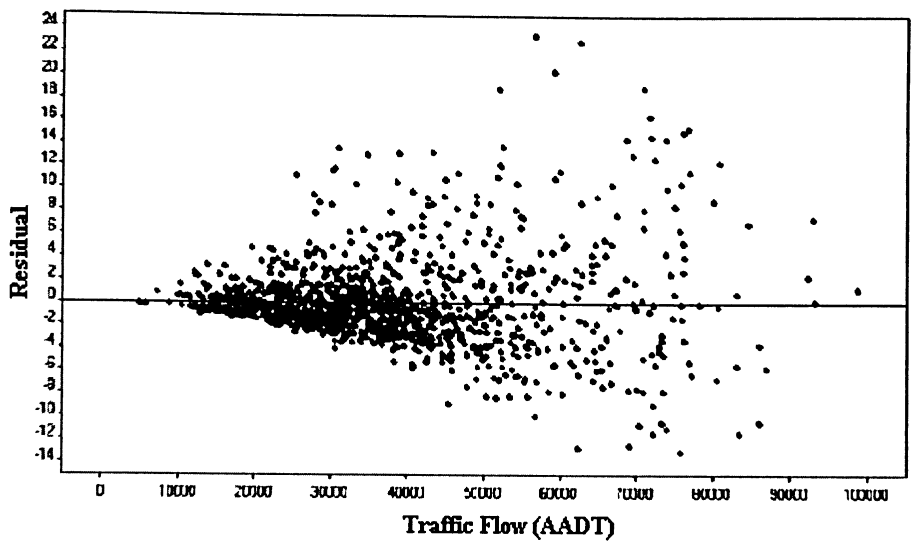


Figure 2.1 Residual versus AADT

This method of CURE consists of plotting the cumulative residuals in ascending order of the variable (e.g. AADT) as illustrated by a dotted line in Figure 2.2. For a well fitted model, this line should move up and down around zero. There are two solid lines plotted in Figure 2.2 and these lines are the upper and lower boundaries of the CURE curve. If any portion of the CURE plot sits outside the boundaries, one can say that the portion is not well-fitted in that particular range of the variable. The two boundaries are plotted using the values of $\pm 2\sigma(n)$, where $\sigma(n)$ is the standard deviation of cumulative residuals. Additional information for CURE method can be found in (*6*) and (*10*).

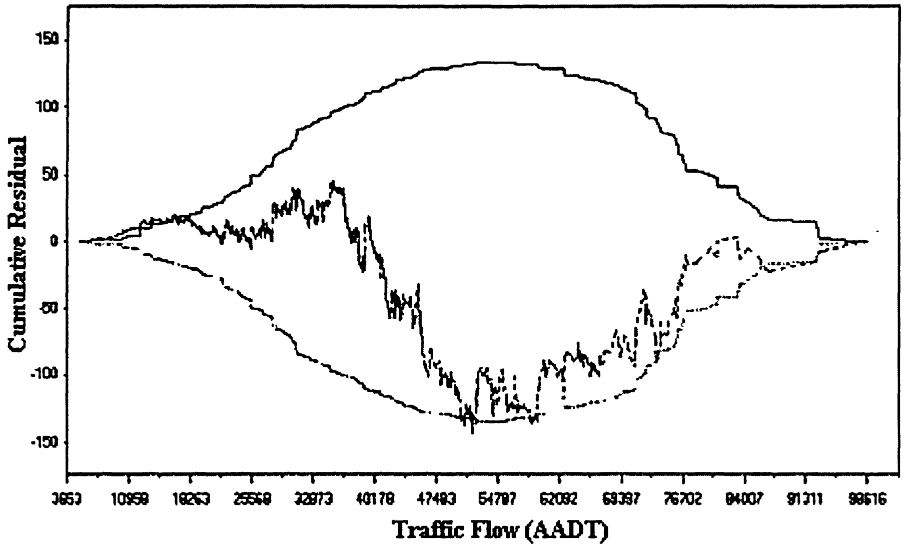


Figure 2.2 Cumulative residuals versus AADT

2.3 Empirical Bayes Analysis

The empirical Bayes (EB) approach is utilized to estimate accidents for applications such as screening a road network. The main aim of the EB approach is to minimize the effects from the random fluctuations of accident counts and estimate the safety by a long-term mean rather than as a short-term count (*11*). This avoids problems due to regression-to-the-mean discussed in Section 2.1.

The EB approach is a method that combines the observational resources (e.g. accident counts or frequencies) and the fitted values from a mathematical model (e.g. SPF). Two estimated weights (w and $1-w$), containing information from both sources, are calculated and then applied to the fitted and observed value respectively. The mathematical expression is the following:

$$m = wY_1 + (1-w)\frac{\sum_{i=1}^{n}(Y_{i2})}{\sum_{i=1}^{n}\left(\frac{Y_{i1}}{Y_{11}}\right)} \quad (2.11)$$

where Y_1 and Y_2 are the predicted value (from an SPF) and observed value, while m and n are the long-term mean and number of years respectively.

In general the weight value determines the relative influence of the predicted and observed values in estimating the long-term means. When the prediction model has a relatively high variance, and when there are many years of accident counts, a lower weight value will be applied to the model prediction and a higher value will be given to the observed value. In contrast, when the prediction model has a relatively low variance, and/or there are few years of accident counts, the predicted value will have more influence.

The end-product of this approach is used in one of the network screening methods called Potential for Safety Improvement (PSI) method which is discussed in Chapter 3.

2.4 Chapter Summary

The definition of road safety, the theory behind accident prediction model fitting, the validation checks for prediction models and the application of the empirical Bayes theorem to adjust the model predicted value have been introduced in this chapter. The methods of road network screening for specific accident types will be provided in next chapter.

Chapter 3 Screening Methods for Specific Accident Types

The ultimate goal of road network screening is to measure how safe each site is by identifying which sites have a greater potential to have their safety improved. A ranking by this potential is provided after the screening processes. This chapter briefly discusses road safety improvement programs aimed at specific collision patterns, the Potential for Safety Improvement (PSI) method applied in screening for specific accident types, and the method of screening for high proportions of specific accident types.

3.1 Road Safety Improvement Program and Collision Pattern Selection

Road network screening is the first step of a road safety improvement program; more precise results from screening make it possible for a more efficient allocation of a safety improvement budget. The five stages which are usually included in the overall safety improvement program are as follows:

- Network screening and site selection
- Detailed Engineering Studies
- Countermeasure identification and selection
- Implementation
- Evaluation

As mentioned before, the end-product of screening is a list of top-ranked site-specific entities. Engineers then try to identify the reasons that contribute to the accidents at the top-ranked sites; this process is called a Detailed Engineering Study (DES). DES concludes as a list of identified deficiencies and corresponding recommended countermeasures at each 'problem' site.

The idea of collision pattern selection (screening for specific accident types) is similar to DES in that both are dealing with deficiencies and countermeasures. Mollett (*12*) mentioned the first step of collision pattern selection as identifying which sites had the target collisions associated with the corresponding countermeasures, and Hauer (*3*) defined target collisions to be all those that can be affected by specific treatments. Mollett (*12*) provided a table which contained different collision patterns and their corresponding countermeasures. Several of these are introduced in Table 3.1.

Table 3.1 Selected accident types and their corresponding countermeasures

Collision Patterns	**Suggested Countermeasures**
Left-turn	- Signal Upgrades - Intersection Improvement
Angle	- Signal Upgrades - Resurfacing - Law Enforcement
Rear-end	- Resurfacing (wet) - Speed Control (wet) - Intersection Improvements (dry) - Congestion reducing measures (dry) - Speed Control

For example, if one performs the screening based on left-turn collisions, the results can be used to identify intersections which can use (low-cost) signal upgrades, such as adding an exclusive left-turn phase. Screening for specific accident types appears to be one of the ways to improve the effectiveness of road network screening. Two methods are introduced below.

3.2 Potential for Safety Improvement Based on Expected Accident Frequency or Excess Accident Frequency

The Potential for Safety Improvement (PSI) method is based on the end-result of EB approach – i.e., the EB-adjusted expected accident frequency (X). How this is calculated is outlined below. Consider that one is looking for the collision pattern selection (screening by a specific accident type) of angle accidents at signalized intersections in a jurisdiction; the site-specific SPFs for angle collisions are calibrated first. Then, one can apply the calibrated SPFs in the following steps in order to get EB-adjusted expected accident frequencies for use in ranking sites (*13*).

Step 1: Use the appropriate SPFs and calculate each year's ($y = 1,2,.....Y$) number of predicted accidents (κ_y) for the specific accident type (*TYPE)*.

$$\kappa_{y(TYPE)} = SPF_{(TYPE)} \tag{3.1}$$

Step 2: Use the number of predicted accidents to get the yearly correction factors (C_y) for the specific accident type in different years ($y = 1,2,.....Y$).

$$C_{y(TYPE)} = \frac{\kappa_{y(TYPE)}}{\kappa_{1(TYPE)}} \tag{3.2}$$

Step 3: Use the number of predicted accidents from each year ($\kappa_1,...,\kappa_y$) and the negative binomial (NB) overdispersion parameter (k) as discussed in Section 2.2.3 to get the weights (w) for the specific collision type accidents.

$$w_{TYPE} = \frac{1}{1+\frac{1}{k_{(TYPE)}}\sum_{y=1}^{Y}\kappa_{y(TYPE)}} \tag{3.3}$$

Step 4: The EB-adjusted expected accidents X_1 for the specific accident type in year 1 are calculated.

$$X_{1(TYPE)} = w_{(TYPE)}\kappa_{1(TYPE)} + (1 - w_{(TYPE)})\frac{\sum_{y=1}^{Y}\left(K_{y(TYPE)}\right)}{\sum_{y=1}^{Y}\left(C_{y(TYPE)}\right)} \tag{3.4}$$

Step 5: The last year's ($y = Y$) expected accidents for the specific collision type of the site can be calculated by:

$$X_{Y(TYPE)} = X_{1(TYPE)}C_{Y(TYPE)} \tag{3.5}$$

Step 6: The precision of the expected accident frequencies can be measured by calculating the variance of X_Y for the specific collision type.

$$Var\left(X_{Y(TYPE)}\right) = X_{Y(TYPE)}(1 - w_{(TYPE)})\frac{C_{Y(TYPE)}}{\sum_{y=1}^{Y}\left(C_{y(TYPE)}\right)} \tag{3.6}$$

Step 7: Then, rank the candidates by using expected accident frequencies for the specific collision type $\left(X_{Y(TYPE)}\right)$ as the PSI 'score'. A higher number of X_Y for the specific accident type indicates there's more potential to improve road safety of the entity by using appropriate treatments.

One can use another type of 'score' to rank the candidate entities. As noted earlier, this is called the 'excess accident frequency'. This score is the difference between every candidate's expected accident frequency and SPF-predicted accident frequency. In other words, the excess accident frequency compares each site by the difference between its expected accidents and what similar sites normally have. To obtain the value of excess accident frequency, two additional steps are required.

Step 8: Calculate the excess accident frequency by:

$$Excess_{Y(TYPE)} = X_{Y(TYPE)} - \kappa_{Y(TYPE)} \tag{3.7}$$

Step 9: Calculate the variance of the excess accident frequency by:

$$Var(Excess_{Y(TYPE)}) = Var(X_{Y(TYPE)}) + \frac{\left(\kappa_{Y(TYPE)}\right)^2}{k_{(TYPE)}} \tag{3.8}$$

3.3 Screening for High Proportions of Specific Accident Types

Screening sites with promise by ranking the sites' EB-adjusted expected or excess accident frequencies is now the accepted method that is being implemented in SafetyAnalyst, a set of tools being developed to manage a safety improvement program (*13*). This EB-adjusted expected or excess accident frequency, as mentioned in the preceding section, requires the SPF-predicted accident frequency as fundamental information for the calculations. The procedure in calibrating the SPFs requires accident data and traffic flow data at a minimum. The problem is that many jurisdictions don't have traffic flow data and/or accident data readily available because of resource limitations. And they may not have staff with the required training to calibrate these SPFs.

Screening for high proportions of specific accident types is an alternative way for selection of sites by collision pattern. A site with an unusually high proportion of certain accident types can be screened out by comparing its pattern 'score' to the others in the jurisdiction. The background of this method is described in the following section.

3.3.1 Theoretical Background

The main advantage of screening for high proportions of specific accident types is that it does not require a large amount of data, not even traffic flow data. This method, which only requires accident counts for several years, was introduced by Heydecker and Wu (*14*). The theory is shown in the following paragraphs.

First, assume a long-term proportion mean of certain collision type at an entity

(i) to be θ_i. Then the probability of a given target accident (x_i), like rear-end accident, out of total accidents (n_i) follows a Binomial distribution as below:

$$f(x_i \mid n_i, \theta_i) = \binom{n_i}{x_i} \theta_i^{x_i} (1-\theta_i)^{n_i - x_i} \qquad (0 \le x_i \le n_i) \qquad (3.9)$$

where $\binom{n_i}{x_i}$ can be expressed as $\frac{n!}{x!(n-x)!}$

The long-term mean of each site for specific accident type (θ_i) varies from site to site and is assumed to follow a Beta (prior) distribution according to Heydecker and Wu (*14*).

$$g(\theta \mid \alpha, \beta) = \frac{\theta^{\alpha-1}(1-\theta)^{\beta-1}}{B(\alpha,\beta)} \qquad (0 < \theta < 1) \qquad (3.10)$$

where

$$B(\alpha,\beta) = \frac{\Gamma(\alpha)\Gamma(\beta)}{\Gamma(\alpha+\beta)} \qquad (3.11)$$

α and β are the parameters of Beta distribution.

The mean of a Beta distribution ($E(\theta)$) is

$$E(\theta) = \frac{\alpha}{\alpha+\beta} \qquad (3.12)$$

and the variance is:

$$Var(\theta) = \frac{\alpha\beta}{\left[(\alpha+\beta)^2(\alpha+\beta+1)\right]} \qquad (3.13)$$

where $E(\theta)$ is the prior estimate of θ_i

Combining the Binomial distribution of observed accidents (Eq. 3.9) with a Beta distribution of θ over similar entities (Eq. 3.11) results in the unconditional Binomial-Beta distribution,

$$h(x_i \mid n_i, \alpha, \beta) = \binom{n_i}{x_i} \frac{B(\alpha + x_i, \beta + n_i - x_i)}{B(\alpha, \beta)} \tag{3.14}$$

Applying Bayes' theorem,

$$g(\theta \mid n_i, x_i, \alpha, \beta) = \frac{f(x_i \mid n_i, \theta) \cdot g_b(\theta \mid \alpha, \beta)}{h(x_i \mid n_i, \alpha, \beta)} \tag{3.15}$$

we get the posterior distribution of θ as,

$$g(\theta \mid \alpha', \beta') = \frac{\theta^{\alpha'-1}(1-\theta)^{\beta'-1}}{B(\alpha', \beta')}, \qquad (0 < \theta < 1) \tag{3.16}$$

where α' and β' are posterior parameters, expressed as:

$$\alpha' = \alpha + x_i \tag{3.17}$$

$$\beta' = \beta + n_i - x_i \tag{3.18}$$

From the posterior distribution, the expected value (θ_i) and variance at each site can be calculated by,

$$E(\theta_i) = \frac{\alpha'}{\alpha' + \beta'} \tag{3.19}$$

$$Var(\theta_i) = \frac{\alpha'\beta'}{\left[(\alpha' + \beta')^2 (\alpha' + \beta' + 1)\right]} \tag{3.20}$$

Finally, the 'score' used for ranking the site, also called the pattern score, is the probability that the expected value (θ_i) is greater than a given value of Beta prior distribution (θ_m). The pattern is calculated by,

$$P(\theta_i > \theta_m) = 1 - B(\theta_m, \alpha', \beta') \tag{3.21}$$

The value of π is between 0 and 1. The value of π is defined as 0.5 in this thesis since we assumed the mean proportion of a certain collision type to be constant and neutral. This assumption is the same as what Heydecker and Wu (13) and Mollett (12) used. When π is at this neutral value, θ_m is the median of Beta prior distribution. The mathematical expression is,

$$\int_{\theta_m}^{1} g(\theta) \mid \alpha,\beta) d\theta = \pi \tag{3.22}$$

3.3.2 Parameter Estimation for Beta Prior Distribution by Using Maximum Likelihood Method

The method of Maximum Likelihood (ML) estimation was used by Heydecker and Wu (*14*) and Mollett (*12*) to estimate α and β as follows.

First, derive the likelihood function from Equation 3.16 to

$$L_i = \binom{n_i}{x_i} \frac{B(\alpha + x_i, \beta + n_i - x_i)}{B(\alpha,\beta)} \tag{3.23}$$

Then convert the likelihood function to a more convenient form by applying the logarithm, known as the log-likelihood function.

$$\ln(L_i) = \ln\binom{n_i}{x_i} + \ln\left(B(\alpha + x_i, \beta + n_i - x_i)\right) - \ln(B(\alpha,\beta)) \tag{3.24}$$

The first term of left-hand side is:

$$\begin{aligned} \ln\left[B(\alpha + x_i, \beta + n_i - x_i)\right] = \ln\left[\Gamma(\alpha + x_i)\right] + \ln\left[\Gamma(\beta + n_i - x_i)\right] \\ - \ln\left[\Gamma(\alpha + \beta + n_i)\right] \end{aligned} \tag{3.25}$$

The second term is converted to be

$$\ln\left[B(\alpha,\beta)\right] = \ln\left[\Gamma(\alpha)\right] + \ln\left[\Gamma(\beta)\right] - \ln\left[\Gamma(\alpha + \beta)\right] \tag{3.26}$$

Next, substitute Equations 3.25 and 3.26 into Equation 3.24,

$$\begin{aligned} \ln(L_i) = \ln\left[\Gamma(\alpha + x_i)\right] + \ln\left[\Gamma(\beta + n_i - x_i)\right] - \ln\left[\Gamma(\alpha + \beta + n_i)\right] \\ - \left(\ln\left[\Gamma(\alpha)\right] + \ln\left[\Gamma(\beta)\right] - \ln\left[\Gamma(\alpha + \beta)\right]\right) \end{aligned} \tag{3.27}$$

The binomial coefficient ($\ln\binom{n_i}{x_i}$) is ignored in the process of maximizing log-likelihood and is treated as a constant in this case. Both α and β have to be a positive number. The values of α and β that maximize $\ln(L_i)$ are the maximized likelihood estimates. The parameters are substituted back into the equation of beta prior distribution in order to apply Bayes' theorem. Mollet (*12*) converted Equation 3.29 to:

$$\begin{aligned}\ln(L_i) = &\, gamma\ln(\alpha + x_i) + gamma\ln(\beta + n_i - x_i) - gamma\ln(\alpha + \beta + n_i) \\ &- (gamma\ln(\alpha) + gamma\ln(\beta) - gamma\ln(\alpha + \beta))\end{aligned} \quad (3.28)$$

Finally, sum up $\ln(L_i)$ for each entity and maximize the total number of $\ln(L_i)$ for all sites, by changing the values of α and β in the Solver function of Microsoft Excel, for example.

3.4 Chapter Summary

Two methods for screening specific accident types were introduced in this chapter. The background of the PSI method and the calculation procedures, using SPFs, were described. The method of screening for high proportions of specific accident types, which was introduced by Heydecker and Wu (*14*) in 1991, is an alternative method especially suitable for jurisdictions which do not have their own SPFs.

At present, there is no absolutely 'preferable' method between two PSI methods applied to specific accident types and screening method for high proportions of specific accident types. Both types of screening methods for specific accident types will be applied to the signalized intersections in Greater Toronto Area for a case study that is described in Chapter 5; a description of the used data will be presented in Chapter 4.

