Inservice Road Safety Audit Review of Toronto Intersections

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Abstract

This project uses a practical procedure for conducting in-service road safety reviews of existing intersections.The procedure in this project is based on current experience in Canada and other countries and applies road safety engineering research to the Canadian environment.An in-service road safety review is an in-depth engineering study of an existing road using road safety principles with the aim of identifying cost-effective countermeasures that would improve road safety and operations for all road users.A review can be done for any road section, intersection, or interchange, and is generally most effective when conducted at locations where a high collision risk has been identified.In-service reviews typically include a structured review of collision history, geometric characteristics, and traffic operational efficiency, and could also include traffic conflict observations and a human factors assessment.The main output from in-service road safety reviews is the identification of road safety problems and the development of cost-effective countermeasures to overcome these road safety problems.

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1. Introduction

1.1 Road Safety Problem

It has been reported that traffic collisions lead to around 1.2 million people being killed and around 39 million being injured each year worldwide. Road collisions are the tenth leading cause of human death [1].In Canada, traffic collisions resulted in more than 2,900 fatalities and 227,500 injuries in 2000 [2].Health Canada estimates that Canadians spend $25 billion every year on emergency care, rehabilitation, and other costs resulting from traffic collisions.According to comparative statistics issued by the Organization for Economic Cooperation and Development (OECD) for 2000, Canada's traffic collision fatality rate was 9.8 per 100,000 people, which ranked 12th best among a group of 28 industrialized countries [4].The best rates were recorded in the Netherlands, Norway, Sweden and the United Kingdom. Canada ranked fifth among OECD countries in 2000, with a rate of 9.37 traffic deaths per billion kilometers traveled [4].

1.1.2 Evaluation of Road Safety Information

Research into road safety is made difficult because the data required are often inadequately documented are scattered.Road safety information should be collected on an on-going basis in a proper and systematic manner so that the data are readily available to interested agencies.Road Safety Audits (RSA), Road Safety Audit Reviews (RSAR), In-service Road Safety Reviews and traditional safety review are important analyses that require good quality road safety data.These processes are all conducted in Canada and the USA and are provide great benefits to local, international, private and public agencies involved in road safety.

Road safety audits were first introduced in the United Kingdom in the 1980s.They were introduced in New Zealand and Australia in the 1990s.RSAs and RSARs can be used in any phase of a project where safety is a concern from preliminary planning to design and construction. They can be used on any size of the project from minor intersections to major highways.

1.1.3 Canada's Road Safety Vision 2010

Canada's road safety performance is similar to that of other OECD countries.As stated in Canada's Road Safety Vision 2010, "Continued efforts must be made to promote successful existing strategies and introduce targeted initiatives" [4].Policy makers, road safety professionals, and concerned stakeholders are working at several levels to reduce the risk and cost of collisions. Road Safety Vision 2010 is aimed at making Canada's roads the safest in the world through a combination of education, enforcement, and engineering initiatives.The Vision was adopted in 2000 by The Council of Ministers Responsible for Transportation and Highway Safety.The national target is a 30 percent decrease in traffic deaths and injuries between 2008 and 2010, compared to the period between 1996 and 2001[4].There are nine sub-targets, including a 40 percent decrease in fatalities or serious injuries on rural roadways, a 20 percent decrease in fatalities or serious injuries in speed- or intersection-related crashes, and a 30 percent decrease in vulnerable road user deaths and injuries [8].Recent initiatives introduced at the provincial and municipal levels include graduated licensing, the increased use of road safety audits, the introduction of red-light running camera enforcement programs, and planning initiatives aimed at decreasing the dependence on auto travel and the promotion of walking and cycling as alternative modes.

1.1.4 Definitions

Definition of Road Safety Audit (RSA):

The internationally accepted definition of an RSA: "An RSA is a formal and independent safety performance review of a road transportation project by an experienced team of safety specialists, addressing the safety of all road users."

Definition of In-service Road Safety Reviews

According to the Canadian Guide of In-service Road Safety Reviews, "An In-Service Road Safety Review is an in-depth engineering study of an existing road using road safety principles with the purpose of identifying cost-effective countermeasures that would improve road safety and operations for all road users."

In-Service Road Safety Reviews can be conducted for any road section, intersection, or interchange. However, in order to optimize the usefulness of available resources, In-Service Reviews are most effective when conducted at locations where a high collision risk has been identified.

1.1.5 Introduction to Road Safety Audits

In the past, highway safety focused on crash reduction at those sites where accidents occur frequently.

Road Safety Audits are designed to make road projects safer in two ways:

1) RSAs are designed to eliminate safety hazards like unsafe sight distance and dangerous intersection curves during the design and planning process; and

2) RSAs are designed to promote and encourage safety devices in order to reduce crashes. Examples include guard rails, sign boards, reflectors etc

The purpose of the safety audit is to:

- Minimize the risk of road crashes;
- Minimize the severity of road crashes;

- Minimize the need for remedial work after construction;

- Reduce the life cycle cost of the project; and

- Increase awareness of safety design and safety devices among the people involved in design, construction planning and maintenance;

A) International Experience of Road Safety Audits

According to International experience of Road Safety Audits suggests that collisions can be reduced.

In New York [12]:

- Crash reduction occurred at high crash locations treated with low cost improvements; and.

- The crash reduction ranged from 20 % to 40 %. The reduction depends upon the improvement provided...

In Australia [12], a recent study of RSAs found that:

- The benefit to cost ratio ranged from 3:1 to 242:1; and

- It required a very low cost response like 1000 Dollar for mostly 65% of recommendation.

- The benefit to cost ratio ranged from 2.4:1 to 84:1

- 95 % of all recommendation costs less than a 1000 dollar.

Examples of RSA results from other international research include:

- A 1% to 3% reduction in injuries with an associated decrease in the cost of the injuries [12]

- Remedial work not required or if required in a minimize aspect;

- Reduced the life cycle cost analysis;

- Improved awareness of safety concerns;
- Improved coordination and cooperation between agencies.

1.1.6 Introduction to In-service Road Safety Reviews

Improving the physical and operational characteristics of existing roads is a proven and effective method of improving road safety. The geometric and operational characteristics of many existing roads (particularly older roads) are incompatible with the current demands placed on them. Traffic volumes, the surrounding land use, road user behavior, population demographics, vehicle characteristics, traffic operations technology, and road safety engineering knowledge change over time [6]. By upgrading the operational and physical characteristics of existing roads to be more compatible with current traffic conditions and safety knowledge, significant gains in safety can be achieved. Many of the collisions attributed to road user errors can also be prevented or made less severe by improving the road environment. Engineers with an understanding of human behavior can improve roads to prevent common driver errors from resulting in a collision. The road environment can be made more forgiving so that a collision caused by driver error is less severe. In-Service Reviews typically include:

- A structured review of collision history;
- Geometric characteristics;
- Traffic operational efficiency;
- Traffic conflict observations;
- Human factors assessment;
- Short and long term countermeasures; and
- Lower cost solutions.

Lower-cost solutions include changes to traffic signs, pavement markings, signal operations, and traffic control visibility.

Higher-cost solutions include road widening to add travel lanes or turning lanes, providing sidewalks and new signal installations.

