A RISK-BASED DECISION POLICY TO AID THE PRIORITIZATION OF UNSAFE SIDEWALK LOCATIONS FOR MAINTENANCE AND REHABILITATION

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By

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ABSTRACT

Air pollution and a general concern for lack of physical activity in North America have motivated governments to encourage non-motorized modes of transportation. A key infrastructure component for these forms of transportation is sidewalks. The City of Saskatoon has identified the need to formalize sidewalk management policies to demonstrate diligence for community protection regarding sidewalk safety. Prioritization of sidewalk maintenance and rehabilitation actions must be objective and minimize risk to the community. Most research on prioritization of pedestrian facilities involved new construction projects. This research proposes a decision model that prioritizes a given list of existing unsafe sidewalk locations needing maintenance or rehabilitation using a direct measure of pedestrian safety, namely, quality-adjusted life years lost per year.

A decision model was developed for prioritizing a given list of unsafe sidewalk locations, aiding maintenance and rehabilitation decisions by providing the associated risk to pedestrian safety. The model used data mostly from high quality sources that had already been collected and validated. Probabilities and estimations were used to produce value-added decision policy.

The decision analysis framework applied probability and multi-attribute utility theories. This study differed from other research due to the inclusion of age and gender groups. Total average daily population of the city was estimated. This population was distributed to sidewalk locations using probabilities for trip purposes and a location's ability to attract people relative to the city total. Then trip injury events were predicted. Age and gender distribution and trip injury type estimations were used to determine the impact of those injuries on quality of life.

There exist much observable high quality data that can be used as indicators of unknown or unobserved events. A decision policy was developed that prioritizes unsafe sidewalk locations based on the direct safety impact on pedestrians. Results showed that quality-adjusted life years lost per year sufficiently prioritized a given list of unsafe sidewalk locations. It was demonstrated that the use of conditional probabilities (n=594) allowed for the ability to abstract data representing a different source population to another.

Average daily population confined and distributed within the city boundary minimized problems of accuracy. Gender-age distribution was important for differentiating the risk at unsafe sidewalk locations. Concepts from this research provide for possible extension to the development of sidewalk service levels and sidewalk priority maps and for risk assessment of other public services.

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NOTATION

		Units
a	Trip purpose designation - to shop or buy	…
B	Body part affected	group
b	Trip purpose designation - work or personal business	…
C	Curb	metres
c	Commercial designation	…
d	Trip purpose designation - education or daycare	…
DA	Dissemination area	…(x)
D_Y	Days in a year	days
D	Days	days
E	Elementary School	…
e	Trip purpose designation - to entertainment, recreation	…
f	Trip purpose designation - to eat out, restaurants	…
g	seniors designation	
H	Households	count
h	Trip purpose designation - to return home	…
HUI	Health Utility Index Score	…
I	Injury type	group
i	Gender categories where i =1 (male), 2 (female)	…
j	Age group cohorts where j = 1(0-11), 2(12-14), 3(15-19), 4(20-24), 5(25-34), 6(35-44), 7(45-54), 8(55-64), 9(65-74), 10(75 and over)	…
k	All commercial attraction trip purposes; k = (a, b, d, e, f, m, w)	…
L	A 400m radius land area centred at a sidewalk location	…
ℓ	Length	metres
LYL	Life years lost	years
M	Mode of transportation	…
m	Trip purpose designation - medical services	…
N	Total count	count
n	Count	count
Ø	Previous trip injury event	…
P	Daily Population	count
þ	Probability, also identified by P( )	…
þ'	Probability of trip purpose for non-residents in the city	…
QALYs	Quality-adjusted Life Years	years
Q_L	Total QALYs Lost per year at a sidewalk location (L)	yrs lost/ yr
q_o	Quarter (o) of the year	…
r	Residential designation	…