Chapter 4 General Features of Data Used

4.1 Traffic Safety Improvement Program Data

The data used in this thesis was extracted from the database of Toronto's Traffic Safety Improvement Program (TSIP). The whole database, which included accident data, traffic volume data and geometric information, was assembled by the City of Toronto and the consulting company – iTRANS. The data was organized and stored in electronic and geo-coded format. Signalized intersection data were used for this study. All collisions within 20m radius of the center-point of the intersections were considered as 'intersection-related' accidents; the datasets contained the data from 1996 to 2000.

4.2 Accident Data

There were 1700+ signalized intersections included in the dataset. The intersections were each represented with a unique number (PX) and classified as 3-legged or 4-legged. The accident data was categorized into five accident types, including general collision, angle collision, rear-end collision, left-turn collision and pedestrian collision. The data were reported as three severities, namely fatal, non-fatal injury and property damage only (PDO). Relevant statistics from the datasets of angle, left-turn and rear-end collisions used for the case study, are presented in Chapters 5 and 6. Tables 4.1 and 4.2 show some statistical data for 3 and 4-legged signalized intersections in Greater Toronto Area (GTA).

Table 4.1 Accident Data (3-legged signalized intersections in GTA)

Number of 3-legged intersection = 440											
Total accident			FI accident			Total rear-end accident			FI rear-end accident		
MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM
0	154	13592	0	49	1785	0	62	4685	0	25	1785
Total left-turn accident			FI left-turn accident			Total angle accident			FI angle accident		
MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM
0	33	1621	0	22	644	0	46	2501	0	18	727

Table 4.2 Accident Data (4-legged signalized intersections in GTA)

Number of 4-legged intersection = 1267											
Total accident			FI accident			Total rear-end accident			FI rear-end accident		
MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM
0	287	78667	0	103	26888	0	172	24105	0	69	9038
Total left-turn accident			FI left-turn accident			Total angle accident			FI angle accident		
MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM	MIN	MAX	SUM
0	71	11647	0	33	4881	0	73	17710	0	27	6298

4.3 Traffic Volume Data

Each intersection stored in the traffic volume data had a unique number (PX) that matched its counterpart in the accident data. The average traffic volumes of each approach, including through, right-turn and left-turn movements, were reported. All the traffic flow data were presented as Average Annual Daily Traffic (AADT). Table 4.3 shows the statistical information for 3 and 4-legged intersection in GTA.

Table 4.3 Traffic Volume Data (3and 4-legged signalized intersections in GTA)

3-legged intersection						4-legged intersection					
Major		Minor		Total Entering		Major		Minor		Total Entering	
MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
2444	57410	6	28916	4502	84756	2978	76892	189	45474	5022	98693

4.4 Geometric Information

The numbers of left-turn and right-turn approaches for each approach of the intersections could be found in the geometric information database. Similar to the case for accident and traffic data, each intersection was denoted by a unique PX number corresponding to other datasets.

4.5 Map Data

Relevant digital maps and the traffic signal database were prepared by City of Toronto separately. The digital maps, which included Toronto centreline and Toronto Property Data Map (PDM) boundaries, were in 'shape' format. This is a format which can be applied to the GIS computer program – ArcGIS. The geographic coordinates systems of the point, line and polygon features are identical. They are in units of the three-degree Modified Transverse Mercator (MTM) projection, and are based on the 1927 North American Datum. The appropriate X and Y coordinates of each signalized intersection were extracted from traffic signal database. Again, each signalized intersection was assigned a unique PX number which corresponded to that in accident, traffic volume and geometric data.

Since all datasets had the identical PX number for each signalized intersection, PX values became the bridge between accident, traffic volume, geometric and digital map data and allowed the merging of these datasets for analysis purposes.

Chapter 5 Application to Screening Toronto Signalized Intersections for Specific Accident Types Based on PSI Methods and the High Proportion Method

As mentioned in Chapter 3, two screening methods for specific accident types are applied to the signalized intersections in the Toronto area in this case study. In the first section, the calibration of parameters and the validation of SPFs are described; and the subsequent sections show the rankings for screening using PSI based on expected accident frequency, PSI based on excess accident frequency, and high proportions of specific accident types.

5.1 Models for Specific Accident Types

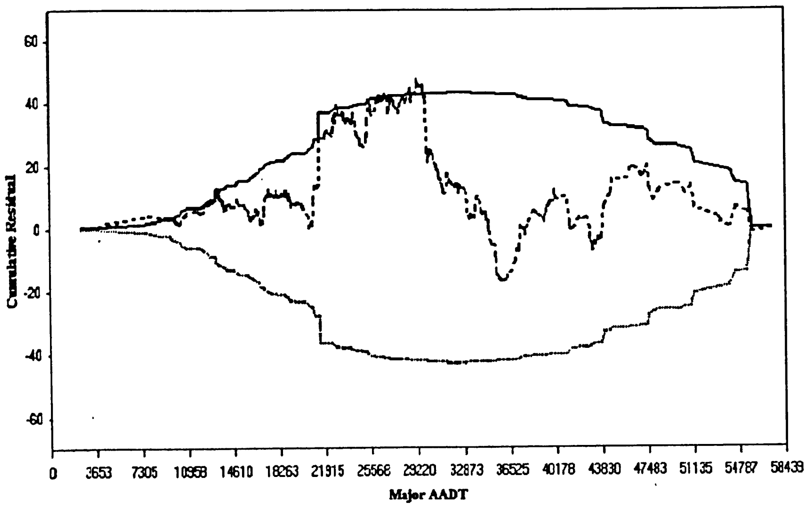
Twelve accident prediction models are described in this section. Seven of them are newly developed and others are provided by Persaud et al. (*15*). These models include fatal and injury (FI) and total accidents at three or four-legged intersections for angle, left-turn and rear-end collisions. AADT was the only variable used for calibrating accident prediction models by Persaud et al. (*15*). This is logical since AADT explains more than 70% of the variety of accidents.

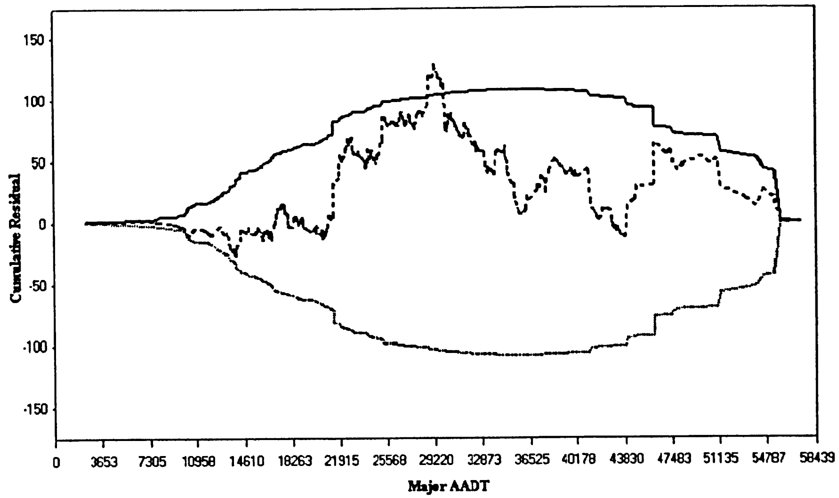
Generalized linear modeling was used to estimate the parameters of accident prediction models using the GENMOD procedure of statistical software package SAS (*16*). A negative binomial distribution of errors was assumed during calibration and the resulting overdispersion parameter (k) was also estimated. This parameter can be one of the factors used to check the quality of the model in that a smaller value of the parameter shows that a better model will result for a given dataset. (See Section 2.2.3.2 for more information.) The calibration parameters and the quality check information for the models are shown in Tables 5.1 to 5.3 and Exhibits 5.1 to 5.6.

Table 5.1 Calibration results – FI and total angle collisions (3 & 4-legged)

Angle	Model form	ln α	β_1	β_2	β_3	k
FI (3-legged)	$\alpha(\text{major})^{\beta_1}(\text{minor})^{\beta_2}$	-14.144	0.8290	0.5800		0.4500
FI (4-legged)	$\alpha(\frac{\text{major}}{1000})^{\beta_1}(\frac{\text{minor}}{1000})^{\beta_2}e^{\beta_3(\frac{\text{minor}}{1000})}$	-2.4434 (0.1907)	0.2636 (0.0544)	0.9377 (0.0620)	-0.0361 (0.0061)	0.3322
Tot (3-legged)	$\alpha(\frac{\text{major}}{1000})^{\beta_1}(\frac{\text{minor}}{1000})^{\beta_2}$	-2.3109 (0.3262)	0.5411 (0.0999)	0.6136 (0.0439)		0.4089
Tot (4-legged)	$\alpha(\frac{\text{major}}{1000})^{\beta_1}(\frac{\text{minor}}{1000})^{\beta_2}e^{\beta_3(\frac{\text{minor}}{1000})}$	-1.4310 (0.1349)	0.2608 (0.0390)	0.9180 (0.0429)	-0.0307 (0.0044)	0.2099

In Table 5.1, the parameters of accident models, including FI and total angle accidents at 3 or 4-legged signalized intersections, are shown. The independent variables 'major' and 'minor' represent the streets with the higher and lower traffic flows at the intersection, respectively. The SPF for FI angle collisions at 3-legged intersection was extracted from Persaud et al. (*15*) and the coefficients for the other SPFs were calibrated by SAS. Exhibits 5.1 and 5.2 show the quality check information for the four different SPFs and the CURE plot for each SPF. As discussed in Section 2.2.4.4, one can have a basic idea whether the accident prediction model is a good fit overall by looking at the CURE plot. If the dotted line stays within the upper and lower boundaries, the model is good fit at that range of major AADT. In contrast, if the dotted line sits out of the boundaries, the model does not fit well for the AADTs for which this occurs. Detailed information on the validation of models was given in Section 2.2.4. By looking at the CURE plots for angle collisions, all the models are reasonably fit since the cumulative residual curves sit within or not significantly beyond the boundaries within the whole range of major AADT.

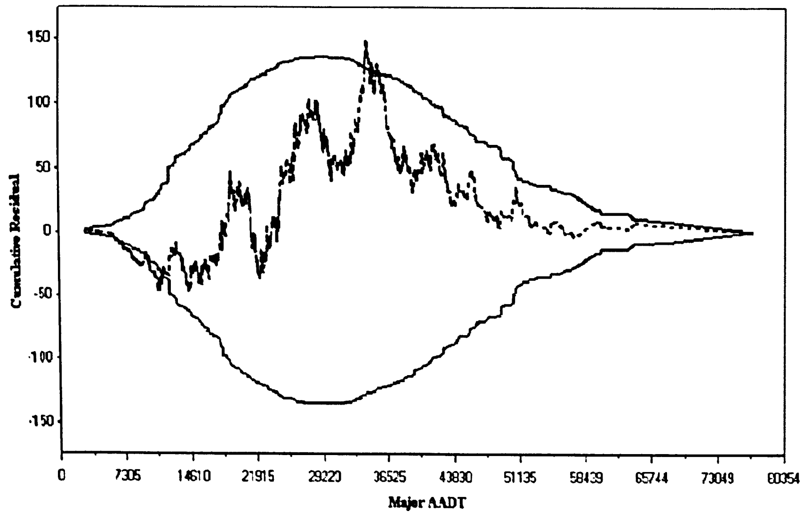


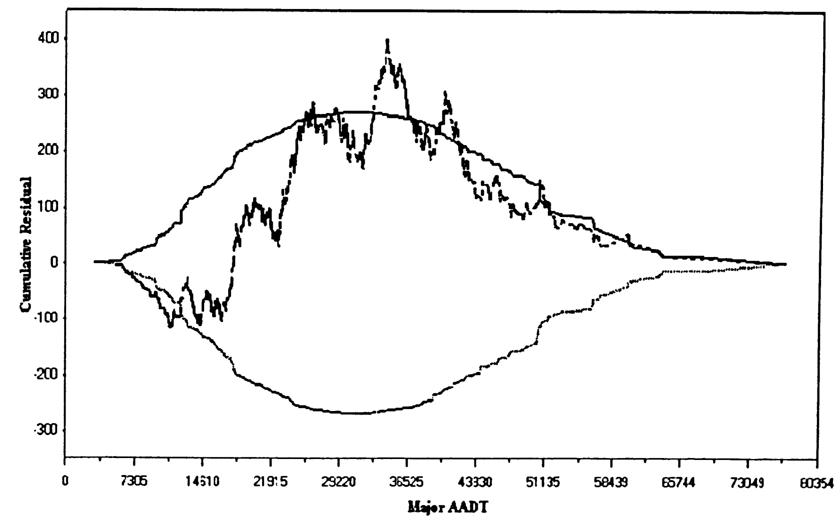


Model	FI collision at 3-legged intersection (Angle)	Model	Total collision at 3-legged intersection (Angle)
Out of range[1]	$Q_{major} \approx 29200-30000$	Out of range	$Q_{major} \approx 29200-30000$
r[2]	0.4279	r	0.5484
MPB[3]	0.1136	MPB	0.0808
MAD[4]	1.3601	MAD	3.3620

Exhibit 5.1 Quality test for FI and total angle collision at 3-legged intersections

[1] 'Out of range' shows the range of dotted line which sits out of the boundaries.
[2] Pearson's product moment correlation coefficient (closer to 1 is better).
[3] Mean Prediction Bias (near 0 is better).
[4] Mean Absolute Deviation (smaller is better).





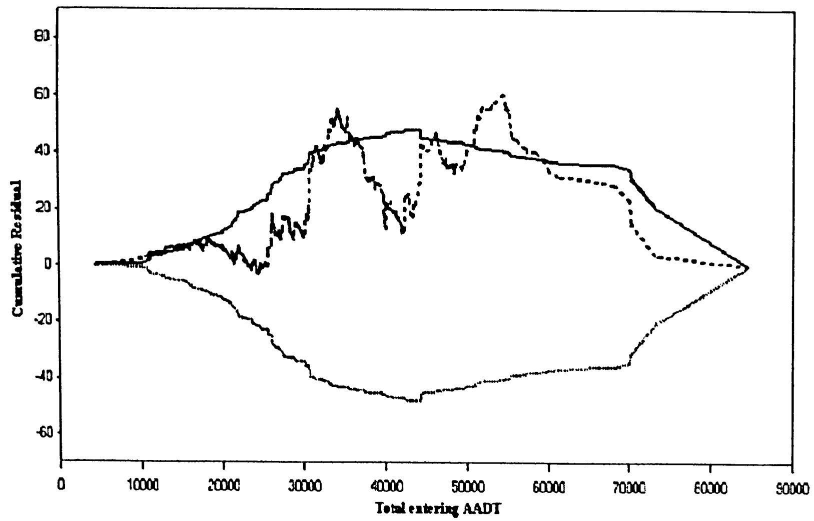
Model	FI collision at 4-legged intersection (Angle)	Model	Total collision at 4-legged intersection (Angle)
Out of range	$Q_{major} = 8500-13000, 33000-35000$	Out of range	$Q_{major} = 33000-37000, 41000-43000$
r	0.6498	r	0.7868
MPB	0.0007	MPB	-0.0228
MAD	2.7006	MAD	5.3695

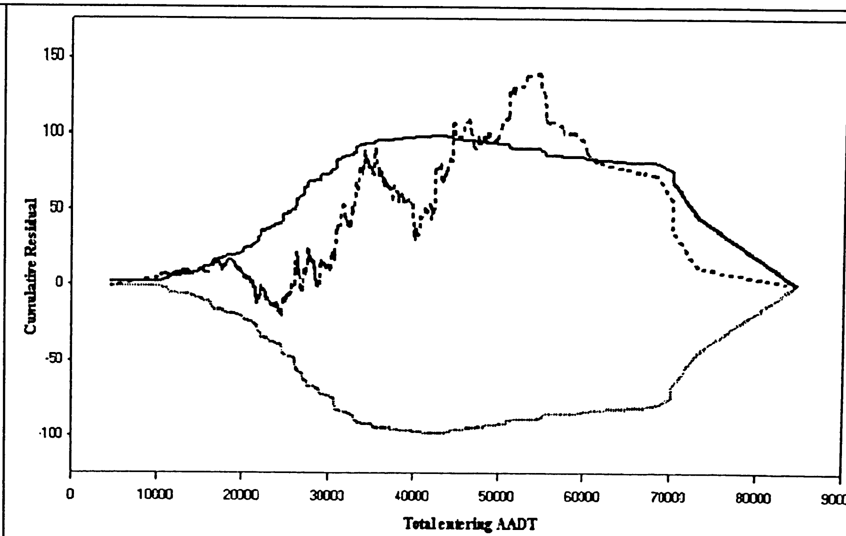
Exhibit 5.2 Quality test for FI and total angle collision at 4-legged intersections

Table 5.2 Calibration results – FI and total left-turn collisions (3 & 4-legged)

Left-turn	Model form	ln α	β_1	β_2	k
FI (3-legged)	$\alpha(\text{major+minor})^{\beta_1}(\frac{\text{LT}}{\text{major+minor}})^{\beta_2}$	-14.7937	1.4770	0.6590	0.7700
FI (4-legged)	$\alpha(\text{major+minor})^{\beta_1}(\frac{\text{LT}}{\text{major+minor}})^{\beta_2}$	-18.7417	1.8460	0.4600	0.5600
Tot (3-legged)	$\alpha(\frac{\text{major+minor}}{1000})^{\beta_1}\left(\frac{\text{LT}}{(\text{major+minor})/1000}\right)^{\beta_2}$	-3.8010 (0.5141)	1.4699 (0.1493)	0.6017 (0.0657)	0.6567
Tot (4-legged)	$\alpha(\frac{\text{major+minor}}{1000})^{\beta_1}\left(\frac{\text{LT}}{(\text{major+minor})/1000}\right)^{\beta_2}$	-5.0157 (0.1957)	1.7606 (0.0517)	0.3749 (0.0244)	0.4239

In Table 5.2, the parameters of accident models, including those for FI and total left-turn accidents, at 3 or 4-legged signalized intersections are shown. The independent variables of 'major' and 'minor' represent the streets with the higher and lower traffic flows at the intersection, respectively, and the variable 'LT' is the total left-turning traffic flow at the intersection. The SPF of FI collision at 3 and 4-legged intersection was extracted from Persaud et al. (*15*) and the coefficients for the other SPFs' were calibrated by SAS. Exhibits 5.3 and 5.4 also show the quality check information for the SPFs. From the CURE plots for left-turn collisions, one can observe that the cumulative residual curves mostly sit within the boundaries in the whole range of major AADT and only minimal portions of the curves go slightly beyond the boundaries, demonstrating that the models are reasonably fit.