1.1.7 Relationship between In-service Road Safety Reviews and Road Safety Audits

In-Service Road Safety Reviews are complementary to Road Safety Audits. In-Service Reviews may be classified as an audit stage, the last in a sequence that includes planning, preliminary design, final design, construction and pre-opening audits [6].

In Canada, it is common for the term "road safety audit" to refer to independent safety reviews (or assessments) that occur prior to the opening of a road. Audits aim to introduce remedial actions that minimize collision risks before the remedial actions are introduced to the road system. In contrast, In-Service Reviews typically aim to reduce an already existing collision risk. Audits are typically more dependent on the experience and judgment of the audit team while In-Service Reviews make more use of the analysis of empirical data related to collision history, traffic volumes, geometric measurements, human factors observations, and traffic conflicts [8]. In-Service Road Safety Reviews are not specifically related to collision reconstruction. Collision reconstruction studies attempt to explain in detail the events leading up to an individual collision and the actions that may have caused that particular collision. In-Service Reviews examine the overall collision history and patterns among many other measures in order to identify cost-effective countermeasures for the site in question.

1.1.8 Distinction between Road Safety Audit and Road Safety Reviews

Road Safety Audits deal with the evaluation of a plan or a design whereas In-Service Road Safety Reviews deal with the evaluation of a roadway section or intersection either just before opening or already open to traffic is becoming more pronounced. Terms such as RSAR, in-service road safety review, road infrastructure assessment, road review, roadway assessment, and roadway inspection have been used to differentiate a Review of an existing roadway from an RSA of a plan.

The following distinctions should be noted:

- A safety review required one or two member while an audit require four to five people;
- Review members are usually part of the design team while audit team members are independent;
- Field reviews are a necessary part of a safety audit, but not part of a safety review;
- Safety reviews concentrate on the evaluation of the design whereas audits use a checklist to examine field features;
- Safety reviews usually do not consider human factors issues, only consider driver error, visibility etc whereas audits consider all factors that can cause collisions;
- Safety reviews focus on the needs of the roadway user while audits consider the needs of pedestrians, cyclists and large trucks as well as automobile drivers.
- Safety reviews are reactive in that the location studied is identified from a crash analysis and the review aims to rectify problems identified whereas audits are proactive and aim to ensure that corrective and preventative measures are taken before the road is built.

2.0 ISSUES AND BENEFITS

2.1.1 Collision Problem

As reported in Chapter 1, 1.2 million people die every year in road side crashes around the world.About 70 % of these deaths occur in developing countries. Over ten million are injured worldwide each year. If proper action is not taken, the number of injuries may increase to 60 million injuries in the next ten years (2).The majority of victims in developing countries are motorized vehicle drivers or passengers, pedestrian, motorcyclist and bicyclists.According to the World Health Organization and World Bank report of 1990, the world's ninth most important health problem was traffic crashes. It was forecast that by 2020, traffic crashes would reach third place [1].

It is important to consider the relationship between the number of collisions and the demographic conditions of different countries.The crash rate per 100,000 population can be used for comparison.

2.1.2 Economic Perspective

Gross National Product (GNP) is a key indicator in the economic assessment of a country. Road crashes cost approximately one to three percent of a country's annual GNP [5]. This is almost twice the amount that developing countries receive as assistance from the world.It is a duty of a government to reduce these losses and to improve road safety as an investment as well as on humanitarian grounds.

2.1.3 Road Safety Plan

A road safety plan should be introduced for the medium and long term. The plan should include road safety targets, the building of local safety institutions, and alternate sources of financing for road safety should be done.

2.1.4 Responsibility of Institutions

To improve road safety, local, provincial and federal agencies should work together to make the roads safe for all road users.The roles and responsibilities of the different organizations should be set out clearly so that the organizations can work together effectively.

2.1.5 Implementation, Monitoring and Evaluation

To track road safety activities, proper monitoring and evaluation systems should be developed to track progress in a systematic manner.Monitoring and evaluation are part of the safety action plan.

2.1.6 Road Crash Data

Road crash data are the essential for monitoring road safety and for trying to solve the problem of road collisions.The data should include the categories of road users involved in crashes, pattern, road conditions, maneuvers etc.

2.1.7 Financial Perspective

Funds are required for road safety research and for the implementation of road safety measures.Sources of funding include fuel taxes and insurance premiums. Insurance premiums can be a source of funding for crash prevention because it is in the interest of insurance companies to reduce the number and severity of crashes.

2.1.8 Safety Engineering

The design of roads plays an important role in road safety and complements improvements in vehicle standards and driver testing requirements.As traffic patterns are different in developing countries compared to developed countries, road standards are likely to differ.The number of road crashes can be reduced where critical locations are identified and a safer design introduced.The countermeasures are usually low cost and can be done with limited resources.

2.1.9 Safety Audits

The safety audit and review is used to check the safety aspect of new and existing roadways.The review is part of the design, construction and maintenance phases of road projects.In many countries, safety may be considered during the design phase, but the final design may fail to incorporate the safety measures.The same may apply to maintenance work which may concentrate on pot holes and the cleaning of drainage systems, but fail to fix missing sign boards, damaged guard-rails, poor road markings and other safety features.If a road safety side audit is conducted according to the guidelines, the audit will reduce the number of crashes with a minimum benefit to cost ratio.

2.1.10 Traffic Education and Publicity Programs

Traffic safety awareness should be provided to everyone, especially to children. A course on road safety should be included as a compulsory subject in schools.

2.1.11 Driver Testing and Training

Defensive driving techniques should be taught to reduce road users' errors. Special training can be provided by professional driving instructors.Examinations can be conducted with the help of modern technologies.

2.1.12 Traffic Laws and Traffic Police

Traffic laws should be enforced. Traffic police should be trained properly and must have the resources required to stop traffic violations effectively.Good traffic laws and enforcement will definitely help in reducing the crashes.

2.1.13 Safety Standards for Vehicles

Vehicle design should protect the occupant.Vehicle maintenance is important to prevent crashes caused by vehicles which are not road worthy.The use of safety features like seat belt, airbags, and car seats for children also help to reduce injuries and the number of crashes.Random road side inspections should be carried out by an enforcement agency. Overloading should be prevented and the use of heavy trucks during peak hours should be minimized.

2.1.14 Rescue Centers

A rescue center is a single emergency centre which alerts police, medical ambulance, fire fighters and other resources.A rescue centre with emergency medical services should be provided at each highway facility to minimize response time.

2.1.15 Research and Development

Research into the factors involved in a collision and the best modifications for sites with poor accident records will help to reduce the number of crashes.

2.1.16 NGOs, Volunteers, Community Centers

Road safety is not the responsibility of a limited number of organizations. Community center and Non profitable government organization can increase people awareness of safety issues.Volunteers can help.

2.2 Benefits

The benefit of including a safety audit in the design process is that the audit will address problems and ultimately save money before the road has been constructed and before the road needs to be redesigned. Some of the benefits are listed below:

- A reduction in the number and severity of human injuries;
- A reduction in the number and severity of accidents.
- A reduction in the road and intersection costs by building safety into the design from the beginning and avoiding design changes later;
- The promotion of safety issues;
- The integration of multimodal security concerns; and
- The consideration of human factors in the design process.

2.3 CHECKLISTS AND PROMPT LISTS (NCHRP& Austroads))

2.3.1 Check list

The key tool in conducting the safety audit is the checklist.The safety audit checklist has been developed to help safety auditors to review projects and to ensure that all the issues that can affect safety are properly addressed. Road Safety Audit from Austroads [7] and Guidelines for the Road Safety Audit of Highways from IHT contain extensive checklists that can be used for each audit stage.

2.3.2 Prompt List

Many countries are now using prompt lists. Prompt lists are less prescriptive than checklists and identify broader areas for the audit team to examine during the field review. The Canadian Road Safety Audit Guide contains an example of a prompt list.
The check list or prompt list should be made before the road site visit and inspection.The list should be agreed during the pre audit meeting and then taken to the site inspection.

The team can use an existing list and modify it to fit the project.There are several different road safety audit checklist styles available for different types of project, but the most important point is that the list should address all the relevant safety concerns.

2.4 Canadian Road Safety Prompt List

Individual road safety auditors will have different preferences regarding the use of checklists.Some auditors have indicated that they find long and comprehensive checklists to be useful in completing audits, and that the list provides the centerpiece of the audit report.Other auditors find that simple prompt lists and professional experience are sufficient.In reality, even long checklists cannot cover all aspects of a project, especially with the varied conditions that exist across Canada.As checklists become more voluminous in order to be comprehensive, they become cumbersome to use, time consuming, and some or even many of the "points" become inapplicable to the particular projects.The Canadian Road Safety Audit guide consists of following parameters for a prompt list [9].

1. General project parameters

a. Road classification
b. Design speed
c. Applicable design standards/guidelines
d. Surrounding land use
e. Profile and volume of expected users
f. Previous audit results

2. Geometric design

a. Horizontal alignment
b. Vertical alignment
c. Cross-section
d. Stopping, crossing and decision sight distances and sight line obstructions
e. Lane continuity, passing and climbing lanes

f. Merge, weave, and diverge areas

g. Acceleration and deceleration lanes

h. Interchange design features, including ramps and loops

i. Intersection design features, including turn radii

j. Clear zone, hazard protection and barrier design

k. Drainage

l. Pavement condition

m. Vertical clearances (at overpasses) and lateral clearances

n. Spacing of design elements

o. Linkage/transition to existing sections

p. Traffic calming requirements

q. Combinations of limit conditions

r. Consistency within new Design and between Old and New Sections

s. Barrier end treatment

<u>3. Traffic operations</u>

a. Operating speeds

b. Congestion and delays

c. Queuing

d. Access (driveways and major generators)

e. Intersection conflict points

f. Crash records/history

g. Turn movements at intersections and driveways

h. Turn lane requirements

i. Maintenance: Ability to safely access areas requiring maintenance

j. Progression

k. Speed limits and speed zones

l. Potential for traffic diversion / network impacts

m. Future traffic growth

4. Control devices

a. Regulatory and advisory signs .

b. Pavement markings and rumble strips

c. Delineation devices and hazard warning signs

d. Changeable message signs

e. Advance warning flashers

f. Spacing of control devices

g. Location of control devices (overhead / side-mounted)

h. Over-signing

i. At grade rail crossing control requirements

5. Human factors

a. Control device visibility

b. Background visual attraction or clutter

c. Driver expectancy of the environment

d. Driver overload

e. Need for positive guidance

6. Environment

a. Integration with surrounding land use

b. Night / Dawn / Dusk conditions and the need for lighting

c. Rapid change in light conditions and tunnels

d. Extreme weather conditions wind and fog

e. Headlight glare

f. Landscaping impacts

g. Gateway treatments

7. Needs of All Road Users

a. Pedestrians

b. Children, the elderly, and people with disabilities

c. Bicycles

d. Motorcycles

e. Equestrians

f. Trucks (including runaway truck requirements)

g. Buses (transit and otherwise)

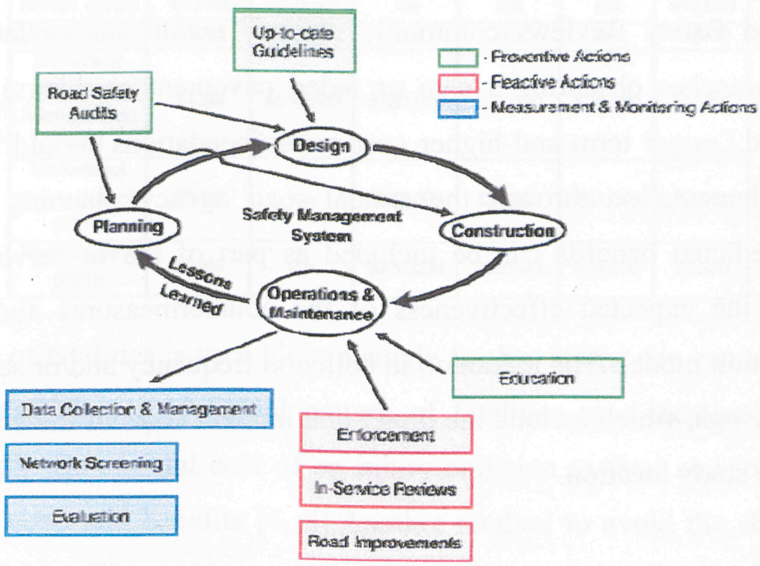
h. Recreational Vehicles

i. Cars

j. The safety of rollerblades, roller skaters, skateboarders, scooters, and golf carts

3. SAFETY MANAGEMENT SYSTEMS (SMS)

A safety management system (SMS) is a coordinated process used to achieve safety goals by ensuring that opportunities to improve road safety are identified, considered, implemented, and evaluated in all phases of planning, design, maintenance and operations [8].The elements of an effective SMS for roads are shown in the figure 1.



(Fig 1. Ref : In-service Road Safety Review Guide)

In-Service Road Safety Reviews are typically part of the SMS used by a road agency to reduce the risk of collisions.

Preventive actions (shown in green on the figure) include road safety audits at the planning, design, construction, and reopening stage of road and transportation projects, and driver education.Reactive actions (shown in red on the figure) include in-service road safety reviews, remedial road work, targeted enforcement campaigns, and awareness campaigns.Measurement and monitoring actions (shown in blue on the figure) include data collection, management, and analysis, including collision, volume, and speed data.

3.1 Costs and Benefits

The cost of conducting an In-Service Review varies according to the size and complexity of the location being studied, and the scope of the study.The cost of implementing the recommendations of the In-Service Review will vary significantly from project to project. In-Service Reviews generally include both short-term, typically lower-cost recommendations, and long-term, typically higher –cost recommendations [6, 8].

In-Service Road Safety Reviews commonly identify maintenance-related deficiencies (such as tree branches obscuring a sign or faded pavement markings) that should be quickly rectified.Longer term and higher cost recommendations should be programmed for future implementation through the annual road agency planning and budgeting process.The predicted benefits can be included as part of the In-Service Road Safety Review, using the expected effectiveness of the countermeasures and tools such as collision prediction models.The reduction in collision frequency and/or severity results in societal cost savings, which include the direct and indirect costs of the collisions that are prevented at the study location.