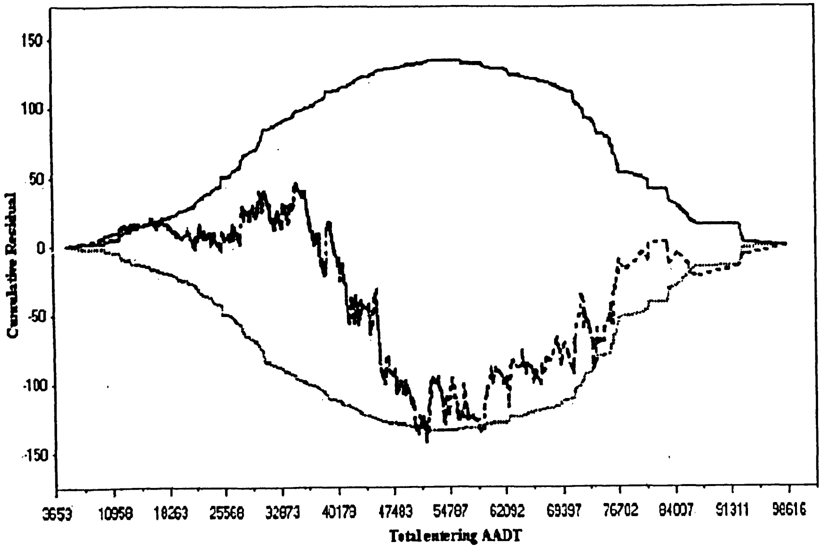




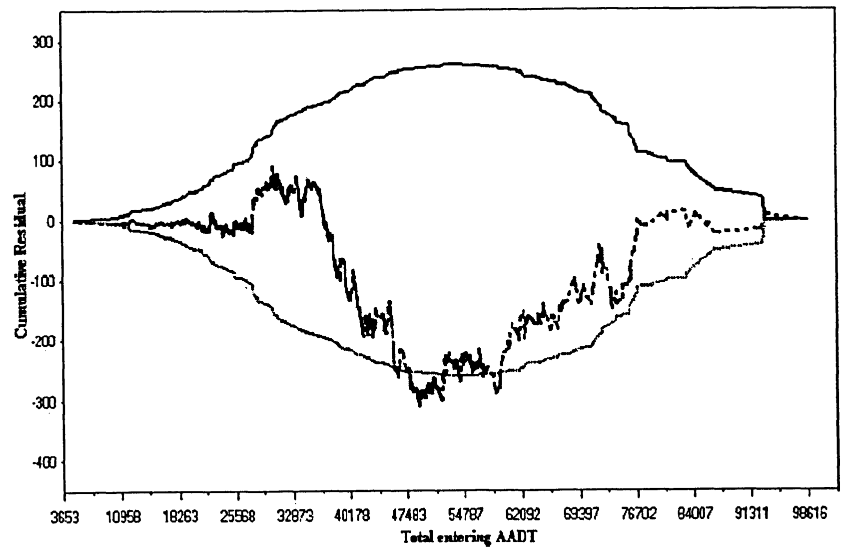
Model	FI collision at 3-legged intersection (Left-turn)	Model	Total collision at 3-legged intersection (Left-turn)
Out of range	$Q_{totalenter} = 32000-36000, 52000-59000$ [5]	Out of range	$Q_{totalenter} = 45000-46000, 50000-60500$
r	0.3655	r	0.3835
MPB	0.1023	MPB	0.2082
MAD	1.3859	MAD	2.9560

Exhibit 5.3 Quality test for FI and total left-turn collision at 3-legged intersections

[5] Total entering AADT ($Q_{totalenter}$) = Major AADT + Minor AADT



Model	FI collision at 4-legged intersection (Left-turn)
Out of range	$Q_{totalenter} = 86000 - 91000$
r	0.7690
MPB	0.0712
MAD	2.4375



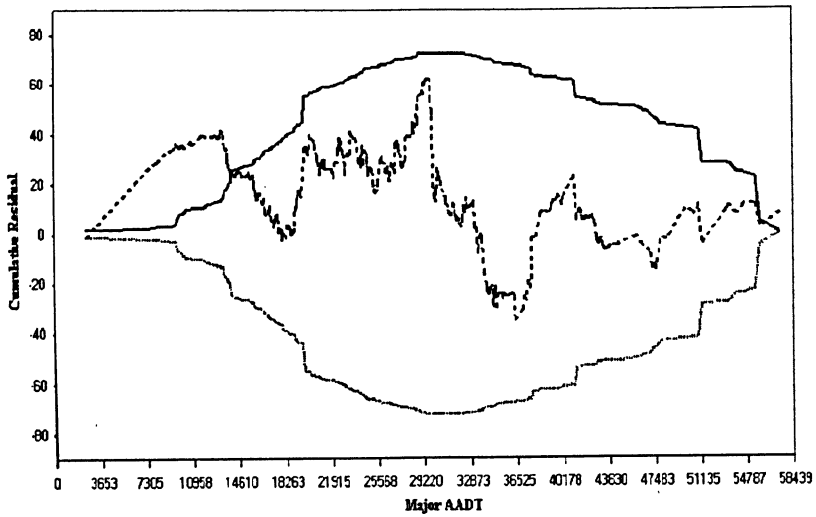
Model	Total collision at 4-legged intersection (Left-turn)
Out of range	$Q_{totalenter} = 46000 - 52000, 60000 - 60500$
r	0.8142
MPB	-0.1278
MAD	4.8182

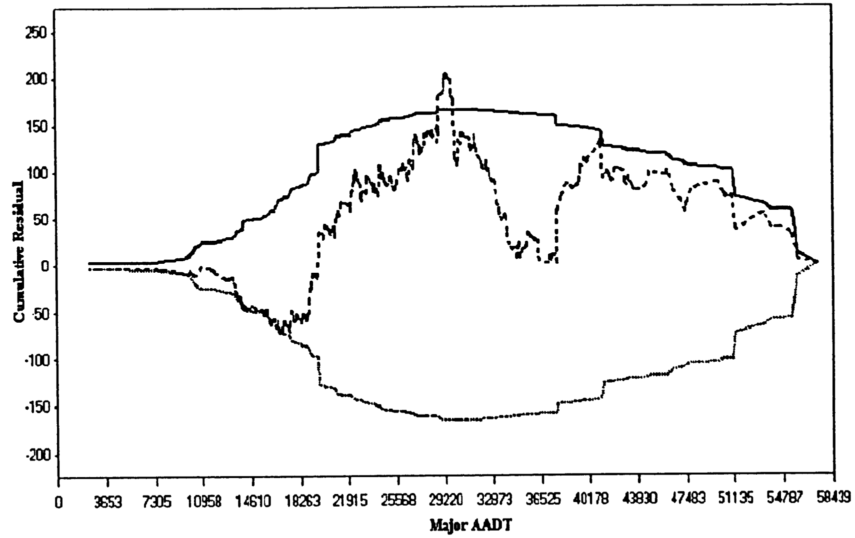
Exhibit 5.4 Quality test for FI and total left-turn collision at 4-legged intersections

Table 5.3 Calibration results – FI and total rear-end collisions (3 & 4-legged)

Rear-end	Model form	ln α	β_1	β_2	k
FI (3-legged)	$\alpha(\text{major})^{\beta_1}(\text{minor})^{\beta_2}$	-11.4727	0.7780	0.4390	0.3700
FI (4-legged)	$\alpha(\text{major})^{\beta_1}(\text{minor})^{\beta_2}$	-14.9964	1.0150	0.5490	0.2900
Tot (3-legged)	$\alpha\left(\frac{\text{major}}{1000}\right)^{\beta_1}\left(\frac{\text{minor}}{1000}\right)^{\beta_2}$	-2.2621 (0.2954)	0.7711 (0.0901)	0.4718 (0.0363)	0.3678
Tot (4-legged)	$\alpha\left(\frac{\text{major}}{1000}\right)^{\beta_1}\left(\frac{\text{minor}}{1000}\right)^{\beta_2}$	-3.0149 (0.1302)	0.9056 (0.0408)	0.6042 (0.0180)	0.2574

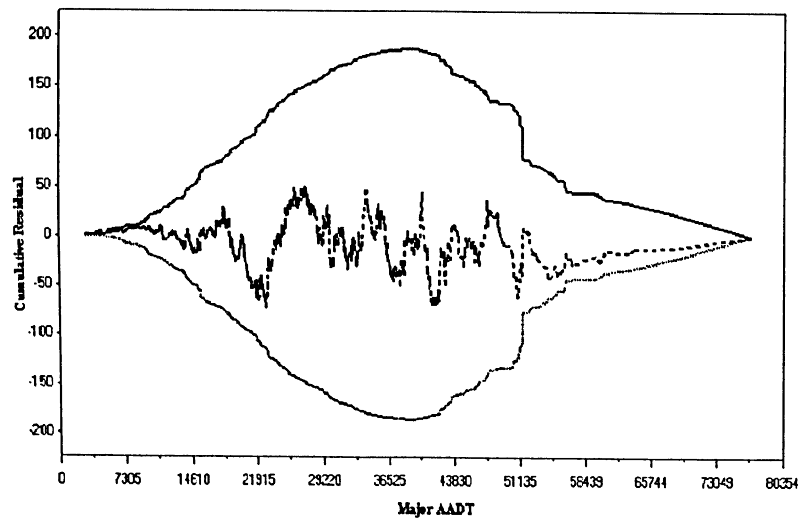
In Table 5.3, the parameters of accident models, including those for FI and total rear-end accidents at 3 or 4-legged signalized intersections are shown. The independent variables 'major' and 'minor' represent the streets with the higher and lower traffic flows at the intersection, respectively. The SPF of FI collision at 3 and 4-legged intersection was extracted from Persaud et al. (*15*) and the coefficients for the other SPFs' coefficients were calibrated by SAS. Exhibits 5.5 and 5.6 also show the quality check information for the SPFs. The CURE plots for rear-end collisions show that all the models are fairly fit as the cumulative residual curves sit within or not much beyond the boundaries within the whole range of major AADT.

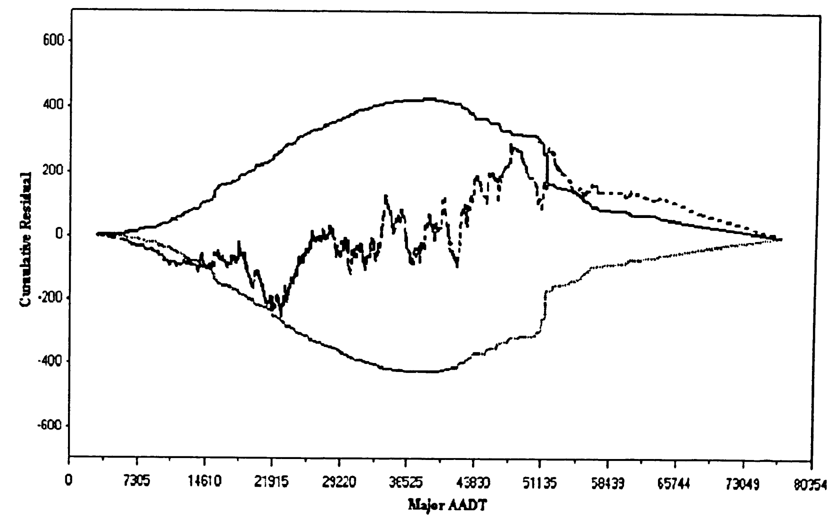




Model	FI collision at 3-legged intersection (Rear-end)	Model	Total collision at 3-legged intersection (Rear-end)
Out of range	$Q_{major} = 3600 - 14000$	Out of range	$Q_{major} = 29000 - 29500$
r	0.5624	r	0.6165
MPB	0.6282	MPB	0.0456
MAD	2.4265	MAD	5.2586

Exhibit 5.5 Quality test for FI and total rear-end collision at 3-legged intersections





Model	FI collision at 4-legged intersection (Rear-end)
Out of range	-
r	0.8256
MPB	0.1622
MAD	3.4598

Model	Total collision at 4-legged intersection (Rear-end)
Out of range	$Q_{major} = 51000 - 80000$
r	0.8687
MPB	-0.3753
MAD	7.5593

Exhibit 5.6 Quality test for FI and total rear-end collision at 4-legged intersections

5.2 Ranking Sites by PSI Based on Expected Accident Frequency

5.2.1 Results

The background and procedures for screening specific accident types by PSI methods were introduced in Chapter 3. This section shows the rankings by using PSI based on expected accident frequency for both FI and total collisions for angle accidents (see Table 5.4 and 5.5) at 4-legged signalized intersection in Greater Toronto Area. Ranking results for other accident types and for 3-legged intersections are presented in Appendix A.

Table 5.4 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Expected Accident
0033	YONGE ST	RICHMOND ST	1
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	2
0018	CHURCH ST	RICHMOND ST	3
0409	LAWRENCE AV	WARDEN AV	4
1363	STEELES AV	BIRCHMOUNT RD	5
0079	UNIVERSITY AV	RICHMOND ST	6
1287	WARDEN AV	MCNICOLL AV	7
0992	FINCH AV	MARTINGROVE RD	8
0616	DUFFERIN ST	BRIDGELAND AV/ YORKDALE RD	9
1001	ALBION RD	FINCH AV	10

Table 5.5 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Expected Accident
0079	UNIVERSITY AV	RICHMOND ST	1
0033	YONGE ST	RICHMOND ST	2
0018	CHURCH ST	RICHMOND ST	3
0204	LAKE SHORE BL	YORK ST	4
1541	LAKE SHORE BL	YONGE ST	5
0214	PARLIAMENT ST	ADELAIDE ST	6
0416	LAWRENCE AV	BELLAMY RD	7
0409	LAWRENCE AV	WARDEN AV	8
0131	STEELES AV	YONGE ST	9
0008	JARVIS ST	DUNDAS ST	10

5.2.2 Comparison of the Rankings for Fatal & Injury and Total Angle Accidents

Table 5.6 presents the rankings obtained by using PSI based on the expected accident frequency for total and FI angle collisions at 4-legged signalized intersections in Greater Toronto Area. The ranking for total angle collisions is used as the reference group. Four entities fall within the top ten sites for both rankings. This is likely because the percentage of FI accidents for those entities is more than 30% of total angle accidents. There is a trend indicating that, for an entity with a higher rank for total angle accidents, a relatively higher rank is expected for FI angle accidents. In contrast, the entities which sit at 9th and 10th in the total angle accidents ranking are placed low at 100th and 106th in FI angle accidents ranking, likely because their percentages of FI accidents are relatively smaller than for the other intersections.

Table 5.6 Ranking based on total and FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Major AADT	Minor AADT	Expected Total (Angle)	Expected FI (Angle)	% of Expected FI (Angle)	Tot	FI
0079	UNIVERSITY AV	RICHMOND ST	50460	36428	13.30	4.33	32.5	1	6
0033	YONGE ST	RICHMOND ST	32822	18822	13.28	4.84	36.5	2	1
0018	CHURCH ST	RICHMOND ST	39444	15206	13.09	4.66	35.6	3	3
0204	LAKE SHORE BL	YORK ST	44290	27962	12.02	3.62	30.1	4	18
1541	LAKE SHORE BL	YONGE ST	38130	24378	9.48	3.26	34.4	5	27
0214	PARLIAMENT ST	ADELAIDE ST	31690	10384	9.44	3.39	35.9	6	24
0416	LAWRENCE AV	BELLAMY RD	40186	15780	9.10	3.60	39.6	7	19
0409	LAWRENCE AV	WARDEN AV	45588	28302	8.76	4.51	51.5	8	4
0131	STEELES AV	YONGE ST	50068	42256	8.75	2.19	25.0	9	100
0008	JARVIS ST	DUNDAS ST	29742	19464	8.56	2.18	25.5	10	106

5.2.3 Comparison of the Rankings for Different Accident Types

Table 5.7 shows the ranking obtained using PSI based on expected accident frequency for total and FI angle, left-turn and rear-end collisions at 4-legged signalized intersections. The top ten sites for total angle accidents is used as a base. The table shows that there is no strong relationship between the rankings of angle, left-turn and rear-end total accidents.

Table 5.7 Ranking based on total and FI collisions (angle, left-turn and rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Expected Total Accident (Angle)	Expected Total Accident (Left-turn)	Expected Total Accident (Rear-end)	Expected FI Accident (Angle)	Expected FI Accident (Left-turn)	Expected FI Accident (Rear-end)
0079	UNIVERSITY AV	RICHMOND ST	1	548	277	6	908	476
0033	YONGE ST	RICHMOND ST	2	884	597	1	946	883
0018	CHURCH ST	RICHMOND ST	3	561	758	3	436	553
0204	LAKE SHORE BL	YORK ST	4	225	87	18	192	87
1541	LAKE SHORE BL	YONGE ST	5	350	121	27	383	133
0214	PARLIAMENT ST	ADELAIDE ST	6	952	815	24	1097	773
0416	LAWRENCE AV	BELLAMY RD	7	144	251	19	151	123
0409	LAWRENCE AV	WARDEN AV	8	562	32	4	286	24
0131	STEELES AV	YONGE ST	9	584	30	100	496	31
0008	JARVIS ST	DUNDAS ST	10	302	340	106	448	556

5.3 Ranking Sites by PSI Based on Excess Accident Frequency

5.3.1 Results

Similar to the previous section, this part presents the rankings obtained by using PSI based on excess accident frequency for both FI (see Table 5.8) and total collisions for angle accidents (see Table 5.9) at 4-legged signalized intersection in the Greater Toronto Area. Ranking results for other accident types and for 3-legged intersections are presented in Appendix A.

Table 5.8 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Excess Accident
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	1
0033	YONGE ST	RICHMOND ST	2
0018	CHURCH ST	RICHMOND ST	3
1380	FINCH AV	SANDHURST CIR	4
1363	STEELES AV	BIRCHMOUNT RD	5
0992	FINCH AV	MARTINGROVE RD	6
1287	WARDEN AV	MCNICOLL AV	7
0545	QUEEN ST	CARLAW AV	8
1590	FINCH AV	YORKGATE DR	9
0409	LAWRENCE AV	WARDEN AV	10

Table 5.9 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Excess Accident
0033	YONGE ST	RICHMOND ST	1
0018	CHURCH ST	RICHMOND ST	2
0079	UNIVERSITY AV	RICHMOND ST	3
0204	LAKE SHORE BL	YORK ST	4
0214	PARLIAMENT ST	ADELAIDE ST	5
0921	YONGE ST	CHARLES ST	6
0545	QUEEN ST	CARLAW AV	7
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	8
1380	FINCH AV	SANDHURST CIR	9
0416	LAWRENCE AV	BELLAMY RD	10

5.3.2 Comparison of the Rankings for Fatal & Injuries and Total Angle Accidents

Table 5.10 shows the ranking obtained by using PSI based on excess accident frequency for Total and FI angle collision at 4-legged signalized intersections in Greater Toronto Area. The top ten ranked sites for total angle collisions are used as the reference group. There are five entities sitting in the top ten for both rankings, probably due to the percentages of expected FI for top ten entities (tot) being above 30%. A trend, similar to that in Table 5.6 is found, indicating that for an entity with a higher rank for total angle accidents, a relatively higher rank for FI angle accidents is expected.

Table 5.10 Ranking based on total and FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Major AADT	Minor AADT	Excess Total Accident (Angle)	Excess FI Accident (Angle)	% of Expected FI (Angle)	Tot	FI
0033	YONGE ST	RICHMOND ST	32822	18822	8.80	3.26	36.5	1	2
0018	CHURCH ST	RICHMOND ST	39444	15206	8.78	3.12	35.6	2	3
0079	UNIVERSITY AV	RICHMOND ST	50460	36428	7.95	2.59	32.5	3	12
0204	LAKE SHORE BL	YORK ST	44290	27962	6.76	1.84	30.1	4	28
0214	PARLIAMENT ST	ADELAIDE ST	31690	10384	6.11	2.17	35.9	5	17
0921	YONGE ST	CHARLES ST	17954	6732	5.79	2.17	37.3	6	18
0545	QUEEN ST	CARLAW AV	12245	9618	5.66	2.77	45.1	7	8
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	33298	5232	5.12	3.88	64.6	8	1
1380	FINCH AV	SANDHURST CIR	18182	4958	4.93	3.11	56.3	9	4
0416	LAWRENCE AV	BELLAMY RD	40186	15780	4.70	2.03	39.6	10	21

5.4 Ranking Sites by High Proportions of Specific Accident Types

5.4.1 Results

The background of the screening methods for high proportion of specific accident types, which is denoted as the 'High Proportion method' here, was introduced in Chapter 3. The rankings obtained by using the high proportion method for both FI and total collisions for angle accidents at 4-legged signalized intersection are introduced in this section. Rankings for other accident types and for 3-legged intersections are presented in Appendix A.