Societal collision costs include wage and productivity losses, medical expenses, motor vehicle and property damage insurance costs, emergency response costs, and employer costs.Insurance costs reflect the payments by insurance companies to settle claims arising from a collision.Collision cost estimates vary by jurisdiction, and there are a variety of ways in which these costs are estimated. Some methods estimate the cost of a collision by adding up the components of the total societal or insurance costs.Other methods estimate the notional amount that a person would be wiling to pay to avoid a collision and its consequence, representing the value of the lost quality of life [8].

Collision costs established by various agencies are summarized in the table1.These values are not intended to be directly compared.They are intended to provide a guideline for practitioners in the absence of locally-derived collision cost data.

Collision Cost Estimate Table 1

(Table1 Ref: Road Safety Audit Guide)

SOURCE	Fatal Collision	Injury Collision (weighted average)	Severe Injury Collision	Moderate Injury Collision	Minor Injury Collision	Property Damage Only Collision
INSURANCE COSTS						
Alberta (1995)	n/a	$40,000	n/a	n/a	n/a	$3,400
British Columbia (1997)	$260,000	$25,000	n/a	n/a	n/a	$1,600
SOCIETAL COSTS						
Alberta (2003)	$1.34M	$100,000	n/a	n/a	n/a	$12,000
Ontario (1994)	$6.3M	$27,000	n/a	n/a	n/a	$8,000
US Federal Highways Administration (1991)	$4.2M	$110,000	$350,000	$74,000	$38,000	$6,900
US National Safety Council (2001)	$5.1M	n/a	$250,000	$66,000	$31,000	$2,900
North Carolina (2000)	$4.9M	n/a	$350,000	$69,000	$34,000	$3,500

The societal cost of fatalities is very high; a single fatality at one site can change a safety economic analysis.Unless a historical pattern of fatalities at a location is clear, it is acceptable to apply the societal cost of an injury collision to fatal and injury collisions when estimating costs and benefits [6, 8].Another method to avoid the skew caused by the high cost of fatal collisions is to apply average severity ratios for each collision type, regardless of the actual severities reported at the study site.

Evaluations of road improvements that were conducted according to the recommendations of In-Service Road Safety Reviews have demonstrated significant benefit to cost ratios.An evaluation of the Insurance Corporation of British Columbia's Road Improvement Program was conducted according to state-of-the-art evaluation methods.The evaluation found that at 31 locations where safety improvements were implemented further to an In-Service Review, the ratio of insurance cost savings to implementation cost was 10:1 within five years of implementation[8].Another state-of-the-art evaluation study was conducted for more than 60 intersections that were improved after In-Service Road Safety Reviews in the United States.The results showed an average societal benefit to cost ratio of better than 3:1 within two years [8].

4. DATA MANAGEMENT AND ANALYSIS

4.1 Traffic Volume Counts

For all locations, it is useful to know the Average Annual Daily Traffic Volume (AADT). Traffic counts for all travel modes that use the site are a core data requirement. Traffic counts may include vehicle, pedestrian and bicycle traffic volumes.The counts may also be used to establish classifications, particularly the proportion of heavy trucks and the percentage of road users who school children and the elderly.At intersections, turning movement counts are required for each approach and for every time period of interest. The morning and afternoon peak periods are usually analyzed as a minimum [12].

4.2 Traffic Operational Characteristics

Typical traffic operational characteristics data required for In-Service Road Safety Reviews include: posted speed limits along all roads in the study area, traffic signal phasing and timing plans, traffic signal characteristics (size and location of signal heads and mast arms), traffic signal controller capabilities, parking regulations, traffic sign locations and messages (regulatory, advisory and directional) and pavement markings[12].

4.3 Collision History

The collision history of the studied site is a core data requirement for an In-service Road Safety Review.Collision reports are prepared by the police or are self-reported to the police.Reports prepared by the police are considered to be of significantly higher quality and reliability.The quality of the data that is available is highly dependent on the collision data management systems in place at the road agency.

4.4 Recent and Planned Changes

The history of the study site should be established for the period covered from the start of the collision records to the present.This information is available from the road authority. The timing and scope of any construction and significant maintenance projects at or near the site should be documented.It can also be useful to gain a general understanding of the regular maintenance activities such as the typical patterns of snow removal, line painting, and sign replacement.

4.5 Traffic Conflicts

Traffic conflicts are far more common than traffic collisions.The observation, recording and analysis of traffic conflicts can increase the understanding of why collisions are occurring at the study location. Traffic conflict data are collected on field forms that capture the conflict type, location, severity, time, travel directions of the road users involved, and other relevant characteristics[13].

4.6 Additional Traffic Measurements

Depending on the particular needs of the study location, additional traffic measurements may be required to address specific issues[12]. These may include:

- Vehicle speed studies;
- Gap acceptance studies;
- Walking speed studies;
- Violation surveys; and
- Collision reconstruction reports.

4.7 Stakeholder Input

Stakeholder input may be included in the scope of the In-Service Safety Review.As a minimum, the study team conducting the In-Service Safety Review should obtain input from the staff members of the road agency responsible for the study location and from the police detachment responsible for enforcement. Stakeholder consultation could range from simple phone calls to a series of workshops.

4.8 Collision Prediction Models

Collision prediction models (also known as safety performance functions or SPFs) can be an important tool in analyzing the safety performance of a site that is subject to an In-Service Road Safety Review.Collision prediction models allow safety researchers to use statistical modeling to capture systematic relationships between collisions, traffic volumes, and road geometry [15,16] . Collision prediction models can be also be used in the network screening process (see Section 5) to identify collision-prone sites.

A collision prediction model is a mathematical model that relates the collision frequency experienced by a road entity (for example, an intersection or road segment) to the traffic and geometric characteristics of that entity. Collision prediction models have several road safety engineering applications such as identifying problematic locations and evaluating the effectiveness of road safety improvement measures.

The technique of Generalized Linear Regression Modeling (GLM) has been found to offer the most appropriate and sound approach for developing collision prediction models.Collision prediction models are dependent on collision and volume data that are subject to regular fluctuation.There is also significant variation across the country in driving habits, geographic conditions, and collision reporting thresholds. While models that are developed for one jurisdiction should only be used in other jurisdictions with caution, methods for calibrating and transferring models across jurisdictions have been proposed [15].

5. NETWORK SCREENING

Network screening provides a systematic and unbiased method of identifying and selecting sites which need to be reviewed.

5.1 Analytical Methods

The analytical network screening process consists of evaluating the safety performance of the network. Several collision measures and tools are available, including:

- Collision frequency;
- Collision rate;
- Critical collision rate;
- Collision severity; and
- Collision prediction models.

Average values from the last three to five years of data can be used, or the analysis can be conducted for each year of data and the results compared.Analysis of the different collision measures should be conducted separately for the different road elements in the network (signalized intersections, unsignalized intersections, mid-block locations, and interchanges) [8, 19].

5.1.1 Collision Frequency

For intersections and interchanges, collision frequency simply represents the number of collisions reported per year.For road segments, collision frequency represents the number of collisions per year per kilometer. Simply ranking by collision frequency will tend to identify the locations that serve the highest volumes of traffic as having the highest collision risk [19].

5.1.2 Collision Rate

Collision data and traffic volume data can be combined to calculate the annual collisions per million entering vehicles for intersections and interchanges, and the annual collisions per million vehicle kilometers for road segments[19].

Collision rates offer advantages:

- The collision rate represents a better measure of collision risk than the number of collisions, since the exposure (traffic volume) is normalized;
- Collision rates allow comparisons of collision risk along roads of a similar class (for example, arterials) that could have a range of traffic volumes; and
- Collision rate analysis is also relatively simple to conduct, and requires only collision data and traffic volume data.

Collision rates also have important disadvantages which can lead to misleading results:

- Ranking by collision rate leads to a tendency for low volume sites to be identified as high collision risk locations;
- Collision rates do not account for severity; and
- Collision rates do not account for correctability.

5.1.3 Critical Collision Rate

Ranking sites according to the critical collision rate reduces the likelihood that low volume locations with low collision frequencies will be designated as "high risk".The critical collision rate is referred to as the rate quality control method [8, 19].

Critical collision rate analysis method reduces the likelihood that low traffic volume, low collision frequency locations will be identified as high risk, but it shares the other disadvantages described for collision rate analysis.

5.1.4 Collision Severity

Collision severity examines the consequences of the collision, and therefore provides a relative estimate of the costs incurred by society. Collision severities are often classified as fatality, injury or property damage only.

5.1.5 Collision Prediction Models

Collision prediction models (CPMs) predict the number of collisions that could be expected at any given site, using the site characteristics such the volume, geometric characteristics, the collision history of the site, and the collision history of similar sites.If the observed number of collisions (corrected for randomness) at a given site is greater than the predicted number, then the site can be classified as "high risk".Where well-calibrated models are available, CPMs should be used for network screening. However, the unavailability of CPMs should not hinder network screening from proceeding using the many other available tools [19].

5.1.6 Composite and Integrated Rankings

The various network screening techniques described above will likely yield different ranked lists of sites.It may be useful to compare and combine the results from each method to produce a final list of ranked locations that can be assessed for correctability. Composite ranking systems allow the selection of locations that meet a combination of threshold values.Another method of integrating the various rankings is by assigning the highest ranked location according to every network screening method a 100 percent score, and prorating the other sites relative to this score[8,19].

5.1.7 Correctability

Correctability analysis attempts to identify the sites where feasible engineering improvements can reduce the identified collision risk.The analysis attempts to screen out sites where the likelihood of finding effective countermeasures is low [19].

5.1.8 Other Considerations

Other considerations include planned projects, geographic representation, the public's comments, media attention given to high profile collisions, regression to the mean, environmental considerations and proactive countermeasures.

5.2 Selection of Toronto Intersection Reviewed Based on Total Collisions at 4-legged signalized intersections

The data used in this project 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 [Ref 20].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 [Ref 20]. The data were reported as three severities, namely fatal,non-fatal injury and property damage only (PDO).

This section just shows the rankings by using PSI based on expected accident frequency for total collisions for angle accidents at 4-legged signalized intersection in Greater Toronto Area [Ref 20].

Intersection Ranked based on total collision [Ref 20].

PX	Major Street	Minor Street	Expected Accident
79	UNIVERSITY AV	RICHMOND ST	1
33	YONGE ST	RICHMOND ST	2
18	CHURCH ST	RICHMOND ST	3
204	LAKE SHORE BL	YORK ST	4
1541	LAKE SHORE BL	YONGE ST	5
214	PARLIAMENT ST	ADELAIDE ST	6
416	LAWRENCE AV	BELLAMYS RD	7
409	LAWRENCE AV	WARDEN AV	8
131	STEELES AV	YONGE ST	9
8	JARVIS ST	DUNDAS ST	10

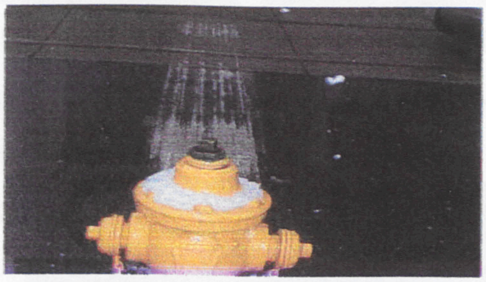
The 3 out of 5 reviewed intersection were selected on the basis of there given below ranking.The intersections are Yonge-Richmond Street,Church-Richmond Street and Lawrence-Warden intersection.The other two intersections Yonge-Dundas and Steeles-Woodbine were randomly selected

6.1RICHMOND STREET AND YONGE STREET INTERSECTION

- When vehicles left turn (LT) from Richmond Street to Yonge, there is no marking for the LT.
- When vehicles LT from Richmond Street to Yonge, turning radii is too short.
- When vehicles LT from Richmond Street to Yonge, no vehicle should be standing in Yonge side. The presence of a vehicle creates problems for the traffic flow.
- The first through lane on Yonge North should have a stop line 1.5 m ahead of intersection so that LT vehicle can easily turn with no sight obstruction.
- There is no posted speed sign near the intersection.
- No bicycle lanes are provided.
- Lighting needs to be improved.
- Poles are very close to the moving traffic
- The street name sign for Yonge should be increased so that it becomes visible and easily read.
- The no LT/RT sign on Yonge Street should be increased in size.
- Construction work should be done on holidays or at night.
- The hydrant should be removed and reinstalled 10 m away from the intersection.
- The pedestrian walkway requires repainting
- The vehicle lanes path requires repainting
- The road needs clear LT, RT and Through lane road markings.
- The Stop line requires repainting.
- Day time construction work is creating a conflict point for RT traffic.
- The Do not enter sign should be visible and should be larger.
- If the traffic signals were mounted in the middle of the road, the signals would have more visibility
- The diameter of the traffic signals could be increased.
- More Green time is required for Yonge traffic. This is feasible as there is not much queuing in Richmond street

- Pedestrian traffic towards North of Yonge side is high. The pedestrian crossing time needs adjustment.
- Newspaper Boxes are installed very close to the traffic flow. This can cause severe injuries to both pedestrians and drivers.See photograph (Richmond Street and Yonge)

- A hydrant installed very close to the pedestrian walkway could cause an injury to a driver. The hydrant should be removed and re-installed 15 m away from the intersection.



- On East and West side of Richmond Street, a hydro pole is located between the sidewalk and the pavement edge. The locations could be hazardous and could increase the consequences of a collision if hit by an errant vehicle. If possible, the both poles should be relocated. Alternatively, the poles should be painted in a color that can be seen in the dark to minimize the possibility of being hit by an errant vehicle.

- The marking for the through line required repainting. As Richmond Street is one way, the lines should be clearly marked to ensure driver awareness.

- Bicycle lanes should be provided in order for safe riding. The police use bicycles for patrolling (see picture).

- The Stop line requires repainting so that drivers can stop before entering the pedestrian walkway area.


- Pedestrian walkway lines should be remarked and repainted on all the sides of the intersection to improve safety for pedestrians.