Table 5.11 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	High Proportion
0033	YONGE ST	RICHMOND ST	1
0018	CHURCH ST	RICHMOND ST	2
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	3
0214	PARLIAMENT ST	ADELAIDE ST	4
0079	UNIVERSITY AV	RICHMOND ST	5
1380	FINCH AV	SANDHURST CIR	6
1372	MCCOWAN RD	SANDHURST CIR	7
0213	LAKE SHORE BL	BAY ST	8
0545	QUEEN ST	CARLAW AV	9
0223	PARLIAMENT ST	RICHMOND ST	10

Table 5.12 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	High Proportion
0018	CHURCH ST	RICHMOND ST	1
0033	YONGE ST	RICHMOND ST	2
0214	PARLIAMENT ST	ADELAIDE ST	3
0079	UNIVERSITY AV	RICHMOND ST	4
0545	QUEEN ST	CARLAW AV	5
0419	LAWRENCE AV	GREENCEDAR CIR/ GREENBRAE CIR	6
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	7
0019	CHURCH ST	QUEEN ST	8
0886	BIRCHMOUNT RD	BERTRAND AV	9
1359	KIPLING AV	WIDDICOMBE HILL BL	10

5.4.2 Comparison of the Rankings for Fatal & Injury and Total Angle Accidents

Table 5.13 shows the rankings obtained with the high proportion method for Total and FI angle collision at 4-legged signalized intersections in Greater Toronto Area. The top ten ranked sites for total angle collision is used as the base or reference group. There are six entities sitting in the top ten for both rankings, likely due to the fact that the percentage of observed angle accidents for most of the top ten entities is above 50%. The entity which places at 9th in total angle ranking is sitting at the 113th place of the FI ranking, likely because the percentage of FI angle accidents is only 28% of total angle collisions.

Table 5.13 Ranking based on total and FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	% of Angle (Angle/Tot)	% of Angle FI (AngleFI/AngleTot)	Tot	FI
0018	CHURCH ST	RICHMOND ST	57.1	36.1	1	2
0033	YONGE ST	RICHMOND ST	52.1	37.0	2	1
0214	PARLIAMENT ST	ADELAIDE ST	59.8	36.5	3	4
0079	UNIVERSITY AV	RICHMOND ST	47.1	32.9	4	5
0545	QUEEN ST	CARLAW AV	51.7	46.7	5	9
0419	LAWRENCE AV	GREENCEDAR CIR	54.2	41.0	6	16
1005	LAWRENCE AV	GREENCREST CIR	53.3	67.5	7	3
0019	CHURCH ST	QUEEN ST	47.6	38.5	8	22
0886	BIRCHMOUNT RD	BERTRAND AV	59.5	28.0	9	113
1359	KIPLING AV	WIDDICOMBE HILL BL	65.6	47.6	10	41

5.5 Comparison of the Results for the Three Ranking Methods and Discussion

In preceding sections, three ranking methods were used for different accident impact types and severities. Not surprisingly, the rankings from using expected and excess accident frequencies are more similar to each other that they are to the ranking from applying the high proportion method; this is because the first two methods are based on SPFs. After ranking the entities, the next task is to select a set of entities on which to perform a Detailed

Engineering Study (DES); this section uses total angle collisions at 4-legged signalized intersection as an example to illustrate the application of the methods in combination to improve the efficiency of site selection for DES. Tables 5.14 to 5.16 show rankings of sites by the 3 methods using, in turn, the highest ranked sites by different methods as reference groups.

Table 5.14 Ranking based on total collisions (angle) by using expected accidents as reference at 4-legged signalized intersections

PX	Major Street	Minor Street	Expected Accident	Excess Accident	High Proportion
0079	UNIVERSITY AV	RICHMOND ST	1	3	4
0033	YONGE ST	RICHMOND ST	2	1	2
0018	CHURCH ST	RICHMOND ST	3	2	1
0204	LAKE SHORE BL	YORK ST	4	4	14
1541	LAKE SHORE BL	YONGE ST	5	11	36
0214	PARLIAMENT ST	ADELAIDE ST	6	5	3
0416	LAWRENCE AV	BELLAMY RD	7	10	12
0409	LAWRENCE AV	WARDEN AV	8	26	820
0131	STEELES AV	YONGE ST	9	22	1185
0008	JARVIS ST	DUNDAS ST	10	16	34

Table 5.15 Ranking based on total collisions (angle) by using excess accidents as reference at 4-legged signalized intersections

PX	Major Street	Minor Street	Excess Accident	Expected Accident	High Proportion
0033	YONGE ST	RICHMOND ST	1	2	2
0018	CHURCH ST	RICHMOND ST	2	3	1
0079	UNIVERSITY AV	RICHMOND ST	3	1	4
0204	LAKE SHORE BL	YORK ST	4	4	14
0214	PARLIAMENT ST	ADELAIDE ST	5	6	3
0921	YONGE ST	CHARLES ST	6	20	11
0545	QUEEN ST	CARLAW AV	7	13	5
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	8	33	7
1380	FINCH AV	SANDHURST CIR	9	47	23
0416	LAWRENCE AV	BELLAMY RD	10	7	12

Table 5.16 Ranking based on total collisions (angle) by using high proportion method as reference at 4-legged signalized intersections

PX	Major Street	Minor Street	High Proportion	Expected Accident	Excess Accident
0018	CHURCH ST	RICHMOND ST	1	3	2
0033	YONGE ST	RICHMOND ST	2	2	1
0214	PARLIAMENT ST	ADELAIDE ST	3	6	5
0079	UNIVERSITY AV	RICHMOND ST	4	1	3
0545	QUEEN ST	CARLAW AV	5	13	7
0419	LAWRENCE AV	GREENCEDAR CIR/ GREENBRAE CIR	6	36	12
1005	LAWRENCE AV	GREENCREST CIR/ GREENHOLME CIR	7	33	8
0019	CHURCH ST	QUEEN ST	8	35	24
0886	BIRCHMOUNT RD	BERTRAND AV	9	210	67
1359	KIPLING AV	WIDDICOMBE HILL BL	10	323	73

Sites with PX index {0018, 0033, 0079, 0214} are the entities that may be considered most worthy of DES when focused on angle crashes, since those sites sit in top 10 by all screening methods. These sites are classified as 'Group 1'. Sites with PX index {0204, 0416, 0545, 1005} might be considered second priority for DES since they sit in the top 10 for two of the screening methods. Finally the third priority (Group 3) might be the sites that are only listed in the top 10 for only one of the screening methods. These are the sites with PX index {0008, 0019, 0131, 0409, 0419, 0886, 0921, 1359, 1380, 1541}. In total, the 18 intersections most worthy of DES with focus on angle crashes have been identified using this approach. If the budget allows for more DES, then for example, top 20 ranked sites as the starting point instead of the top 10, and so on. The results for other accident types at 3 and 4-legged intersections are presented in Table 5.17 and the comparison tables for other accident types are shown in Appendix A.

Table 5.17 Contrast comparison for different accident groups

Type	Group 1	Group 2	Group 3	# of sites for DES
3-legged Angle FI	0017, 0221, 0622, 0890, 1491, 1540, 1608	0599, 1246, 1310	0892, 1147, 1244	13
3-legged Angle Tot	0017, 0622, 1147, 1491, 1540, 1608	0103, 0221, 0274, 0614	0570, 0769, 0882, 1489	14
4-legged Angle FI	0018, 0033, 1005	0079, 0409, 0545, 0992, 1287, 1363, 1380	0213, 0214, 0223, 0616, 1001, 1372, 1590	17
4-legged Angle Tot	0018, 0033, 0079, 0214	0204, 0416, 0545, 1005	0008, 0019, 0131, 0409, 0419, 0886, 0921, 1359, 1380, 1541	18
3-legged Left-turn FI	0457, 0588, 0622, 0958, 1246, 1491	0890, 0957, 1608	0723, 1172, 1244, 1331, 1531, 1619	15
3-legged Left-turn Tot	0457, 0622, 1246, 1331, 1540, 1608	0102, 1329, 1491, 1619	0588, 0958, 1214, 1531	14
4-legged Left-turn FI	0437, 0458, 0626, 0702, 0878, 1363	0380, 0420, 0454, 0652, 0917	0912	12
4-legged Left-turn Tot	0380, 0878, 0917	0420, 0534, 0619, 0810, 1191, 1363	0131, 0412, 0437, 0479, 0602, 0652, 0748, 0869, 0927	18
3-legged Rear-end FI	0252, 0446, 1002	0215, 0346, 0390, 0453, 0588, 0640, 0682	0099, 0965, 1004, 1260, 1610, 1663, 1723, 1745	18
3-legged Rear-end Tot	0390, 0446, 0453	0395, 0588, 0682, 0822, 1002	0102, 0215, 0252, 0387, 0415, 0496, 1004, 1172, 1260, 1329, 1360	19
4-legged Rear-end FI	0456, 0618, 0675, 0694, 0744, 0752, 1348	0407, 0589, 1192	0696, 1162, 1420	13
4-legged Rear-end Tot	0618, 0675, 0694, 0744, 0752, 1348	0407, 0589	0128, 0203, 0428, 0696, 1162, 1192, 1407, 1420	16

From the contrast comparison table (Table 5.17), one can compare the PSI index for the selection based on FI and total accidents for different accident groups. For example, one can consider that may be worthwhile to upgrade the traffic signal (e.g., by adding a left-turn phase) at the intersections of Eglinton Ave and Sinnott Rd. (0457), Rexdale Bl. and Queen's Plate Dr. (0622) and HWY #27 and Queen's Plate Dr. (1246) since those sites are ranked in the top 10 for both FI and total left turn accidents for 3-legged intersections.

5.6 Chapter Summary

This chapter has described the results for screening signalized intersections in the Greater Toronto Area for specific accident types using three different methods. The calibration parameters and quality check information for the SPFs estimated for this application have been presented.

Despite that PSI methods do not require any assumptions on the mean proportion of a given collision type, it is difficult to draw a solid conclusion on which method is the most suitable for screening the intersections. The comparison between total and FI rankings reveals that high-ranked entities for total accidents have a relatively high position in the FI ranking. This chapter has also described a way to combine the results from the three methods by placing entities into 3 DES priority groups, namely the 'top 10 in all three rankings', 'top 10 in only two rankings' and 'top 10 in only one ranking'.

Chapter 6 Integrating Spatial Methods with Network Screening

Road network screening can also be done for a combined group of intersections in a small geographic region. Two different sets of approaches are explored in this chapter.

In Section 6.1.1, four different accident reduction plans are introduced for a concept in which the level of accident clustering will determine which plan will be the most suitable for a jurisdiction. A graphical method to determine the level of accident clustering is described in Section 6.1.2.

In order to increase the efficiency and reduce the budget when running a road safety improvement campaign in a large area, the authority may want to upgrade road safety at groups of flagged entities in one area, instead of individual ones that are widely spread. Two tools, one which combines safety performance function (SPF) and a Geographic Information System (GIS) and the other which combines the Potential for Safety Improvement (PSI) method and GIS, are demonstrated in Sections 6.2 and 6.3 for screening groups of entities in a small region.

6.1 Accident Clustering Methods

6.1.1 Introduction

The distribution of accidents is usually unevenly spread over the transportation system in a jurisdiction. In other words, accidents tend to form clusters. Nicholson (*2*) said that the greater the inequality of accident distribution, the greater is the level of clustering.

The idea of accident clustering can be the starting point in formulating countermeasure plans; these plans are single-site plans, route action plans, area action plans and mass action plans. The single-site (or black-spot) and route action plans involve screening processes that identify some unusually 'dangerous' sites or routes. Mass action plans primarily involve a process of finding locations to apply known remedies, like installing the red light cameras at some signalized intersections in a jurisdiction. Finally, area action plans are the combination of the single-site plans and mass action plans. On the one hand, area plans can involve a detailed analysis of accident data in order to diagnose the safety problem and identify appropriate remedial treatments in a particular region. These approaches are the same as single-site plans and route action plans. On the other hand, area plans, like mass action plans, may involve deciding of the nature of the remedial treatment in advance. Nicholson (*2*) compared the efficiency of each action plan; the results are shown in Table 6.1 in terms of expected accident reduction and expected economic return.

Table 6.1 Expected effects of different action plans (*2*)

Plan Type	Expected accident reduction, %	Expected economic return, %
Single site	33	>50
Route action	15	>40
Area action	10	10-25
Mass action	15	>40

This table shows that the single-site plan seems to be the best accident reduction strategy. However, various levels of accident clustering can be found in different jurisdictions, so a single-site plan is not always the best solution. Nicholson (*2*) stated 'A high level of accident clustering indicates that a "black-spot" program is the most appropriate and, as the level of clustering reduces, a "black-route" program becomes more appropriate, with a "black-area" program becoming the most appropriate when there is a very low level of clustering'. Nicholson (*2*) presented several methods to calculate the level of accident clustering, either graphically or numerically. The method of graphical presentation will be demonstrated in the following section by applying it to the Toronto signalized intersection accident data for year 2000.

6.1.2 Data Preparation and Graphical Presentation

The first step in finding the level of accident clustering in a jurisdiction is to extract the relevant information from the accident data and set up a table containing the following variables:

n_k = number of sites with k accidents during the period

K = maximum number of accidents at any site during the period

K_i = accident count at the i^{th} site

N = the total number of sites = $\sum_{k=0}^{K} n_k$

M = the total number of accidents = $\sum_{k=0}^{K} kn_k$

$\bar{k}$ = the arithmetic mean accident count = $\sum_{k=0}^{K} kn_k / \sum_{k=0}^{K} n_k$

The relative accident count (i^{th} site) = k_i/K $\quad i = 1,\ldots, N$

The relative frequency = $n_k/\max(n_0, n_1 \ldots n_k) k = 0,\ldots, K$

The accident proportion = kn_k/M $\quad k = 0,\ldots, K$

The population proportion = n_k/N $\quad k = 0,\ldots, K$

a_k = The population of total accidents occurring at sites with k or less accidents

$$= \sum_{j=0}^{k} jn_j / M = \sum_{j=1}^{k} jn_j / M$$

Table 6.2 only shows a portion of the findings and the full table is found in Appendix B.

Table 6.2 Statistical data for Toronto (2000)

Accident count (k)	Frequency (n_k)	Accident (kn_k)	Relative accident count (k/K)	Relative frequency	Accident proportion (kn_k/M)	Population proportion (n_k/N)	Cumulative accident proportion (a_k)	Cumulative population proportion
0	80	0	0	0.5333	0	0.0467	0	0.0467
1	93	93	0.0141	0.6200	0.0050	0.0543	0.0050	0.1011
2	117	234	0.0282	0.7800	0.0126	0.0683	0.0176	0.1694
3	109	327	0.0423	0.7267	0.0176	0.0637	0.0353	0.2331
4	150	600	0.0563	1.0000	0.0324	0.0876	0.0677	0.3207
...	...	...	...	...	...	...	...	...
67	1	67	0.9437	0.0067	0.0036	0.0006	0.9962	0.9994
68	0	0	0.9577	0	0	0	0.9962	0.9994
69	0	0	0.9718	0	0	0	0.9962	0.9994
70	0	0	0.9859	0	0	0	0.9962	0.9994
71	1	71	1	0.0067	0.0038	0.0006	1.0000	1.0000

In 2000, Toronto recorded 18531 accidents (M) at 1712 signalized intersections (N), which had 10.824 accidents on average ($\bar{k}$) with a maximum number of 71(K). Nicholson (*2*) used the accident count profile diagram and the accident count concentration curve to show the inequality of the accident distribution. Firstly, the accident count profile diagram is created by plotting the relative accident count against the cumulative population proportion (Figure 6.1). The curve 'actual profile' represents the observed data. The line 'perfect equally', which represents no clustering of accidents, is shown in the diagram to contrast with any inequality of accident appearance in the observed data. The diagram clearly shows that the distribution of accidents at signalized intersections is unevenly spread.

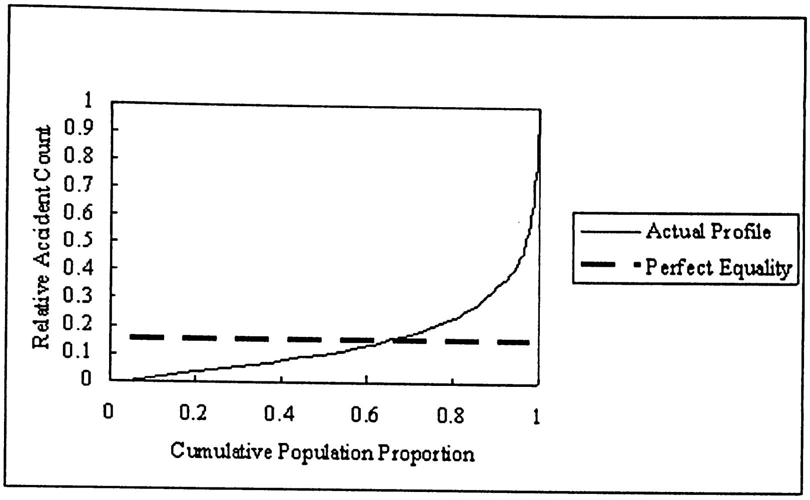


Figure 6.1 Accident count profile

The second diagram is the accident count concentration curve (Figure 6.2), where the cumulative accident proportion is plotted against the cumulative population proportion. If the jurisdiction has an uniformly distributed accident pattern, each site will contribute equally to the accident total, and the plot of cumulative accident proportion against cumulative population proportion will be a straight line, called the 'Perfect equality' line. The greater the difference between the actual profile line and the perfect equality line, the greater accident clustering is.

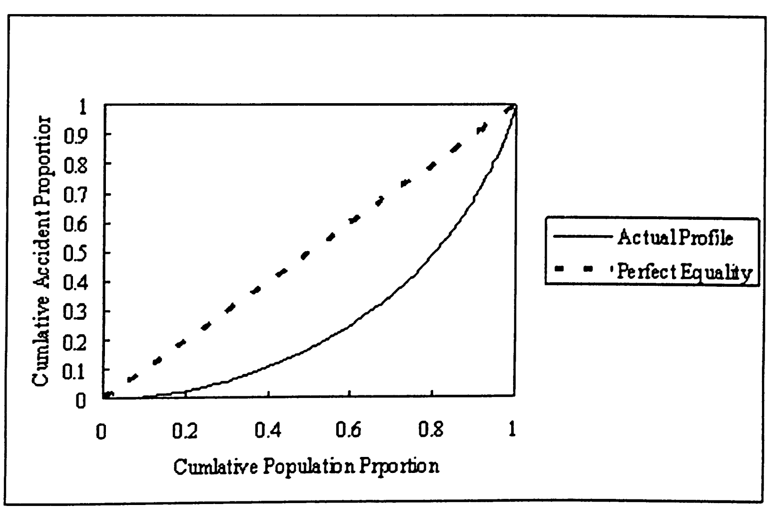


Figure 6.2 Accident count concentration curve

Figures 6.1 and 6.2 both show that the accident distribution at signalized intersections in Toronto is unevenly spread; i.e., the single-site plan seems to be the most suitable accident reduction strategy compared to the other three plans.

6.2 Combining Safety Performance Function and Geographic Information System

Safety Performance Function (SPF) is the mathematical function used to model the relationship between accident counts, traffic flows and other relevant information for similar entities. A detailed discussion of SPFs has already been given in Chapter 2. If one wants to determine which region, or geographical group of entities, has more accidents on relative basis, a tool that combines SPF and GIS can allow this to be achieved. This is demonstrated in the following section.

6.2.1 Spatial Analysis Procedures

GIS is a system for managing spatial data and associated attributes. In other words, it is capable of integrating, storing, editing, analyzing and displaying geo-referenced information. If one needs to calibrate an accident prediction model by combining regional information, this information needs to be integrated to the original accident data as a new attribute; GIS is the ideal solution to merge the information.

In this section the total rear-end accidents at 3-legged signalized intersections in the Greater Toronto Area (GTA) are utilized as a case study to demonstrate the calibration of the SPF of a specific accident type for a group of signalized intersections in a small region in a jurisdiction. The computer software packages ArcGIS 9 (*17*) and SAS 9 (*16*) are used in this study. The data analysis procedure follows the following steps:

Step 1: Divide the jurisdiction into several regions for further investigation. For instance, the Greater Toronto Area (GTA) divided vertically into 21 regions as shown in Figure 6.3.