- The Do not enter sign should larger in size and should be visible to all traffic.The arrow head showing the direction of traffic flow should also be larger in size and should be posted on both corners.


- Construction work should be done when traffic is light. As can be seen in the picture, turning traffic is experiencing problems due to construction.

- The lighting system requires improvement. There are not enough lights and the lights are inadequate during bad weather.

- Recreational Vehicles should not be allowed to turn at the intersection in the day time as they cause traffic delays and traffic hazards.

- The signal and board for the traffic coming from Yonge Street obstructs the view of Richmond Street.

- Parking should be prohibited close to the intersection. Additional parking reinforcement is required near the intersection.

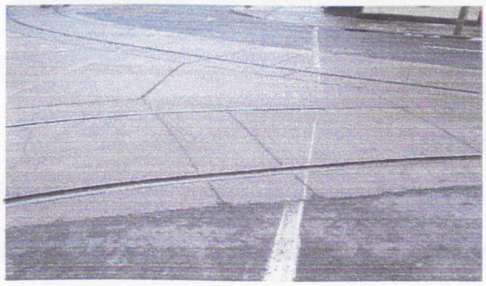
6.2 RICHMOND STREET AND CHURCH STREET INTERSECTION

- Newspaper Boxes are installed very close to the traffic flow. This can cause severe injuries to both pedestrians and drivers. See photograph (Richmond Street and Church). The newspaper boxes also create sight problem for motorists who need to see the pedestrians and the turning traffic.

- At Church Street and Richmond Street, on each side of the street, a hydro pole is located between the sidewalk and the pavement edge. The locations could be hazardous and could increase the consequences of a collision if hit by an errant vehicle. If possible, the both poles should be relocated. Alternatively, the poles should be painted in a color that can be seen in the dark to minimize the possibility of being hit by an errant vehicle.

- The Do not enter sign should be larger in size and should be visible by all traffic.The arrow head showing the direction of traffic flow should also be larger in size and should be posted on both sides.

- The pedestrian walkway lines should be remarked and repainted on all the sides of the intersection to improve pedestrian safety. The workmanship regarding painting work should also be improved.



- The Stop line requires repainting so that drivers can stop before entering the pedestrian walkway area.

- The Right Turn lane marking should be done correctly and should be visible to the motorist.

- The lighting system is adequate as far as the number of lights is concerned, but more lighting is required at the intersection.

- There are too many signs in one pole: the Richmond Street name sign, a Parking sign, a Traffic flow sign, a Do not enter sign, a flashing sign for pedestrians, and a No LT sign. So many signs are likely to confuse motorists.

6.3 YONGE AND DUNDAS INTERSECTION

- The pedestrian walkways on all the four sides of the Dundas and Yonge intersection require marking and repainting. Pedestrian flows are very high at the intersection.

- Newspaper boxes are installed very close to the traffic flow. This can cause severe injuries to both pedestrians and drivers. See photograph (Yonge and Dundas Streets). The newspaper boxes also create sight problem for motorists who need to see the pedestrians and the turning traffic.

- On Yonge and Dundas Streets, on each side of the street, a hydro pole is located between the sidewalk and the pavement edge. The locations could be hazardous and could increase the consequences of a collision if hit by an errant vehicle. If possible, the both poles should be relocated. Alternatively, the poles should be painted in a color that can be seen in the dark to minimize the possibility of being hit by vehicle.

- On Dundas Street, one No LT/RT sign is near the signal while the other sign is near the pedestrian walkway signal. They should be providing at a same height.

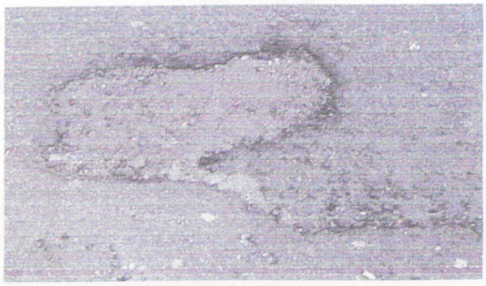
- Street cars should stop only at their designated stops so that people do not take risks and so that queues do not develop where it is unsafe.

- The pedestrian walkway signal is too high and its black background makes the signal hard for pedestrians and motorists to see.

- The hydrant and the nearby pole with a concrete foundation are both close to the intersection and could cause injuries to motorists and pedestrians. The hydrant and the nearby pole should be moved 10m away from the intersection.

- The Stop line requires repainting so that motorists can stop before reaching any conflict points with the pedestrian. Repainting requires good paint and excellent workmanship.

- Pot holes should be properly sealed to avoid deterioration in the surface of the pavement and to reduce wear and tear on passing vehicles.



- The rail track is uneven in Dundas Street East causing motorists to avoid using the lane or to suddenly try to change lane.

- The green time of both Yonge and Dundas Street is the same, but Dundas requires more green time as Dundas has longer queues and more delays than occur on Yonge Street.

6.4 STEELES AND WOODBINE INTERSECTION

- The pedestrian walkways on all the four sides of the Steeles and Woodbine intersection require marking and repainting. Pedestrian flows are high during business hours.

- The LT lanes from Steeles West to Woodbine North, from Woodbine South to Steel East, and from the 404 to Steeles West all require repainting.

- Yellow covering strip is missing of one of the three wires grounded. It can cause injury to the pedestrians especially in the dark.

- A concrete or asphalt pedestrian walkway is required on the North East side of the Woodbine/Steeles intersection. Pedestrians could trip and fall on the present surface.

- A continuous stop line is required for traffic flowing in the direction of the 404 South and Steeles East.

- No wheel chair access is available towards Steeles West for crossing the street.

- Street name signs are needed at the intersection. The signs should be large enough to be clearly visible to motorists.

- A well designed pedestrian walkway should be provided for pedestrians wanting to cross the road from the Steeles East side. Pedestrians have to cross the road to Woodbine North and then cross Steeles.

- The Do Not Enter sign should be large enough to be clearly visible to motorists and it should be properly fixed.

- On Steeles and Woodbine Streets, on each side of the street, a hydro pole is located between the sidewalk and the pavement edge. The locations could be hazardous and could increase the consequences of a collision if hit by an errant vehicle. If possible, the both poles should be relocated. Alternatively, the poles should be painted in a color that can be seen in the dark to minimize the possibility of being hit by an errant vehicle.

- The route directions for each lane going from Woodbine South are shown, but it also required showing the streets/highway where they are going.

- Pot holes should be fixed so that road users can make full use of the lane and to end the problem of motorists suddenly changing lane to avoid the lane with the pot holes.

6.5 Lawrence and Warden Intersection

- Newspaper boxes are installed very close to the traffic flow. This can cause severe injuries to both pedestrians and drivers. See photograph (Lawrence and Warden). The newspaper boxes also create sight problem for motorists who need to see the pedestrians, the turning traffic and people leaving the rear side of the bus.

- Hydrants installed very close to the pedestrian walkway could cause an injury to a driver. The hydrant should be removed and re-installed 15 m away from the intersection.

- Pedestrians should be given more time to cross the road. As can be seen from the picture, the pedestrian signs change to flashing while pedestrians are still in the middle of the road.

- Strips are being provided to cover the wires but it required to be repainted. They are usually of yellow color so that pedestrian can see them especially in the night.

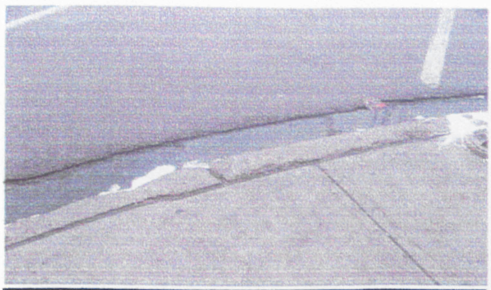
- Pedestrian crossing buttons are provided on all sides of the Lawrence and Warden intersection. The pedestrian crossing buttons help pedestrians to cross the road safely, but there are a number of conflict points for the RT vehicle

- The Lawrence name sign and the Warden name sign should be made larger.The placing of the name signs should be consistent. The signs are usually positioned on the right side of the road.The placing of the yield yellow sign could also be improved.

At present, drivers give priority to the signal. The sign should be placed on the right side 2m away from the intersection.


- The part of the median coming that provides a pedestrian refuge should be repainted in yellow color to make it more conspicuous, especially at night.

- The side slope is not well designed to meet to the needs of the handicapped and others who use the slope. The slope should meet standard specifications.



- The red light camera is situated very close to moving traffic. To avoid any conflict with the traffic, the camera should be positioned in a safer position.

- The cable boxes are very large and should be removed as they create a line of sight problem for turning traffic, obscuring traffic and pedestrians who are crossing the road.

- The pedestrian walkways on all the four sides of the Lawrence and Warden intersection need marking and repainting. Pedestrian flows are high during business hours.

- The whole intersection requires a review of signal timing. Delays occur on all sides, even outside peak hours. See pictures. The traffic flow requires more green time.

7. Safety Improvements for the Intersections Reviewed

The intersections selected are located in Toronto. One street is considered a major street and the other is considered a minor street. The major and minor streets provide access to commercial activities and to residential neighborhoods.Before and after study was conducted to improve the safety of the intersection.

Lane Width:

The through lanes along Steeles are wider than those of the other streets audited. Wide lanes may encourage motorists to travel at speeds greater than the posted speed limit and may lead to increased consequences should a collision occur.

Consider providing pavement narrowing or pavement markings to reduce pavement width to discourage speeding, thus reducing the consequence of a collision.

Physically Challenged Users:

No wheelchair ramps were provided at the north east corner of the Steeles and Woodbine intersection, unnecessarily increasing the exposure of physically challenged road users.

Provide wheelchair ramps for the physically challenged at crosswalk locations.

Pedestrians:

There is a lack of continuity and consistency in the marked crosswalks at all the audited intersections. Other pedestrian problems noted include:

- The pedestrian crossing time allowed on crosswalks at Steeles and Woodbine and at Lawrence and Warden is inadequate ; and
- The pedestrian crossing sign on Dundas East near the Dundas and Yonge intersection is not at the standard height creating a visibility problem.

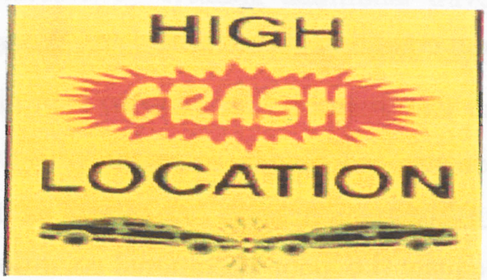
Provide pedestrian crossing signs at the crosswalk locations. Review the desire lines of pedestrian movements at the locations, and provide continuity for the crosswalks. The timing should also be reviewed. The markings, paint and workmanship should be high quality. If possible, a different surface material should be used for the pedestrian walkway. The pedestrian walkway should be visible and safe for the pedestrian.

Roadside Hazards:

Newspaper boxes are installed very close to the traffic flow, a potential cause of injury to both pedestrians and drivers.They should be placed in a position which is safe for the ongoing traffic.At all of the intersections, hydro poles are located between the sidewalk and the pavement edge. The poles may increase the consequences of a collision if hit by an errant vehicle. Where possible, relocate the poles to minimize the possibility of an errant vehicle hitting the pole. The poles should be painted in a color that is easily seen by drivers at night.

High Crash Location Sign

High Crash Locations signs should be provided so that drivers and pedestrians are aware of the crash record. High Crash Locations signs could be provided at the Lawrence and Warden intersection, the Richmond and Church intersection, and the Richmond and Yonge intersection.



Visibility of Traffic Control Devices

The visibility and clarity of all the traffic control devices is one of the basic parameters used in conducting an In service Road Safety Review. The visibility and clarity of the traffic control devices should be improved at the Lawrence and Warden intersection, the Yonge and Dundas intersection, and the Steeles and Woodbine intersection.

Drainage

Drainage facilities should clears the road surface of rain water effectively. The collision history of all the intersections, and especially Steeles and Woodbine should be reviewed for a high number of rear end and run off the road collisions on wet roads caused by drainage issues. Poor drainage and standing water also results in poor visibility of road markings.

Pavement condition

A surface that shows cracks, rutting or other signs of distress will reduce friction and result in the need for longer breaking distances with a higher risk of rear end collisions [49]. Skid tests could be done at the Steeles and Woodbine intersection and at the Lawrence and Warden intersection to determine the coefficient of friction under wet and dry conditions. The pavement condition at the Steeles and Woodbine intersection should be reviewed.

Poor signal operational condition

If the signal cycle is not adequate (i.e. poor operational condition) frustrated drivers will run red lights and make left turns with an insufficient gap. A signal operation review is required at the Lawrence and Warden intersection.

Lane Changes Caution Sign

Unexpected lane changes can cause rear end and side swipe collisions. The number of these collisions can be reduced by putting a caution sign at all the intersections reviewed.

Improve Pavement Marking

Improved pavement markings are needed at all the intersections reviewed to reinforce stopping points, channelization and turning paths.It will assist driver decision making in a complex area. At night time, reflectors should be used.The markings may reduce_head on collisions by 30 to 40 %, reduce sideswipe crashes by 10 to 30 % [Refs 40,44].

Increased Road Capacity

Road capacity can be increased by creating additional travel or turning lanes. Road capacity increases may be considered at locations with high crash frequency due to vehicle delays. Increases in road capacity will decrease rear end crashes by 30 % to 40 %.[Refs 40,44]. Road capacity increases should be considered at the Lawrence and Warden intersection and at the Steeles and Warden intersection.

Speed Limit Review

The speed limit would be appropriate to local land use and road characteristics.A lower speed limit is intended to increase reaction time and decrease collision severity, and should decrease run off the road crashes by 10 % to 20 %[40,44].A speed limit reduction by 10 kph in the Steeles area should be considered.

Provide Improved Lighting

Improved lighting will improve visibility at night and help to delineate travel paths. Improved lighting is expected to reduce off road fixed object crashes by 25 % to 40 % and reduce night time crashes by 60 % [Ref 48].Lighting improvements are required at the Steeles and Woodbine intersection, the Richmond and Church, intersection, the Lawrence and Warden intersection and the Richmond and Yonge intersection.