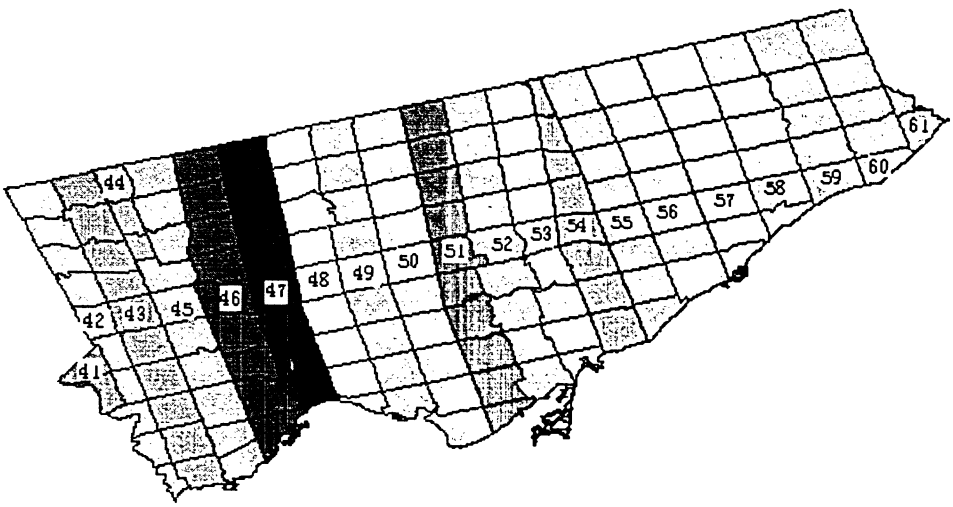


Figure 6.3 21 regions in GTA

Step 2: Use the 'Intersect' function in the ArcGIS 9 Overlay option to classify the signalized intersections into their corresponding regions.

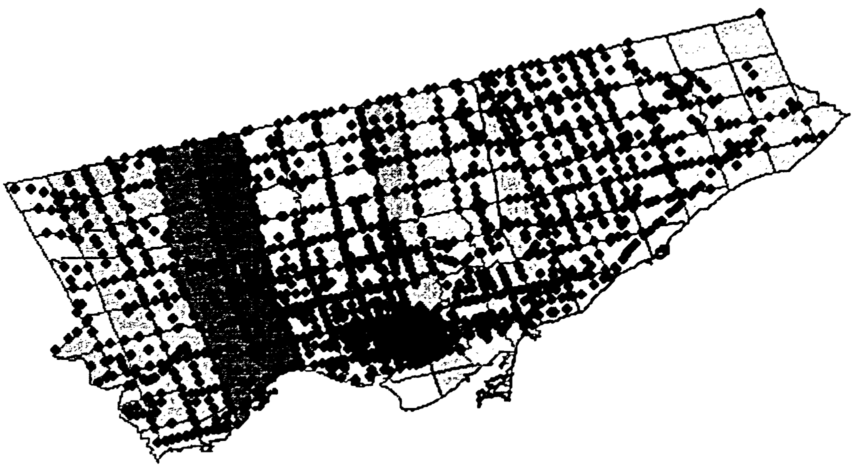


Figure 6.4 Classifying the signalized intersections to different regions

Step 3: Since some of the intersections are located at the boundary of different regions, the same entities may fall into different regions. Hence, one needs to decide which region each of those intersections belongs to.

For example, the signalized intersection at Western Road and Lanyard Road, as shown in Figure 6.5, sits on the boundary of region 45 and 46. In this study, a rule was devised whereby the intersections on the boundary of different regions are always assigned to a smaller number of the region. Thus, the results of ranking on a regional basis will not be affected by the duplicated entries. In the case of signalized intersection at Western Road and Lanyard Road, it belongs to the region 45.

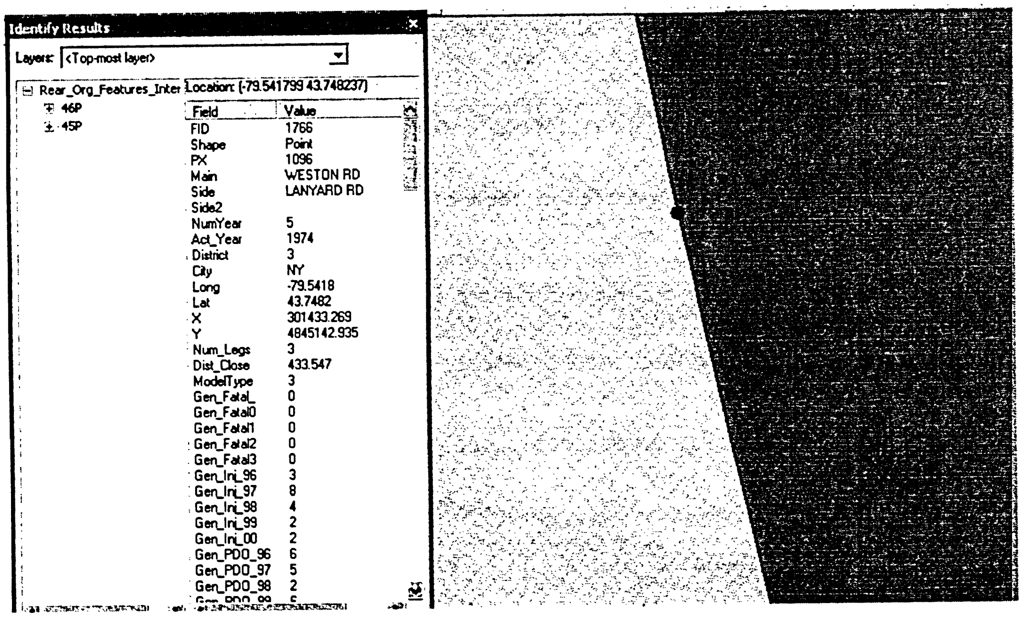


Figure 6.5 The signalized intersection at Western Road and Lanyard Road

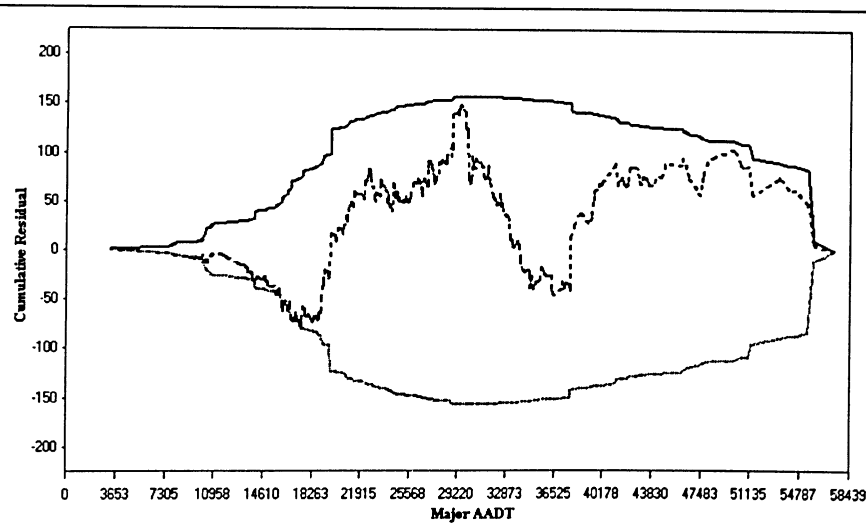
Step 4: After removing the duplicated entries, the database can be imported to the SAS and the GENMOD procedure was run to calibrate the SPF with regional information. The attribute 'region' is defined as a categorical variable; whereas the variable 'major' traffic flow, 'minor' traffic flows and 'region' are used for calibrating rear-end accidents. Different regions have their own alphas (α) but the coefficients

(β_1 and β_2) for 'major' and 'minor' will remain the same. The SPF for rear-end collision at 3-legged signalized intersection is:

$$Acc/yr = \alpha_{(region)} \left(\frac{\text{major}}{1000}\right)^{\beta_1} \left(\frac{\text{minor}}{1000}\right)^{\beta_2} \tag{6.1}$$

where major and minor represent the streets with the higher and lower traffic flows at the intersection respectively

Step 5: By using the CURE plot and overdispersion parameter, verify results of the SPF. When the cumulative residual curve (dotted line) is located within the upper and lower boundaries (solid line), a well-fitted model is expected (as defined in Section 2.2.4.4.). Moreover, a small overdispersion parameter also represents a model is well-fitted to its corresponding accident database. Exhibit 6.1 presents the CURE plot and the overdispersion parameter of the model used in this case study.



Model	FI collision at 3-legged intersection (Rear-end)
Out of range	-
Overdispersion parameter (k)	0.3178

Exhibit 6.1 The validation of SPF for rear-end collision at 3-legged signalized intersection in GTA

Step 6: Since each region has its own alpha (α) and all regions have the same betas (i.e., β_1 and β_2), the regions can be ranked in descending order of alphas to determine which regions have the highest accident potential. This ranking for rear-end collisions at 3-legged signalized intersections is shown in Table 6.4. Figure 6.6 spatially presents the top 5 ranked regions.

Table 6.3 Regional ranking for rear-end collisions at 3-legged signalized intersections

Rank	Region	Alpha
1	48	0.14284
2	46	0.13742
3	45	0.13438
4	49	0.12325
5	56	0.12191
6	47	0.11933
7	53	0.11293
8	54	0.11172
9	52	0.11167
10	57	0.10146
11	55	0.10100
12	51	0.09909
13	43	0.09304
14	59	0.09137
15	50	0.09106
16	58	0.07525
17	42	0.06344
18	44	0.06282
19	60	0.02764
20	41	1.9659E-10

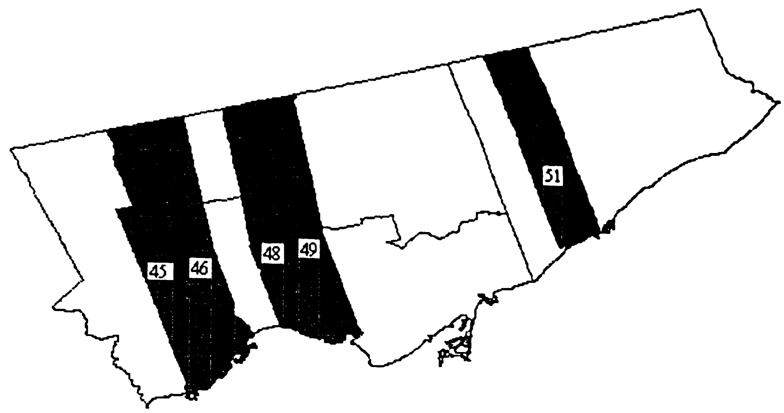


Figure 6.6 Top 5 ranked regions for rear-end collisions at 3-legged signalized intersections

Table 6.3 shows that region 48 has the most rear-end accident at 3-legged signalized intersections when the major and minor traffic flows (as defined in Eq. 6.1) are stable in every region. Region 61 is ignored in this case since there are no 3-legged signalized intersections in this area.

6.3 Combining Potential for Safety Improvement Method and Geographic Information System

The background and sample application of two PSI methods – ranking each entity by the expected accident frequency and by excess accident frequency – have been introduced in Chapter 3 and 5 respectively. By combining PSI methods and GIS, one can give the rankings by regions instead of by sites.

In this section, total angle accidents at 3-legged signalized intersections in Greater Toronto Area (GTA) are utilized as a case study to demonstrate the benefit of regional rankings using expected and excess accident frequencies. The computer software packages ArcGIS 9 is again used in this study.

6.3.1 Ranking Regions by Expected Frequency of Specific Accident Types

The basic idea of ranking regions by expected frequency of a specific accident type is similar to that of ranking of site-specific locations. The step-wise procedure is described in the following:

Step 1: Divide the jurisdiction into several regions for further investigation. For example, the Greater Toronto Area is separated into 158 regions as shown in Figure 6.7.

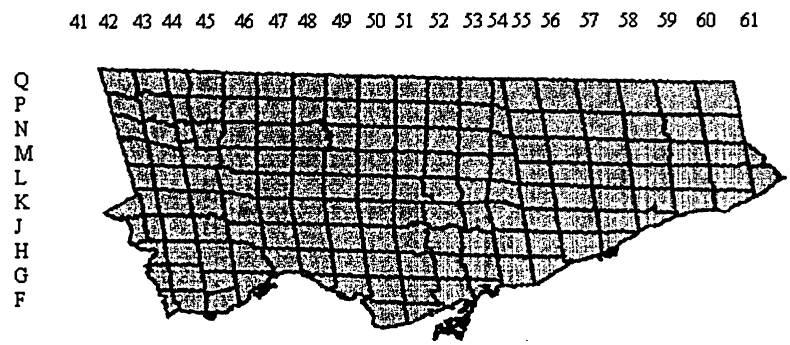


Figure 6.7 Dividing GTA in 158 regions

Step 2: Use the 'Intersect' function in the Overlay option to classify the signalized intersections into their corresponding regions.

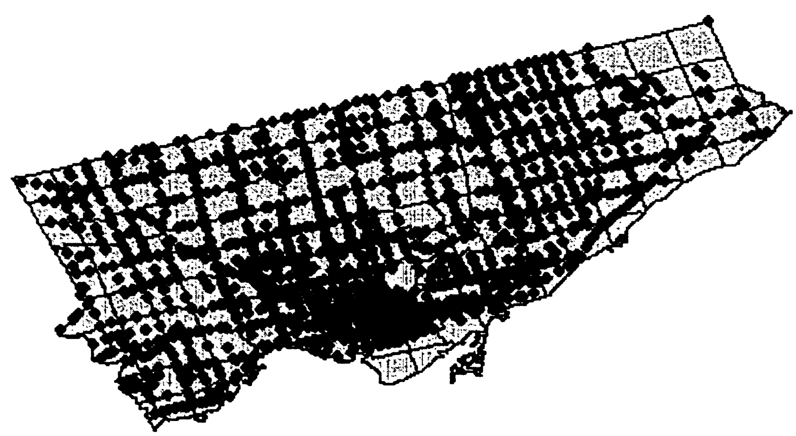


Figure 6.8 Classifying the signalized intersections to different regions

Step 3: Similar to the third step of Section 6.2, some of the intersections are located at the boundary of different regions, and duplicated entries can be found. Thus, one needs to decide which region each of those intersections belongs to.

As done in Section 6.3, the intersections on the boundary of different regions are always designated to the smaller number and in alphabetical order. In the case of the signalized intersection at Western Road and Lanyard Road (Figure 6.5), the intersection should belong to 45P.

Step 4: After removing the duplicated entries, we can export the data to MS Excel and calculate the expected accident frequency of each entity by following the first seven steps in Section 3.2. Table 6.4 shows the top-ten highest ranked entities based on total angle collisions at 3-legged signalized intersections in the GTA

Table 6.4 Ranking by expected accident frequency of total angle collisions at 3-legged signalized intersections

PX	Main	Side	Expected Accident	Region	Rank
1147	BAYVIEW AV	BAYVIEW MEWS LN	8.12	51P	1
1608	UNIVERSITY AV	GERRARD ST	6.72	50H	2
1540	MIDLAND AV	MCNICOLL AV	6.35	56Q	3
0017	CHURCH ST	ADELAIDE ST	5.53	51G	4
1491	STEELES AV	BRIMLEY RD	4.82	56Q	5
0622	REXDALE BL	QUEEN'S PLATE DR	4.54	42N	6
0103	EGLINTON AV	OAKWOOD AV	4.43	49K	7
0274	SPADINA AV	ADELAIDE ST	4.33	50G	8
0614	DUFFERIN ST	ORFUS RD	4.05	49M	9
0822	DON MILLS RD	WYNFORD DR	3.75	53L	10

Step 5: Use the 'Join feature' in ArcGIS to link the entities (Point feature) back to the region layer (Polygon feature) by their common field (Name of the region).

Step 6: Calculate the average expected accident frequency (X_{avg}) in each region.

$$X_{avg} = \frac{\sum X}{n} \tag{6.2}$$

where n is total number of entities in the region and X is the expected accident frequency for each entity in the region.

Figure 6.9 and Table 6.5 present the regional ranking for total angle collision at 3-legged signalized intersections in GTA.

Table 6.5 Regional ranking for total angle collisions at 3-legged signalized intersections

Region	X_{avg}	Regional Rank
42P	3.73	1
42N	2.98	2
56Q	2.66	3
51P	2.42	4
52L	2.38	5
45K	2.31	6
51G	2.21	7
58K	2.00	8
46P	1.97	9
53L	1.91	10

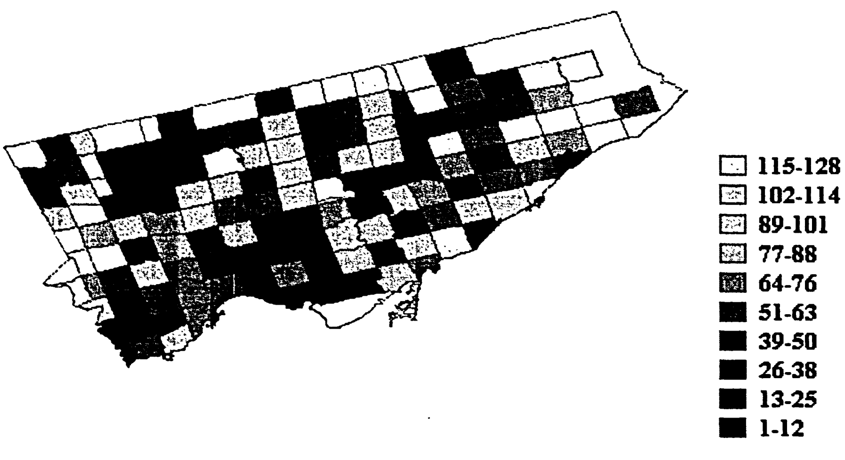


Figure 6.9 Graphical presentation of regional ranking

Of 128 regions containing 3-legged signalized intersections in GTA, region 42P is the highest ranked.

6.3.2 Ranking regions by excess frequency of specific accident types

Excess accident frequency is the difference between every candidate's expected accident frequency and SPF-predicted accident frequency. The procedures for calculating excess accident frequency are similar to calculating expected accident frequency, except that 2 additional steps are required. The detailed information can be found in Section 3.2.

Steps 1 to 3 for ranking the region by excess accident frequency are identical to the first three steps for ranking the region by expected accident frequency in Section 6.3.1. The procedures for Steps 4 to 6 are provided in the following:

Step 4: After removing the duplicated entries, we can export the data to MS Excel and calculate the excess accident frequency of each entity by following the steps in Section 3.2. Table 6.6 shows the top-ten highest ranked entities based on total angle collisions at 3-legged signalized intersections in GTA.

Table 6.6 Ranking by excess accident frequency of total angle collisions at 3-legged signalized intersections

PX	Main	Side	Excess accident	NAME	Rank
1147	BAYVIEW AV	BAYVIEW MEWS LN	5.95	51P	1
1608	UNIVERSITY AV	GERRARD ST	4.55	50H	2
1540	MIDLAND AV	MCNICOLL AV	4.35	56Q	3
0622	REXDALE BL	QUEEN'S PLATE DR	3.15	42N	4
0017	CHURCH ST	ADELAIDE ST	2.71	51G	5
0221	LAKE SHORE BL	STADIUM RD	2.48	49G	6
0103	EGLINTON AV	OAKWOOD AV	2.45	49K	7
0614	DUFFERIN ST	ORFUS RD	2.42	49M	8
0769	ST CLAIR AV	NORTHCLIFFE BL	2.24	49J	9
1491	STEELES AV	BRIMLEY RD	2.21	56Q	10

Step 5: Use the 'Join feature' in ArcGIS to link the intersections (Point feature) back to the region layer (Polygon feature) by their common field (Name of the region).

Step 6: Calculate the average excess accident frequency ($Excess_{avg}$) in each region.

$$Excess_{avg} = \frac{\sum Excess}{n} \tag{6.3}$$

where n is total number of entities in the region and $Excess$ is the excess accident frequency for each entity in the region.

Figure 6.10 and Table 6.7 show the regional ranking graphically and numerically for total angle collision at 3-legged signalized intersections in GTA.

Table 6.7 Regional ranking for total angle collisions (by excess accident frequency)

Region	$Excess_{avg}$	Regional Rank
42N	1.77	1
42P	1.71	2
46P	1.16	3
51P	0.97	4
56Q	0.93	5
45K	0.85	6
45G	0.79	7
47N	0.72	8
43Q	0.66	9
50Q	0.66	10

Figure 6.10 Graphical presentation of regional ranking (by excess accident frequency)

Of 128 regions containing 3-legged signalized intersections in GTA, region 42N is the highest ranked.

6.4 Chapter Summary

Three tools were introduced in this chapter for expanding conventional road network screening to identify regions worthy of a DES at groups of intersections. The level of accident clustering can first be presented by plotting the diagrams of 'accident count profile' and 'accident concentration curve', and the result can be utilized to determine the level of the required accident prevention plan. Then, by combining the techniques of calibrating SPF and GIS, one can perform a quick review to check which region has more potential for improvement of road safety. Finally, combining the Potential for Safety Improvement methods (using expected and excess accident frequencies) and GIS can establish the ranking to find the most 'dangerous' region in a jurisdiction with respect to specific accident types based on specific types of entities.

Chapter 7 Conclusions and Recommendations

In the search for an improved method of road network screening for specific accident types at urban signalized intersections, a case study has been performed, in which 5 years of collision data in the Greater Toronto Area (GTA) have been analyzed. The main screening methods that were presented in this thesis were based on the development of safety performance functions, and the employment of empirical Bayes method, to deal with the regression-to-the-mean situation. An additional screening method was applied to identify intersections with a high proportion of specific accident types.

Safety performance functions (SPFs) were calibrated for fatal and injury (FI) collisions and total collisions for specific accident types (angle, left-turn and rear-end) at signalized intersections in the GTA. In this study, AADT is the only variable considered for the calibration processes. The multivariate SPFs may be considered for the further investigations.

The potential for safety improvement (PSI) methods and screening for high proportions of specific collision types were used to rank the signalized intersections. Then the results from the three methods were applied in combination by placing entities into three detailed engineering study (DES) priority groups to determine which signalized intersections had higher priority for further investigation. The PSI methods have an advantage since these methods do not require the assumption of the mean proportion of a given accident type to be a constant value. Still, we are not able to draw a solid conclusion on which method is the most suitable for network screening by doing additional investigations like the before-after studies.

Accident prevention plans known as a single-site plan, routes plan, area plan and mass action plan were introduced. The distribution of accidents affects the selection of prevention plan. A high level of accident clustering makes the single-site plan the best option. In contrast, the area plan or mass action plan is suitable where there is a lower level of accident clustering.

The integration of conventional network screening technique and geographic information system (GIS) to rank a jurisdiction regionally was also demonstrated. It is possible to use GIS and merge the original accident data with the region maps data for further investigations, including the calibration of SPFs for each region in the jurisdiction and ranking the region by the PSI methods.

It is worthwhile to investigate the capability of GIS in improving road network screening. Since GIS is a system for managing spatial data and associated attributes, the traditional accident data and traffic data can be imported to GIS, which not only informs the engineers about the accident and traffic volume, but also provides an instant vision of the distribution and location of accidents, and even the road design. This may improve the efficiency of network screening and may save costs and efforts.

Appendix A Ranking Sites for Specific Accident Types by Different Screening Methods

A.1 Ranking Sites by PSI Based on Expected Accident Frequency

Table A.1 Ranking based on FI collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
1540	MIDLAND AV	MCNICOLL AV		1	1	1
1608	UNIVERSITY AV	GERRARD ST		2	2	2
1491	STEELES AV	BRIMLEY RD		3	5	6
0890	FINCH AV	WILMINGTON AV		4	3	9
0622	REXDALE BL	QUEEN'S PLATE DR		5	4	7
0017	CHURCH ST	ADELAIDE ST		6	9	3
1244	MCCOWAN RD	NUGGET AV		7	13	22
1246	HWY #27	QUEEN'S PLATE DR		8	8	139
0221	LAKE SHORE BL	STADIUM RD		9	6	5
1147	BAYVIEW AV	BAYVIEW MEWS LN	SPRING GARDEN AV	10	19	37
0588	WESTON RD	SHEPPARD AV		11	15	176
0599	KEELE ST	CALVINGTON DR		12	10	10
0166	UNIVERSITY AV	ARMOURY ST		13	53	25
0147	KINGSTON RD	EGLINTON AV		14	43	33
1310	EVANS AV	GAIR DR		15	7	4
1214	STEELES AV	FOUNDERS RD		16	23	33
0503	LAWRENCE AV	CROCKFORD BL		17	17	35
0957	MARKHAM RD	TUXEDO CT		18	16	72
0346	DANFORTH AV	JONES AV		19	14	110
0226	LAKE SHORE BL	PARKMINOR STREET DR		20	440	84

Table A.2 Ranking based on total collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
1147	BAYVIEW AV	BAYVIEW MEWS LN	SPRING GARDEN AV	1	1	1
1608	UNIVERSITY AV	GERRARD ST		2	2	3
1540	MIDLAND AV	MCNICOLL AV		3	3	2
0017	CHURCH ST	ADELAIDE ST		4	5	5
1491	STEELES AV	BRIMLEY RD		5	10	9
0622	REXDALE BL	QUEEN'S PLATE DR		6	4	8
0103	EGLINTON AV	OAKWOOD AV		7	7	82
0274	SPADINA AV	ADELAIDE ST		8	107	4
0614	DUFFERIN ST	ORFUS RD		9	8	44
0822	DON MILLS RD	WYNFORD DR		10	20	38
0588	WESTON RD	SHEPPARD AV		11	18	339
1246	HWY #27	QUEEN'S PLATE DR		12	14	45
0890	FINCH AV	WILMINGTON AV		13	13	18
0221	LAKE SHORE BL	STADIUM RD		14	6	6
0485	ST CLAIR AV	CHRISTIE ST		15	11	129
1244	MCCOWAN RD	NUGGET AV		16	59	63
0109	AVENUE RD	DUPONT RD		17	27	273
0599	KEELE ST	CALVINGTON DR		18	12	24
0215	LAKE SHORE BL	SPADINA AV		19	440	394
0769	ST CLAIR AV	NORTHCLIFFE - BL		20	9	14

Table A.3 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0033	YONGE ST	RICHMOND ST		1	2	1
1005	LAWRENCE AV	GREENCREST CIR	GREENHOLME CIR	2	1	3
0018	CHURCH ST	RICHMOND ST		3	3	2
0409	LAWRENCE AV	WARDEN AV		4	10	239
1363	STEELES AV	BIRCHMOUNT RD		5	5	68
0079	UNIVERSITY AV	RICHMOND ST		6	12	5
1287	WARDEN AV	MCNICOLL AV		7	7	12
0992	FINCH AV	MARTINGROVE RD		8	6	11
0616	DUFFERIN ST	BRIDGELAND AV	YORKDALE RD	9	13	76
1001	ALBION RD	FINCH AV		10	14	92
0213	LAKE SHORE BL	BAY ST		11	19	8
0731	KIPLING AV	BELFIELD RD		12	15	44
1380	FINCH AV	SANDHURST CIR		13	4	6
1372	MCCOWAN RD	SANDHURST CIR		14	11	7
1590	FINCH AV	YORKGATE DR		15	9	49
0545	QUEEN ST	CARLAW AV		16	8	9
0414	LAWRENCE AV	BRIMLEY RD		17	29	173
0204	LAKE SHORE BL	YORK ST		18	28	87
0416	LAWRENCE AV	BELLAMY RD		19	21	87
0435	DIXON RD	KIPLING AV		20	20	101

Table A.4 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0079	UNIVERSITY AV	RICHMOND ST		1	3	4
0033	YONGE ST	RICHMOND ST		2	1	2
0018	CHURCH ST	RICHMOND ST		3	2	1
0204	LAKE SHORE BL	YORK ST		4	4	14
1541	LAKE SHORE BL	YONGE ST		5	11	36
0214	PARLIAMENT ST	ADELAIDE ST		6	5	3
0416	LAWRENCE AV	BELLAMY RD		7	10	12
0409	LAWRENCE AV	WARDEN AV		8	26	820
0131	STEELES AV	YONGE ST		9	22	1185
0008	JARVIS ST	DUNDAS ST		10	16	34
0810	FINCH AV	SIGNET DR	ARROW RD	11	19	1111
1287	WARDEN AV	MCNICOLL AV		12	13	40
0545	QUEEN ST	CARLAW AV		13	7	5
0063	BAY ST	RICHMOND ST		14	49	35
0437	DIXON RD	MARTINGROVE RD		15	35	886
0495	ST CLAIR AV	JANE ST		16	21	62
1363	STEELES AV	BIRCHMOUNT RD		17	20	130
0224	LAKE SHORE BL	JAMESON AV		18	17	243
0992	FINCH AV	MARTINGROVE RD		19	15	15
0921	YONGE ST	CHARLES ST		20	6	11

Table A.5 Ranking based on FI collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
1246	HWY #27	QUEEN'S PLATE DR		1	1	1
0588	WESTON RD	SHEPPARD AV		2	3	3
0457	EGLINTON AV	SINNOTT RD		3	2	2
1491	STEELES AV	BRIMLEY RD		4	4	4
1608	UNIVERSITY AV	GERRARD ST		5	6	11
0622	REXDALE BL	QUEEN'S PLATE DR		6	5	6
1244	MCCOWAN RD	NUGGET AV		7	16	17
0890	FINCH AV	WILMINGTON AV		8	10	34
0958	WARDEN AV	METROPOLITAN RD		9	9	10
0957	MARKHAM RD	TUXEDO CT		10	8	15
0166	UNIVERSITY AV	ARMOURY ST		11	22	12
1172	JANE ST	EDDYSTONE AV		12	7	17
1540	MIDLAND AV	MCNICOLL AV		13	17	63
0822	DON MILLS RD	WYNFORD DR		14	64	42
1331	QUEEN ST	GLADSTONE AV		15	15	8
0357	DANFORTH RD	DANFORTH AV		16	14	23
1531	KINGSTON RD	RYLANDER BL		17	12	5
1247	SHEPPARD AV	OAKDALE RD		18	11	13
0444	DON MILLS RD	O'CONNOR DR		19	398	77
0723	ALBION RD	ELMHURST AV		20	13	8

Table A.6 Ranking based on total collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0457	EGLINTON AV	SINNOTT RD		1	1	1
1246	HWY #27	QUEEN'S PLATE DR		2	2	2
1608	UNIVERSITY AV	GERRARD ST		3	5	6
0622	REXDALE BL	QUEEN'S PLATE DR		4	3	3
1540	MIDLAND AV	MCNICOLL AV		5	4	7
0588	WESTON RD	SHEPPARD AV		6	19	53
0102	EGLINTON AV	MARLEE AV		7	6	15
1491	STEELES AV	BRIMLEY RD		8	10	14
1329	QUEEN ST	DUFFERIN ST		9	7	24
1331	QUEEN ST	GLADSTONE AV		10	8	8
1619	REXDALE BL	HUMBERWOOD BL		11	9	5
0958	WARDEN AV	METROPOLITAN RD		12	14	9
0822	DON MILLS RD	WYNFORD DR		13	50	41
1244	MCCOWAN RD	NUGGET AV		14	34	31
0485	ST CLAIR AV	CHRISTIE ST		15	12	42
1531	KINGSTON RD	RYLANDER BL		16	11	4
0103	EGLINTON AV	OAKWOOD AV		17	24	117
1566	FINCH AV	MILLIKEN BL		18	18	16
1214	STEELES AV	FOUNDERS RD		19	29	10
0723	ALBION RD	ELMHURST AV		20	13	20

Table A.7 Ranking based on FI collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0420	LAWRENCE AV	MARKHAM RD		1	1	14
0626	DON MILLS RD	YORK MILLS RD		2	8	3
0878	MARKHAM RD	PROGRESS AV		3	7	9
0458	EGLINTON AV	BIRCHMOUNT RD		4	4	4
0454	EGLINTON AV	DON MILLS RD		5	48	6
0437	DIXON RD	MARTINGROVE RD		6	3	6
0652	STEELES AV	BAYVIEW AV		7	15	2
0380	MCCOWAN RD	LAWRENCE AV		8	6	16
1363	STEELES AV	BIRCHMOUNT RD		9	2	5
0702	ELLESMERE RD	MARKHAM RD		10	9	10
0917	THE QUEENSWAY	NORTH QUEEN ST		11	5	1
0627	SHEPPARD AV	DON MILLS RD		12	14	11
0409	LAWRENCE AV	WARDEN AV		13	11	27
0534	FINCH AV	JANE ST		14	10	41
0602	STEELES AV	KEELE ST		15	20	13
1191	STEELES AV	WARDEN AV		16	55	17
0412	LAWRENCE AV	KENNEDY RD		17	38	22
0407	LAWRENCE AV	VICTORIA PARK AV		18	26	44
0452	EGLINTON AV	PHARMACY AV		19	13	15
0131	STEELES AV	YONGE ST		20	147	34

Table A.8 Ranking based on total collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0380	MCCOWAN RD	LAWRENCE AV		1	1	2
0619	STEELES AV	DUFFERIN ST		2	33	4
1191	STEELES AV	WARDEN AV		3	14	3
0810	FINCH AV	SIGNET DR	ARROW RD	4	3	11
0878	MARKHAM RD	PROGRESS AV		5	8	5
0917	THE QUEENSWAY	NORTH QUEEN ST		6	2	1
0131	STEELES AV	YONGE ST		7	57	38
0534	FINCH AV	JANE ST		8	7	32
0420	LAWRENCE AV	MARKHAM RD		9	4	15
0412	LAWRENCE AV	KENNEDY RD		10	25	12
0602	STEELES AV	KEELE ST		11	18	10
0407	LAWRENCE AV	VICTORIA PARK AV		12	17	28
0454	EGLINTON AV	DON MILLS RD		13	138	24
0702	ELLESMERE RD	MARKHAM RD		14	15	20
0437	DIXON RD	MARTINGROVE RD		15	5	16
0748	VICTORIA PARK AV	SHEPPARD AV		16	32	9
0652	STEELES AV	BAYVIEW AV		17	55	7
0744	LESLIE ST	SHEPPARD AV		18	154	60
0460	EGLINTON AV	KENNEDY RD		19	51	37
0627	SHEPPARD AV	DON MILLS RD		20	40	31

Table A.9 Ranking based on FI collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
0390	DAVENPORT RD	CALEDONIA RD		1	1	55
0453	EGLINTON AV	LESLIE ST		2	21	9
0446	O'CONNOR DR	WOODBINE AV		3	3	6
0588	WESTON RD	SHEPPARD AV		4	2	209
0252	PARLIAMENT ST	BLOOR ST		5	5	3
0215	LAKE SHORE BL	SPADINA AV		6	139	13
0682	LAIRD DR	MILLWOOD RD		7	7	135
0346	DANFORTH AV	JONES AV		8	6	43
1002	FINCH AV	TOBERMORY DR		9	4	4
1260	STEELES AV	MIDLAND AV		10	26	114
0822	DON MILLS RD	WYNFORD DR		11	22	156
1379	BAYVIEW AV	POTTERY RD		12	17	85
0643	BAYVIEW AV	POST RD		13	50	336
0395	WESTON RD	ROGERS RD		14	34	33
1321	KIPLING AV	BLOOR ST		15	66	229
0282	BAYVIEW AV	ROSEDALE VALLEY RD		16	37	336
0099	EGLINTON AV	SPADINA RD		17	24	7
0102	EGLINTON AV	MARLEE AV		18	14	123
1663	FINCH AV	JAYZEL DR		19	9	23
0226	LAKE SHORE BL	PARKMINOR STREET DR		20	439	81

Table A.10 Ranking based on total collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0446	O'CONNOR DR	WOODBINE AV		1	4	4
0390	DAVENPORT RD	CALEDONIA RD		2	1	1
0453	EGLINTON AV	LESLIE ST		3	2	9
0682	LAIRD DR	MILLWOOD RD		4	10	16
0395	WESTON RD	ROGERS RD		5	8	11
1004	LAWRENCE AV	SHERMOUNT AV		6	28	34
1360	DAWES RD	CRESCENT TOWN RD		7	29	25
0252	PARLIAMENT ST	BLOOR ST		8	12	38
0415	LAWRENCE AV	BARRYMORE RD		9	68	63
0496	DUNDAS ST	SCARLETT RD		10	22	14
1680	O'CONNOR DR	CURITY AV		11	123	93
0588	WESTON RD	SHEPPARD AV		12	3	2
0505	BATHURST ST	AVA RD		13	122	101
1353	DON MILLS RD	MOATFIELD DR		14	58	54
1008	JANE ST	GILTSPUR DR		15	100	56
0822	DON MILLS RD	WYNFORD DR		16	6	10
0159	KINGSTON RD	BEECH AV		17	165	174
1002	FINCH AV	TOBERMORY DR		18	7	3
1556	STEELES AV	CONACHER DR		19	134	92
1033	LAWRENCE AV	BENNETT RD		20	211	117

Table A.11 Ranking based on FI collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0618	DUFFERIN ST	FINCH AV		2	4	2
0752	KENNEDY RD	SHEPPARD AV		3	2	3
0694	ELLESMERE RD	WARDEN AV		4	3	5
0744	LESLIE ST	SHEPPARD AV		5	7	6
0675	BATHURST ST	FINCH AV		6	5	10
0456	EGLINTON AV	WARDEN AV		7	10	4
1192	STEELES AV	KENNEDY RD		8	6	11
0407	LAWRENCE AV	VICTORIA PARK AV		9	9	18
0589	WESTON RD	FINCH AV		10	8	13
0696	ELLESMERE RD	KENNEDY RD		11	21	8
0460	EGLINTON AV	KENNEDY RD		12	15	19
1407	ALLEN RD	SHEPPARD AV		13	167	27
0938	MCCOWAN RD	SHEPPARD AV		14	22	22
0878	MARKHAM RD	PROGRESS AV		15	19	52
0412	LAWRENCE AV	KENNEDY RD		16	28	31
0454	EGLINTON AV	DON MILLS RD		17	86	41
0420	LAWRENCE AV	MARKHAM RD		18	12	297
0128	YONGE ST	FINCH AV		19	31	59
0650	BAYVIEW AV	FINCH AV		20	29	15

Table A.12 Ranking based on total collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Expected Accident	Excess Accident	High Proportion
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0618	DUFFERIN ST	FINCH AV		2	2	1
0744	LESLIE ST	SHEPPARD AV		3	5	1
0694	ELLESMERE RD	WARDEN AV		4	3	1
0752	KENNEDY RD	SHEPPARD AV		5	4	6
0675	BATHURST ST	FINCH AV		6	6	5
0407	LAWRENCE AV	VICTORIA PARK AV		7	8	11
0589	WESTON RD	FINCH AV		8	7	13
0696	ELLESMERE RD	KENNEDY RD		9	14	12
0128	YONGE ST	FINCH AV		10	11	27
1407	ALLEN RD	SHEPPARD AV		11	94	10
0428	KEELE ST	LAWRENCE AV		12	9	20
1192	STEELES AV	KENNEDY RD		13	10	18
0454	EGLINTON AV	DON MILLS RD		14	83	16
0938	MCCOWAN RD	SHEPPARD AV		15	24	31
1191	STEELES AV	WARDEN AV		16	56	22
0678	STEELES AV	BATHURST ST		17	36	35
0412	LAWRENCE AV	KENNEDY RD		18	54	26
0602	STEELES AV	KEELE ST		19	44	28
0532	WILSON AV	JANE ST		20	15	33