Increase Surface Friction

An increase in surface friction will increase breaking distance, especially on wet surfaces.This can be increased by providing overlays, grooving or open graded pavement. An increase in surface friction can reduce rear end crashes by 40 % to 60 %, off road crashes by 10 % to 20 %, and crashes due to wet pavement conditions by 30 % to 70 % [Refs 49,50].Surface friction should be increased at the Lawrence and Warden intersection, the Yonge and Dundas intersection and the Richmond and Yonge intersection.

Provide Left Turn Channelization

Left turn channelization separates and clarifies the left turn movement path, providing better sight distance for drivers turning left, improved intersection capacity, and increase volume of left turn vehicles. Left turn channelization can reduce left turn crashes by 25 % to 75 % [Ref 51].Left turn channelization has been introduced at the Woodbine and Steeles intersection, but only for Woodbine North. Left turn channelization should also been introduced at the Lawrence and Warden intersection.

Provide Right Turn Channelization

Right turn channelization separates right turn traffic and reduces right turn delays, but increases pedestrian exposure to collision risk.Right turn channelization can decrease right turn crashes by 50 %.[Refs 43,45].This_should be considered at the Lawrence and Warden intersection and at the Steeles and Woodbine intersection.

Provide Median

A median is usually provided near intersections with high speed movements. A median separates opposing traffic, reduces collisions related to left turn access movements, and improves sight distance for left turn traffic if the lanes are aligned. A median can decrease the total number of crashes by 20 % to 30 %[Refs 44,45].The median at the Steeles and Woodbine intersection should be lengthened.

Provide Pavement Marking

Pavement markings provide vehicle guidance through an intersection and help to reduce the number of vehicles encroaching on other lanes and the number of crashes that result. It can reduce the total number of crashes at signalized intersections by 45 % [Ref 44,45].Pavement markings should be provided at all the intersections reviewed.

Provide Transverse Marking/Rumble strips

Transverse marking/rumble strips can be used at the approach to an intersection to help to increase the awareness level. Total crashes may be reduced by 40 % to 60 %. [Refs 44, 45].These strips_should be provided at the Steeles and Woodbine intersection to warn drivers approaching from the 404 North highway of the intersection. .

Provide Larger Diameter Signals

Larger diameter signals increase the visibility of the signals. It is usually necessary to replace or reinforce 300 mm diameter poles and arms as the load of the signal is increased. It can reduce angle crashes by 50 %.[Refs 21,40].Larger diameter signals should be provided at all the intersections reviewed.

Relocate Signal Heads

The preferred location for the primary signal head is over the travel lane. Relocation of signal heads to over the travel lane will increase their visibility and can reduce the number of injury and fatal crashes by 40 % to 50 % [Refs 21,40].The signal heads on all sides of the Steeles and Woodbine intersection should be relocated.

Provide Yellow Back Plates

Yellow back plates increase the visibility of traffic signals and can reduce left turn crashes by 15 % to 30 % [Refs 21,40]. Reflector tape can be added to the back plate for night time visibility. Yellow back plates should be provided at all the intersections reviewed.

Optimize Signal Operation

Optimized signal operation requires capacity analysis and is appropriate where intersection delay is high.It can reduce the total number of crashes by 10 % to 20 %.[Refs 21,40].Optimized signal operation should be considered at the Lawrence and Warden and at the Yonge and Dundas intersection.

Actuated Signal Operations.

Actuated signal operations provide flexibility within existing signal phasing and reduce driver waiting time and frustration during off-peak periods. It can reduce rear end crashes by 75 % and angle crashes by 15 % [Refs 43].Actuated signal operations should be considered at the Steeles and Woodbine intersection, especially for left turn traffic.

Provide Signal Progression Coordination

Signal progression coordination will reduce the delays associated with Stop and Go conditions. It is usually applied on urban or sub urban corridors with appropriately spaced signalized intersections and can reduce angle crashes by 35 % [Ref 43].Signal progression coordination should be considered at the Richmond and Church intersection and at the Richmond and Yonge intersection.

Provide Protected Left Turn Movement

Protected left turn movements separate conflicting left turn and through movements at locations with a high number of left turn crashes or delays. The protected left turn movements may be protected only, protected/permissive, or split phase and can reduce left turn crashes by 35 % [Refs 43,45].Protected left turn movements are provided at the Steeles and Woodbine intersection and at the Lawrence and Warden intersection.

Provide Protected Right Turn Movements

Protected right turn movements indicate that a free flow right turn movement is permitted and are usually applied to locations with a high number of right turn crashes or delays. The disadvantage is that they reduce pedestrian crossing time, but they can reduce the total number of crashes by 25 %[Refs 43,45].Protected right turn movements should be considered at the Steeles and Woodbine intersection, Lawrence and Warden intersection and Richmond and Church intersection.

Provide Pedestrian Refuge

It reduces pedestrian exposure and shortens crossing time and distance at locations where pedestrians face long crossing times (for example, at the Steeles and Woodbine intersection). Pedestrian refuges can also be used to separate opposing vehicles. The refuges can reduce crashes involving pedestrians by 20 % to 60 % and head on crashes by 80 % to 90 %[Refs 8,46].

Provide Curb Extension

Curb extensions increases side walk space, pedestrian comfort and visibility. As the extensions shorten crossing time, they are usually used at locations with a long crossing distance. It can reduce crashes involving pedestrians by 30 % to 50 %[Refs 8,46]. Curb extensions should be considered at the Lawrence and Warden intersection and the Steeles and Woodbine intersection.

Install Pedestrian Actuated Signals

Pedestrian actuated signals provide a better crossing gap for pedestrians at traffic locations where pedestrians have difficulty crossing. The disadvantage for traffic is that as vehicles must stop, delays are increased. It can reduce crashes involving pedestrians by 10 % to 50 %, but rear end crashes will increase by 10 %.[Refs 8,46]. It should be considered at the Steeles and Woodbine intersection.

Pedestrian Grade Separation

Pedestrian grade separation is used to physically separate pedestrians from the traffic flow either overhead or underground. Security is a concern with underground pedestrian paths. It should be considered at all the intersections reviewed.

Pedestrian Fencing

It physically prevents pedestrians from crossing the street, especially mid block, and is used at locations with a high number of mid block pedestrian crashes or jaywalking incidents. The fences must be designed to minimize the risk of being involved in a fixed object collision. Pedestrian fencing can reduce crashes involving pedestrians by 30 % to 50 %[Refs 8,46].It should be considered at the Steeles and Woodbine intersection.

8. Conclusion

In-service Road Safety Reviews provide a set of practical steps for an agency working towards meeting its commitments to safety.The reviews require safety to be measured and monitored.They also provide a mechanism for introducing safety improvements and safety targets. The adoption of In-service Road Safety Reviews requires the agency to keep good quality safety records including up–to-date collision history, up-to-date traffic volume data, and relevant road and intersection data.These data and records are likely to be useful to other safety activities.

Locations identified through network screening provide the basis for extensive work in the area of In-service Road Safety Reviews.The team selected to conduct the reviews must have experience in road safety, traffic operations, road geometry, human factors and traffic conflicts.It is most important that road agencies take action to reduce the safety risks on in-service roads using the best available tools and knowledge.

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