A.2 Ranking Sites by PSI Based on Excess Accident Frequency

Table A.13 Ranking based on FI collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1540	MIDLAND AV	MCNICOLL AV		1	1	1
1608	UNIVERSITY AV	GERRARD ST		2	2	2
0890	FINCH AV	WILMINGTON AV		3	4	9
0622	REXDALE BL	QUEEN'S PLATE DR		4	5	7
1491	STEELES AV	BRIMLEY RD		5	3	6
0221	LAKE SHORE BL	STADIUM RD		6	9	5
1310	EVANS AV	GAIR DR		7	15	4
1246	HWY #27	QUEEN'S PLATE DR		8	8	139
0017	CHURCH ST	ADELAIDE ST		9	6	3
0599	KEELE ST	CALVINGTON DR		10	12	10
0194	ST CLAIR AV	EARLSCOURT AV		11	33	19
1663	FINCH AV	JAYZEL DR		12	21	44
1244	MCCOWAN RD	NUGGET AV		13	7	22
0346	DANFORTH AV	JONES AV		14	19	110
0588	WESTON RD	SHEPPARD AV		15	11	176
0957	MARKHAM RD	TUXEDO CT		16	18	72
0503	LAWRENCE AV	CROCKFORD BL		17	17	35
1255	KEELE ST	WHITBURN CR		18	46	41
1147	BAYVIEW AV	BAYVIEW MEWS LN	SPRING GARDEN AV	19	10	37
1068	KEELE ST	JUNCTION RD		20	42	56

Table A.14 Ranking based on total collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1147	BAYVIEW AV	BAYVIEW MEWS LN	SPRING GARDEN AV	1	1	1
1608	UNIVERSITY AV	GERRARD ST		2	2	3
1540	MIDLAND AV	MCNICOLL AV		3	3	2
0622	REXDALE BL	QUEEN'S PLATE DR		4	6	8
0017	CHURCH ST	ADELAIDE ST		5	4	5
0221	LAKE SHORE BL	STADIUM RD		6	14	6
0103	EGLINTON AV	OAKWOOD AV		7	7	82
0614	DUFFERIN ST	ORFUS RD		8	9	44
0769	ST CLAIR AV	NORTHCLIFFE BL		9	20	14
1491	STEELES AV	BRIMLEY RD		10	5	9
0485	ST CLAIR AV	CHRISTIE ST		11	15	129
0599	KEELE ST	CALVINGTON DR		12	18	24
0890	FINCH AV	WILMINGTON AV		13	13	18
1246	HWY #27	QUEEN'S PLATE DR		14	12	45
0570	THE QUEENSWAY	ATOMIC AV		15	22	10
0194	ST CLAIR AV	EARLSCOURT AV		16	47	22
0489	ST CLAIR AV	LANSDOWNE AV		17	29	136
0588	WESTON RD	SHEPPARD AV		18	11	339
1663	FINCH AV	JAYZEL DR		19	38	88
0822	DON MILLS RD	WYNFORD DR		20	10	38

Table A.15 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1005	LAWRENCE AV	GREENCREST CIR	GREENHOLME CIR	1	2	3
0033	YONGE ST	RICHMOND ST		2	1	1
0018	CHURCH ST	RICHMOND ST		3	3	2
1380	FINCH AV	SANDHURST CIR		4	13	6
1363	STEELES AV	BIRCHMOUNT RD		5	5	68
0992	FINCH AV	MARTINGROVE RD		6	8	11
1287	WARDEN AV	MCNICOLL AV		7	7	12
0545	QUEEN ST	CARLAW AV		8	16	9
1590	FINCH AV	YORKGATE DR		9	15	49
0409	LAWRENCE AV	WARDEN AV		10	4	239
1372	MCCOWAN RD	SANDHURST CIR		11	14	7
0079	UNIVERSITY AV	RICHMOND ST		12	6	5
0616	DUFFERIN ST	BRIDGELAND AV	YORKDALE RD	13	9	76
1001	ALBION RD	FINCH AV		14	10	92
0731	KIPLING AV	BELFIELD RD		15	12	44
1510	BRIMLEY RD	MCNICOLL AV		16	25	58
0214	PARLIAMENT ST	ADELAIDE ST		17	24	4
0921	YONGE ST	CHARLES ST		18	37	28
0213	LAKE SHORE BL	BAY ST		19	11	8
0435	DIXON RD	KIPLING AV		20	20	101

Table A.16 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0033	YONGE ST	RICHMOND ST		1	2	2
0018	CHURCH ST	RICHMOND ST		2	3	1
0079	UNIVERSITY AV	RICHMOND ST		3	1	4
0204	LAKE SHORE BL	YORK ST		4	4	14
0214	PARLIAMENT ST	ADELAIDE ST		5	6	3
0921	YONGE ST	CHARLES ST		6	20	11
0545	QUEEN ST	CARLAW AV		7	13	5
1005	LAWRENCE AV	GREENCREST CIR	GREENHOLME CIR	8	33	7
1380	FINCH AV	SANDHURST CIR		9	47	23
0416	LAWRENCE AV	BELLAMY RD		10	7	12
1541	LAKE SHORE BL	YONGE ST		11	5	36
0419	LAWRENCE AV	GREENCEDAR CIR	GREENBRAE CIR	12	36	6
1287	WARDEN AV	MCNICOLL AV		13	12	40
0039	YONGE ST	WELLESLEY ST		14	25	29
0992	FINCH AV	MARTINGROVE RD		15	19	15
0008	JARVIS ST	DUNDAS ST		16	10	34
0224	LAKE SHORE BL	JAMESON AV		17	18	243
1590	FINCH AV	YORKGATE DR		18	46	145
0810	FINCH AV	SIGNET DR	ARROW RD	19	11	1111
1363	STEELES AV	BIRCHMOUNT RD		20	17	130

Table A.17 Ranking based on FI collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1246	HWY #27	QUEEN'S PLATE DR		1	1	1
0457	EGLINTON AV	SINNOTT RD		2	3	2
0588	WESTON RD	SHEPPARD AV		3	2	3
1491	STEELES AV	BRIMLEY RD		4	4	4
0622	REXDALE BL	QUEEN'S PLATE DR		5	6	6
1608	UNIVERSITY AV	GERRARD ST		6	5	11
1172	JANE ST	EDDYSTONE AV		7	12	17
0957	MARKHAM RD	TUXEDO CT		8	10	15
0958	WARDEN AV	METROPOLITAN RD		9	9	10
0890	FINCH AV	WILMINGTON AV		10	8	34
1247	SHEPPARD AV	OAKDALE RD		11	18	13
1531	KINGSTON RD	RYLANDER BL		12	17	5
0723	ALBION RD	ELMHURST AV		13	20	8
0357	DANFORTH RD	DANFORTH AV		14	16	23
1331	QUEEN ST	GLADSTONE AV		15	15	8
1244	MCCOWAN RD	NUGGET AV		16	7	17
1540	MIDLAND AV	MCNICOLL AV		17	13	63
1619	REXDALE BL	HUMBERWOOD BL		18	26	7
1130	WILSON AV	WENDELL AV		19	22	14
0347	DANFORTH AV	DONLANDS AV		20	33	21

Table A.18 Ranking based on total collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0457	EGLINTON AV	SINNOTT RD		1	1	1
1246	HWY #27	QUEEN'S PLATE DR		2	2	2
0622	REXDALE BL	QUEEN'S PLATE DR		3	4	3
1540	MIDLAND AV	MCNICOLL AV		4	5	7
1608	UNIVERSITY AV	GERRARD ST		5	3	6
0102	EGLINTON AV	MARLEE AV		6	7	15
1329	QUEEN ST	DUFFERIN ST		7	9	24
1331	QUEEN ST	GLADSTONE AV		8	10	8
1619	REXDALE BL	HUMBERWOOD BL		9	11	5
1491	STEELES AV	BRIMLEY RD		10	8	14
1531	KINGSTON RD	RYLANDER BL		11	16	4
0485	ST CLAIR AV	CHRISTIE ST		12	15	42
0723	ALBION RD	ELMHURST AV		13	20	20
0958	WARDEN AV	METROPOLITAN RD		14	12	9
1172	JANE ST	EDDYSTONE AV		15	22	51
0769	ST CLAIR AV	NORTHCLIFFE BL		16	33	27
1427	SHEPPARD AV	SENTINEL RD		17	26	11
1566	FINCH AV	MILLIKEN BL		18	18	16
0588	WESTON RD	SHEPPARD AV		19	6	53
1467	STEELES AV	CACTUS AV		20	29	12

Table A.19 Ranking based on FI collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0420	LAWRENCE AV	MARKHAM RD		1	1	14
1363	STEELES AV	BIRCHMOUNT RD		2	9	5
0437	DIXON RD	MARTINGROVE RD		3	6	6
0458	EGLINTON AV	BIRCHMOUNT RD		4	4	4
0917	THE QUEENSWAY	NORTH QUEEN ST		5	11	1
0380	MCCOWAN RD	LAWRENCE AV		6	8	16
0878	MARKHAM RD	PROGRESS AV		7	3	9
0626	DON MILLS RD	YORK MILLS RD		8	2	3
0702	ELLESMERE RD	MARKHAM RD		9	10	10
0534	FINCH AV	JANE ST		10	14	41
0409	LAWRENCE AV	WARDEN AV		11	13	27
0462	EGLINTON AV	BRIMLEY RD		12	27	25
0452	EGLINTON AV	PHARMACY AV		13	19	15
0627	SHEPPARD AV	DON MILLS RD		14	12	11
0652	STEELES AV	BAYVIEW AV		15	7	2
0734	ALBION RD	KIPLING AV		16	42	26
1413	BIRCHMOUNT RD	MCNICOLL AV		17	55	33
0947	FINCH AV	ISLINGTON AV		18	35	35
0629	DON MILLS RD	ESTERBROOKE AV	FAIRVIEW MALL DR	19	53	21
0602	STEELES AV	KEELE ST		20	15	13

Table A.20 Ranking based on total collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0380	MCCOWAN RD	LAWRENCE AV		1	1	2
0917	THE QUEENSWAY	NORTH QUEEN ST		2	6	1
0810	FINCH AV	SIGNET DR	ARROW RD	3	4	11
0420	LAWRENCE AV	MARKHAM RD		4	9	15
0437	DIXON RD	MARTINGROVE RD		5	15	16
1363	STEELES AV	BIRCHMOUNT RD		6	25	8
0534	FINCH AV	JANE ST		7	8	32
0878	MARKHAM RD	PROGRESS AV		8	5	5
0869	FINCH AV	DON MILLS RD		9	23	25
0479	ST CLAIR AV	SPADINA AV		10	48	19
0731	KIPLING AV	BELFIELD RD		11	34	14
0301	EASTERN AV	COXWELL AV		12	67	13
0462	EGLINTON AV	BRIMLEY RD		13	33	21
1191	STEELES AV	WARDEN AV		14	3	3
0702	ELLESMERE RD	MARKHAM RD		15	14	20
0734	ALBION RD	KIPLING AV		16	46	29
0407	LAWRENCE AV	VICTORIA PARK AV		17	12	28
0602	STEELES AV	KEELE ST		18	11	10
1072	BRIMLEY RD	PROGRESS AV		19	36	18
1287	WARDEN AV	MCNICOLL AV		20	57	41

Table A.21 Ranking based on FI collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0390	DAVENPORT RD	CALEDONIA RD		1	1	55
0588	WESTON RD	SHEPPARD AV		2	4	209
0446	O'CONNOR DR	WOODBINE AV		3	3	6
1002	FINCH AV	TOBERMORY DR		4	9	4
0252	PARLIAMENT ST	BLOOR ST		5	5	3
0346	DANFORTH AV	JONES AV		6	8	43
0682	LAIRD DR	MILLWOOD RD		7	7	135
0965	LESLIE ST	NYMARK AV		8	29	188
1663	FINCH AV	JAYZEL DR		9	19	23
0640	DUNDAS ST	SORAUREN AV		10	27	1
0342	DANFORTH AV	CHESTER AV		11	38	90
1172	JANE ST	EDDYSTONE AV		12	26	444
0357	DANFORTH RD	DANFORTH AV		13	25	27
0102	EGLINTON AV	MARLEE AV		14	18	123
1353	DON MILLS RD	MOATFIELD DR		15	24	431
1330	QUEEN ST	DUNN AV		16	41	15
1379	BAYVIEW AV	POTTERY RD		17	12	85
0387	DAVENPORT RD	OAKWOOD AV		18	23	152
0525	JANE ST	ALLIANCE AV		19	33	439
1074	EGLINTON AV	GLENHOLME AV		20	40	18

Table A.22 Ranking based on total collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
0390	DAVENPORT RD	CALEDONIA RD		1	1	2
0588	WESTON RD	SHEPPARD AV		2	3	12
1002	FINCH AV	TOBERMORY DR		3	7	18
0446	O'CONNOR DR	WOODBINE AV		4	4	1
1172	JANE ST	EDDYSTONE AV		5	15	75
0387	DAVENPORT RD	OAKWOOD AV		6	14	116
1329	QUEEN ST	DUFFERIN ST		7	20	335
0102	EGLINTON AV	MARLEE AV		8	13	230
0453	EGLINTON AV	LESLIE ST		9	2	3
0822	DON MILLS RD	WYNFORD DR		10	6	16
0395	WESTON RD	ROGERS RD		11	8	5
0525	JANE ST	ALLIANCE AV		12	31	57
0614	DUFFERIN ST	ORFUS RD		13	19	335
0496	DUNDAS ST	SCARLETT RD		14	22	10
1663	FINCH AV	JAYZEL DR		15	30	93
0682	LAIRD DR	MILLWOOD RD		16	10	4
0723	ALBION RD	ELMHURST AV		17	41	210
0103	EGLINTON AV	OAKWOOD AV		18	18	414
0640	DUNDAS ST	SORAUREN AV		19	45	44
0599	KEELE ST	CALVINGTON DR		20	25	89

Table A.23 Ranking based on FI collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0752	KENNEDY RD	SHEPPARD AV		2	3	3
0694	ELLESMERE RD	WARDEN AV		3	4	5
0618	DUFFERIN ST	FINCH AV		4	2	2
0675	BATHURST ST	FINCH AV		5	6	10
1192	STEELES AV	KENNEDY RD		6	8	11
0744	LESLIE ST	SHEPPARD AV		7	5	6
0589	WESTON RD	FINCH AV		8	10	13
0407	LAWRENCE AV	VICTORIA PARK AV		9	9	18
0456	EGLINTON AV	WARDEN AV		10	7	4
1420	BLACK CREEK DR	TRETHEWEY DR		11	23	7
0420	LAWRENCE AV	MARKHAM RD		12	18	297
0532	WILSON AV	JANE ST		13	22	25
0294	DANFORTH AV	BROADVIEW AV		14	42	33
0460	EGLINTON AV	KENNEDY RD		15	12	19
0325	BLOOR ST	DUFFERIN ST		16	50	130
0461	EGLINTON AV	MIDLAND AV		17	21	34
0431	WESTON RD	LAWRENCE AV		18	58	39
0878	MARKHAM RD	PROGRESS AV		19	15	52
1162	HWY #27	HUMBER COLLEGE BL		20	41	9

Table A.24 Ranking based on total collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	Excess Accident	Expected Accident	High Proportion
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0618	DUFFERIN ST	FINCH AV		2	2	1
0694	ELLESMERE RD	WARDEN AV		3	4	1
0752	KENNEDY RD	SHEPPARD AV		4	5	6
0744	LESLIE ST	SHEPPARD AV		5	3	1
0675	BATHURST ST	FINCH AV		6	6	5
0589	WESTON RD	FINCH AV		7	8	13
0407	LAWRENCE AV	VICTORIA PARK AV		8	7	11
0428	KEELE ST	LAWRENCE AV		9	12	20
1192	STEELES AV	KENNEDY RD		10	13	18
0128	YONGE ST	FINCH AV		11	10	27
1420	BLACK CREEK DR	TRETHEWEY DR		12	27	7
0325	BLOOR ST	DUFFERIN ST		13	60	167
0696	ELLESMERE RD	KENNEDY RD		14	9	12
0532	WILSON AV	JANE ST		15	20	33
0294	DANFORTH AV	BROADVIEW AV		16	56	53
1162	HWY #27	HUMBER COLLEGE BL		17	48	8
0431	WESTON RD	LAWRENCE AV		18	72	89
1138	FINCH AV	BIRCHMOUNT RD		19	45	23
0100	EGLINTON AV	BATHURST ST		20	25	74

A-3 Ranking Sites by High Proportion Methods

Table A.25 Ranking based on FI collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
1540	MIDLAND AV	MCNICOLL AV		1	1	1
1608	UNIVERSITY AV	GERRARD ST		2	2	2
0017	CHURCH ST	ADELAIDE ST		3	6	9
1310	EVANS AV	GAIR DR		4	15	7
0221	LAKE SHORE BL	STADIUM RD		5	9	6
1491	STEELES AV	BRIMLEY RD		6	3	5
0622	REXDALE BL	QUEEN'S PLATE DR		7	5	4
0892	EVANS AV	THE EAST MALL		8	34	27
0890	FINCH AV	WILMINGTON AV		9	4	3
0599	KEELE ST	CALVINGTON DR		10	12	10
1489	WELLINGTON ST	JOHN ST		11	37	24
0820	LAKE SHORE BL	CHERRY ST		12	38	22
0436	DIXON RD	CELESTINE DR		13	65	38
1282	BRIMLEY RD	DORCOT AV		13	78	37
0598	KEELE ST	TILBURY DR		15	36	25
0762	BROWNS LINE	VALERMO DR		16	56	49
0968	AVENUE RD	YORKVILLE AV		16	48	121
1505	KING ST	DUNN AV		16	63	40
0194	ST CLAIR AV	EARLSCOURT AV		19	33	11
0858	LAWRENCE AV	ORTON PK RD		20	30	30
1568	SHEPPARD AV	MALVERN ST	PROGRESS AV	20	40	21

Table A.26 Ranking based on total collisions (angle) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
1147	BAYVIEW AV	BAYVIEW MEWS LN	SPRING GARDEN AV	1	1	1
1540	MIDLAND AV	MCNICOLL AV		2	3	3
1608	UNIVERSITY AV	GERRARD ST		3	2	2
0274	SPADINA AV	ADELAIDE ST		4	8	107
0017	CHURCH ST	ADELAIDE ST		5	4	5
0221	LAKE SHORE BL	STADIUM RD		6	14	6
1489	WELLINGTON ST	JOHN ST		7	28	25
0622	REXDALE BL	QUEEN'S PLATE DR		8	6	4
1491	STEELES AV	BRIMLEY RD		9	5	10
0570	THE QUEENSWAY	ATOMIC AV		10	22	15
1691	QUEEN ST	YORK ST		11	36	24
0758	VICTORIA PARK AV	HWY #401		12	41	254
1404	ST CLAIR AV	GUNNS RD		13	25	33
0769	ST CLAIR AV	NORTHCLIFFE BL		14	20	9
1310	EVANS AV	GAIR DR		15	97	79
0218	LAKE SHORE BL	BURLINGTON ST		16	78	23
0005	JARVIS ST	RICHMOND ST		17	31	256
0890	FINCH AV	WILMINGTON AV		18	13	13
0825	COLLEGE ST	MCCAUL ST		19	51	51
0166	UNIVERSITY AV	ARMOURY ST		20	23	87

Table A.27 Ranking based on FI collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0033	YONGE ST	RICHMOND ST		1	1	2
0018	CHURCH ST	RICHMOND ST		2	3	3
1005	LAWRENCE AV	GREENCREST CIR	GREENHOLME CIR	3	2	1
0214	PARLIAMENT ST	ADELAIDE ST		4	24	17
0079	UNIVERSITY AV	RICHMOND ST		5	6	12
1380	FINCH AV	SANDHURST CIR		6	13	4
1372	MCCOWAN RD	SANDHURST CIR		7	14	11
0213	LAKE SHORE BL	BAY ST		8	11	19
0545	QUEEN ST	CARLAW AV		9	16	8
0223	PARLIAMENT ST	RICHMOND ST		10	34	33
0992	FINCH AV	MARTINGROVE RD		11	8	6
1287	WARDEN AV	MCNICOLL AV		12	7	7
0247	PARLIAMENT ST	SHUTER ST		13	45	32
0476	ST CLAIR AV	MIDLAND AV		14	118	74
1056	THE EAST MALL	NORTH QUEEN ST		15	150	81
0419	LAWRENCE AV	GREENCEDAR CIR	GREENBRAE CIR	16	46	31
0078	UNIVERSITY AV	ADELAIDE ST		17	51	79
0690	WARDEN AV	COMSTOCK RD		18	89	49
1275	DUNDAS ST	SHAW ST		18	91	43
0392	DANFORTH RD	ST CLAIR AV		20	41	46
0987	BIRCHMOUNT RD	HUNTINGWOOD DR		20	44	34

Table A.28 Ranking based on total collisions (angle) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0018	CHURCH ST	RICHMOND ST		1	3	2
0033	YONGE ST	RICHMOND ST		2	2	1
0214	PARLIAMENT ST	ADELAIDE ST		3	6	5
0079	UNIVERSITY AV	RICHMOND ST		4	1	3
0545	QUEEN ST	CARLAW AV		5	13	7
0419	LAWRENCE AV	GREENCEDAR CIR	GREENBRAE CIR	6	36	12
1005	LAWRENCE AV	GREENCREST CIR	GREENHOLME CIR	7	33	8
0019	CHURCH ST	QUEEN ST		8	35	24
0886	BIRCHMOUNT RD	BERTRAND AV		9	210	67
1359	KIPLING AV	WIDDICOMBE HILL BL		10	323	73
0921	YONGE ST	CHARLES ST		11	20	6
0416	LAWRENCE AV	BELLAMY RD		12	7	10
0223	PARLIAMENT ST	RICHMOND ST		13	57	39
0204	LAKE SHORE BL	YORK ST		14	4	4
0992	FINCH AV	MARTINGROVE RD		15	19	15
0245	PARLIAMENT ST	KING ST		16	175	77
0198	ADELAIDE ST	SIMCOE ST		17	205	99
0476	ST CLAIR AV	MIDLAND AV		18	371	319
1241	PHARMACY AV	MCNICOLL AV		19	65	42
1377	WARDEN AV	ASHTONBEE RD		20	77	29

Table A.29 Ranking based on FI collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accdient	Excess Accident
1246	HWY #27	QUEEN'S PLATE DR		1	1	1
0457	EGLINTON AV	SINNOTT RD		2	3	2
0588	WESTON RD	SHEPPARD AV		3	2	3
1491	STEELES AV	BRIMLEY RD		4	4	4
1531	KINGSTON RD	RYLANDER BL		5	17	12
0622	REXDALE BL	QUEEN'S PLATE DR		6	6	5
1619	REXDALE BL	HUMBERWOOD BL		7	26	18
0723	ALBION RD	ELMHURST AV		8	20	13
1331	QUEEN ST	GLADSTONE AV		8	15	15
0958	WARDEN AV	METROPOLITAN RD		10	9	9
1608	UNIVERSITY AV	GERRARD ST		11	5	6
0166	UNIVERSITY AV	ARMOURY ST		12	11	22
1247	SHEPPARD AV	OAKDALE RD		13	18	11
1130	WILSON AV	WENDELL AV		14	22	19
0957	MARKHAM RD	TUXEDO CT		15	10	8
1467	STEELES AV	CACTUS AV		16	40	25
1172	JANE ST	EDDYSTONE AV		17	12	7
1244	MCCOWAN RD	NUGGET AV		17	7	15
0812	FINCH AV	SENLAC RD		19	25	39
0563	THE QUEENSWAY	STEPHEN DR		20	41	24

Table A.30 Ranking based on total collisions (left-turn) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0457	EGLINTON AV	SINNOTT RD		1	1	1
1246	HWY #27	QUEEN'S PLATE DR		2	2	2
0622	REXDALE BL	QUEEN'S PLATE DR		3	4	3
1531	KINGSTON RD	RYLANDER BL		4	16	11
1619	REXDALE BL	HUMBERWOOD BL		5	11	9
1608	UNIVERSITY AV	GERRARD ST		6	3	5
1540	MIDLAND AV	MCNICOLL AV		7	5	4
1331	QUEEN ST	GLADSTONE AV		8	10	8
0958	WARDEN AV	METROPOLITAN RD		9	12	14
1214	STEELES AV	FOUNDERS RD		10	19	29
1427	SHEPPARD AV	SENTINEL RD		11	26	17
1467	STEELES AV	CACTUS AV		12	29	20
1756	KENNEDY RD	COWDRAY CT		13	44	41
1491	STEELES AV	BRIMLEY RD		14	8	10
0102	EGLINTON AV	MARLEE AV		15	7	6
1566	FINCH AV	MILLIKEN BL		16	18	18
0415	LAWRENCE AV	BARRYMORE RD		17	58	38
0026	ADELAIDE ST	VICTORIA ST		18	24	25
0812	FINCH AV	SENLAC RD		19	41	60
0723	ALBION RD	ELMHURST AV		20	20	13

Table A.31 Ranking based on FI collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0917	THE QUEENSWAY	NORTH QUEEN ST		1	11	5
0652	STEELES AV	BAYVIEW AV		2	7	15
0626	DON MILLS RD	YORK MILLS RD		3	2	8
0458	EGLINTON AV	BIRCHMOUNT RD		4	4	4
1363	STEELES AV	BIRCHMOUNT RD		5	9	2
0454	EGLINTON AV	DON MILLS RD		6	5	48
0437	DIXON RD	MARTINGROVE RD		6	6	3
0912	THE QUEENSWAY	THE WEST MALL		8	32	29
0878	MARKHAM RD	PROGRESS AV		9	3	7
0702	ELLESMERE RD	MARKHAM RD		10	10	9
0627	SHEPPARD AV	DON MILLS RD		11	12	14
0904	THE EAST MALL	EAST MALL CR		12	95	34
0602	STEELES AV	KEELE ST		13	15	20
0420	LAWRENCE AV	MARKHAM RD		14	1	1
0452	EGLINTON AV	PHARMACY AV		15	19	13
0380	MCCOWAN RD	LAWRENCE AV		16	8	6
1191	STEELES AV	WARDEN AV		17	16	55
1208	STEELES AV	ISLINGTON AV		18	30	41
1142	STEELES AV	VICTORIA PARK AV		19	41	41
0905	JANE ST	EGLINTON AV		20	43	27

Table A.32 Ranking based on total collisions (left-turn) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0917	THE QUEENSWAY	NORTH QUEEN ST		1	6	2
0380	MCCOWAN RD	LAWRENCE AV		2	1	1
1191	STEELES AV	WARDEN AV		3	3	14
0619	STEELES AV	DUFFERIN ST		4	2	33
0878	MARKHAM RD	PROGRESS AV		5	5	8
0927	WARDEN AV	ARKONA DR	SCARDEN AV	6	61	24
0652	STEELES AV	BAYVIEW AV		7	17	55
1363	STEELES AV	BIRCHMOUNT RD		8	25	6
0748	VICTORIA PARK AV	SHEPPARD AV		9	16	32
0602	STEELES AV	KEELE ST		10	11	18
0810	FINCH AV	SIGNET DR	ARROW RD	11	4	3
0412	LAWRENCE AV	KENNEDY RD		12	10	25
0301	EASTERN AV	COXWELL AV		13	67	12
0731	KIPLING AV	BELFIELD RD		14	34	11
0420	LAWRENCE AV	MARKHAM RD		15	9	4
0437	DIXON RD	MARTINGROVE RD		16	15	5
0458	EGLINTON AV	BIRCHMOUNT RD		17	29	37
1072	BRIMLEY RD	PROGRESS AV		18	36	19
0479	ST CLAIR AV	SPADINA AV		19	48	10
0702	ELLESMERE RD	MARKHAM RD		20	14	15

Table A.33 Ranking based on FI collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0640	DUNDAS ST	SORAUREN AV		1	27	10
1004	LAWRENCE AV	SHERMOUNT AV		2	52	90
0252	PARLIAMENT ST	BLOOR ST		3	5	5
1002	FINCH AV	TOBERMORY DR		4	9	4
1610	ST CLAIR AV	VIA ITALIA		5	47	27
0446	O'CONNOR DR	WOODBINE AV		6	3	3
0099	EGLINTON AV	SPADINA RD		7	17	24
1745	QUEEN ST	SORAVREN AV		8	78	63
0453	EGLINTON AV	LESLIE ST		9	2	21
1723	YORK MILLS RD			10	151	65
0496	DUNDAS ST	SCARLETT RD		11	69	151
0147	KINGSTON RD	EGLINTON AV		12	21	49
0215	LAKE SHORE BL	SPADINA AV		13	6	139
1443	LAWRENCE AV	BROCKLEY DR		13	57	56
1330	QUEEN ST	DUNN AV		15	41	16
1308	EGLINTON AV	LASCELLES DR		16	141	122
0347	DANFORTH AV	DONLANDS AV		17	81	55
1074	EGLINTON AV	GLENHOLME AV		18	40	20
0095	EGLINTON AV	ORIOLE PKWY		19	98	156
1435	SHEPPARD AV	SHORTING RD		19	59	48

Table A.34 Ranking based on total collisions (rear-end) at 3-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0446	O'CONNOR DR	WOODBINE AV		1	4	4
0390	DAVENPORT RD	CALEDONIA RD		2	1	1
0453	EGLINTON AV	LESLIE ST		3	2	9
0682	LAIRD DR	MILLWOOD RD		4	10	16
0395	WESTON RD	ROGERS RD		5	8	11
1004	LAWRENCE AV	SHERMOUNT AV		6	28	34
1360	DAWES RD	CRESCENT TOWN RD		7	29	25
0252	PARLIAMENT ST	BLOOR ST		8	12	38
0415	LAWRENCE AV	BARRYMORE RD		9	68	63
0496	DUNDAS ST	SCARLETT RD		10	22	14
1680	O'CONNOR DR	CURITY AV		11	123	93
0588	WESTON RD	SHEPPARD AV		12	3	2
0505	BATHURST ST	AVA RD		13	122	101
1353	DON MILLS RD	MOATFIELD DR		14	58	54
1008	JANE ST	GILTSPUR DR		15	100	56
0822	DON MILLS RD	WYNFORD DR		16	6	10
0159	KINGSTON RD	BEECH AV		17	165	174
1002	FINCH AV	TOBERMORY DR		18	7	3
1556	STEELES AV	CONACHER DR		19	134	92
1033	LAWRENCE AV	BENNETT RD		20	211	117

Table A.35 Ranking based on FI collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0618	DUFFERIN ST	FINCH AV		2	2	4
0752	KENNEDY RD	SHEPPARD AV		3	3	2
0456	EGLINTON AV	WARDEN AV		4	7	10
0694	ELLESMERE RD	WARDEN AV		5	4	3
0744	LESLIE ST	SHEPPARD AV		6	5	7
1420	BLACK CREEK DR	TRETHEWEY DR		7	23	11
0696	ELLESMERE RD	KENNEDY RD		8	11	21
1162	HWY #27	HUMBER COLLEGE BL		9	41	20
0675	BATHURST ST	FINCH AV		10	6	5
1192	STEELES AV	KENNEDY RD		11	8	6
0648	SHEPPARD AV	BAYVIEW AV		12	25	143
0589	WESTON RD	FINCH AV		13	10	8
0088	EGLINTON AV	LAIRD DR		14	75	40
0650	BAYVIEW AV	FINCH AV		15	20	29
0150	KINGSTON RD	ST CLAIR AV	BROOKLAWN AV	16	105	79
1456	LAKE SHORE BL	COLBOURNE LODGE RD		17	155	176
0407	LAWRENCE AV	VICTORIA PARK AV		18	9	9
0460	EGLINTON AV	KENNEDY RD		19	12	15
0800	ROGERS RD	CALEDONIA RD		20	101	27

Table A.36 Ranking based on total collisions (rear-end) at 4-legged signalized intersections

PX	Major Street	Minor Street	Minor Street2	High Proportion	Expected Accident	Excess Accident
0618	DUFFERIN ST	FINCH AV		1	2	2
0694	ELLESMERE RD	WARDEN AV		1	4	3
0744	LESLIE ST	SHEPPARD AV		1	3	5
1348	BLACK CREEK DR	LAWRENCE AV		1	1	1
0675	BATHURST ST	FINCH AV		5	6	6
0752	KENNEDY RD	SHEPPARD AV		6	5	4
1420	BLACK CREEK DR	TRETHEWEY DR		7	27	12
1162	HWY #27	HUMBER COLLEGE BL		8	48	17
0203	LAKE SHORE BL	SHERBOURNE ST		9	194	77
1407	ALLEN RD	SHEPPARD AV		10	11	94
0407	LAWRENCE AV	VICTORIA PARK AV		11	7	8
0696	ELLESMERE RD	KENNEDY RD		12	9	14
0589	WESTON RD	FINCH AV		13	8	7
0456	EGLINTON AV	WARDEN AV		14	31	90
0577	WESTON RD	BLACK CREEK DR		15	55	23
0454	EGLINTON AV	DON MILLS RD		16	14	83
0706	DUNDAS ST	ISLINGTON AV		17	64	68
1192	STEELES AV	KENNEDY RD		18	13	10
0087	EGLINTON AV	BRENTCLIFFE RD		19	103	182
0428	KEELE ST	LAWRENCE AV		20	12	9

Appendix B Sample Statistical Data for Calculating the Level of Accident Cluster

Table B.1 Statistical Data for Greater Toronto Area (2000)

Accident count (k)	Frequency (n_k)	Accident (kn_k)	Relative accident count (k/K)	Relative frequency	Accident proportion (kn_k/M)	Population proportion (n_k/N)	Cumulative accident proportion (a_k)	Cumulative population proportion
0	80	0	0.0000	0.5333	0.0000	0.0467	0.0000	0.0467
1	93	93	0.0141	0.6200	0.0050	0.0543	0.0050	0.1011
2	117	234	0.0282	0.7800	0.0126	0.0683	0.0176	0.1694
3	109	327	0.0423	0.7267	0.0176	0.0637	0.0353	0.2331
4	150	600	0.0563	1.0000	0.0324	0.0876	0.0677	0.3207
5	113	565	0.0704	0.7533	0.0305	0.0660	0.0982	0.3867
6	75	450	0.0845	0.5000	0.0243	0.0438	0.1224	0.4305
7	114	798	0.0986	0.7600	0.0431	0.0666	0.1655	0.4971
8	73	584	0.1127	0.4867	0.0315	0.0426	0.1970	0.5397
9	72	648	0.1268	0.4800	0.0350	0.0421	0.2320	0.5818
10	76	760	0.1408	0.5067	0.0410	0.0444	0.2730	0.6262
11	47	517	0.1549	0.3133	0.0279	0.0275	0.3009	0.6536
12	62	744	0.1690	0.4133	0.0401	0.0362	0.3411	0.6898
13	49	637	0.1831	0.3267	0.0344	0.0286	0.3754	0.7185
14	43	602	0.1972	0.2867	0.0325	0.0251	0.4079	0.7436
15	35	525	0.2113	0.2333	0.0283	0.0204	0.4362	0.7640
16	40	640	0.2254	0.2667	0.0345	0.0234	0.4708	0.7874
17	39	663	0.2394	0.2600	0.0358	0.0228	0.5066	0.8102
18	30	540	0.2535	0.2000	0.0291	0.0175	0.5357	0.8277
19	25	475	0.2676	0.1667	0.0256	0.0146	0.5613	0.8423
20	20	400	0.2817	0.1333	0.0216	0.0117	0.5829	0.8540
21	20	420	0.2958	0.1333	0.0227	0.0117	0.6056	0.8657
22	17	374	0.3099	0.1133	0.0202	0.0099	0.6258	0.8756
23	24	552	0.3239	0.1600	0.0298	0.0140	0.6556	0.8896
24	14	336	0.3380	0.0933	0.0181	0.0082	0.6737	0.8978
25	13	325	0.3521	0.0867	0.0175	0.0076	0.6912	0.9054

26	15	390	0.3662	0.1000	0.0210	0.0088	0.7123	0.9141
27	18	486	0.3803	0.1200	0.0262	0.0105	0.7385	0.9246
28	17	476	0.3944	0.1133	0.0257	0.0099	0.7642	0.9346
29	12	348	0.4085	0.0800	0.0188	0.0070	0.7830	0.9416
30	10	300	0.4225	0.0667	0.0162	0.0058	0.7991	0.9474
31	7	217	0.4366	0.0467	0.0117	0.0041	0.8109	0.9515
32	6	192	0.4507	0.0400	0.0104	0.0035	0.8212	0.9550
33	12	396	0.4648	0.0800	0.0214	0.0070	0.8426	0.9620
34	6	204	0.4789	0.0400	0.0110	0.0035	0.8536	0.9655
35	4	140	0.4930	0.0267	0.0076	0.0023	0.8612	0.9679
36	4	144	0.5070	0.0267	0.0078	0.0023	0.8689	0.9702
37	2	74	0.5211	0.0133	0.0040	0.0012	0.8729	0.9714
38	7	266	0.5352	0.0467	0.0144	0.0041	0.8873	0.9755
39	1	39	0.5493	0.0067	0.0021	0.0006	0.8894	0.9761
40	6	240	0.5634	0.0400	0.0130	0.0035	0.9023	0.9796
41	2	82	0.5775	0.0133	0.0044	0.0012	0.9068	0.9807
42	1	42	0.5915	0.0067	0.0023	0.0006	0.9090	0.9813
43	2	86	0.6056	0.0133	0.0046	0.0012	0.9137	0.9825
44	4	176	0.6197	0.0267	0.0095	0.0023	0.9232	0.9848
45	3	135	0.6338	0.0200	0.0073	0.0018	0.9304	0.9866
46	3	138	0.6479	0.0200	0.0074	0.0018	0.9379	0.9883
47	1	47	0.6620	0.0067	0.0025	0.0006	0.9404	0.9889
48	0	0	0.6761	0.0000	0.0000	0.0000	0.9404	0.9889
49	1	49	0.6901	0.0067	0.0026	0.0006	0.9431	0.9895
50	0	0	0.7042	0.0000	0.0000	0.0000	0.9431	0.9895
51	1	51	0.7183	0.0067	0.0028	0.0006	0.9458	0.9901
52	1	52	0.7324	0.0067	0.0028	0.0006	0.9486	0.9907
53	3	159	0.7465	0.0200	0.0086	0.0018	0.9572	0.9924
54	2	108	0.7606	0.0133	0.0058	0.0012	0.9630	0.9936
55	2	110	0.7746	0.0133	0.0059	0.0012	0.9690	0.9947
56	0	0	0.7887	0.0000	0.0000	0.0000	0.9690	0.9947
57	0	0	0.8028	0.0000	0.0000	0.0000	0.9690	0.9947
58	1	58	0.8169	0.0067	0.0031	0.0006	0.9721	0.9953
59	0	0	0.8310	0.0000	0.0000	0.0000	0.9721	0.9953
60	0	0	0.8451	0.0000	0.0000	0.0000	0.9721	0.9953
61	2	122	0.8592	0.0133	0.0066	0.0012	0.9787	0.9965

62	1	62	0.8732	0.0067	0.0033	0.0006	0.9820	0.9971
63	0	0	0.8873	0.0000	0.0000	0.0000	0.9820	0.9971
64	1	64	0.9014	0.0067	0.0035	0.0006	0.9855	0.9977
65	1	65	0.9155	0.0067	0.0035	0.0006	0.9890	0.9982
66	1	66	0.9296	0.0067	0.0036	0.0006	0.9926	0.9988
67	1	67	0.9437	0.0067	0.0036	0.0006	0.9962	0.9994
68	0	0	0.9577	0.0000	0.0000	0.0000	0.9962	0.9994
69	0	0	0.9718	0.0000	0.0000	0.0000	0.9962	0.9994
70	0	0	0.9859	0.0000	0.0000	0.0000	0.9962	0.9994
71	1	71	1.0000	0.0067	0.0038	0.0006	1.0000	1.0000

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