		Units
$\Re$	Radius	metres
R_u	Average remaining lifetime at age u	years
S	Sidewalk designation	
SHR	Saskatoon Health Region	…
T	Total in the city	count
t	Time	hours
T_u	Total number of life years lived beyond age u	years
u	Age in single years	years
U	Trade school or college designation	…
v	Trip purpose designation - to visit others	…
V	Visitors to the city	count
W	Walk as mode of transportation designation	…
w	Trip purpose designation - for spiritual functions	…
x	Dissemination area identification number	ID
Y	High school designation	…
z	High risk land parcel designation	…
α	Households in non-private dwellings designation	…
β	Multi-attribute utility functions related to health status scores	…
γ	Personal motorized vehicle as transportation mode designation	…
δ	Availability adjustment	…
Δ	Death designation	…
ε	Student designation where $-\varepsilon$ = non-student and $+\varepsilon$ = student	…
η	All trip purposes where η = (h, v, k)	…
θ	City resident population designation	…
Ξ	Bus stops designation	count
Λ	Land area	m^2
λ	Daily population equivalents attracted to a location	count/day
$\cap$	AND	…
∂	All land parcel attraction designations where ∂ = (k, r)	…
ς	Commuter daily population equivalents	count/day
τ	Recovery stage where 1=bed, 2=restricted activity, 3= reduced activity	days
φ	Health status score	…
Φ_{ij}	Gender-age group ij	(ij)
Ψ	Bike as mode of transportation designation	…
Ω	Person-visits	count
Γ	Public transit designation	…

CHAPTER 1

INTRODUCTION

1.1 Problem Statement and Background

In municipal governments, a critical component of infrastructure management is to formalize level of service. Documenting well thought out processes followed by approval from City Council provides clear expectations to all members responsible for the administration and operations related to infrastructure. Symptoms of informal processes are inconsistent and subjective decision-making, reactive instead of proactive action and risk vulnerability in litigation related to infrastructure management.

In North America, implications of current societal trends will prompt cities to review their sidewalk management practices due to predicted increases in pedestrian traffic. Growing health concerns with regard to obesity and lack of physical activity have instigated actions by health organizations that promote walking as an inexpensive and effective means to add physical activity to daily lives. Designing and constructing pedestrian-friendly and bicycle-friendly neighbourhoods, walkways and bus structures are City Planning and Transit Departments' response to facilitate these health promotions and to address environmental needs to improve air quality and reduce motorized traffic congestion.

The purpose of constructing new structures for non-motorized traffic is to increase pedestrian, bicycle, and bus connectivity resulting in an increase in non-motorized modal choices. Increased pedestrian traffic volumes on existing sidewalks may strain current sidewalk management practices. Policies designed to minimize risk associated with sidewalk use will increase the defence of operational decisions from a legal, political and customer service perspective.

Recent reports documented concerns about the increasing trend in preventable fall injuries sustained by the elderly (Albert and Cloutier 2001; Li et al. 2006; Saskatchewan Health 2002; Yiannakoulias et al. 2003). This trend is adding strain to limited human resources and expenditures in the health care system as well as decreasing the overall quality of life experienced by the seniors' population. Various health agencies worldwide are aggressively pursuing initiatives for preventing fall injury incidents with the goal of lessening their impact on society.

Lately, Saskatoon has experienced an increase in residential construction and renovation, in part, to accommodate seniors-based communities. A new transit service strategy has been implemented which intends to deliver better service and increase usage. Bus use directly affects sidewalk use because sidewalks connect passengers to and from bus stops. Mass transit is a popular modal choice for young people, the elderly, disabled persons, and persons with low income. These current trends indicate the potential for increased sidewalk usage. Saskatoon sidewalk management policy must effectively deliver safe sidewalks for pedestrians. There is a need to demonstrate that risk minimization is a key consideration when making operational decisions providing a clear defence for proving due diligence with the purpose of reducing potential liability.

Minimizing the risk for pedestrian navigation of sidewalks is a complex directive. At the extreme, it is probable that a person will fall on a sidewalk free of defects. Of the many possible contributors that cause a person to fall on a sidewalk, the only one that municipal sidewalk custodians can minimize is the number of physical sidewalk defects. The following are some contributors outside of the control of sidewalk custodians: pedestrian physical and mental health, pedestrian impairment, pedestrian distraction, pedestrian choice of footwear, pedestrian impaired sight due to poor vision or insufficient lighting, poor weather conditions, and temporary obstructions placed on the sidewalk. Therefore, operational policies and defence must focus on the removal of sidewalk hazards, regardless of defect type and severity beyond the definition of unsafe.

From 1986 to 2005, there were approximately 170 claims against the City of Saskatoon for sidewalk trip injuries (confidential city records). The city paid much more than half of a million dollars because of these claims. This is a small fraction of the total economic burden placed on society not only from litigation but also from caring for the injured. The number of claims ranged from 2 to 17 per year with injuries from minor scrapes and bruises to hospitalizing fractures. Upon review of the actual claims, it was determined that caution was necessary when interpreting these data. The number of claims was assumed anecdotal. The hypothesis underlying this assumption was that not every individual that trips on a sidewalk and sustains an injury pursues legal action that places blame on city for his or her accident. Regardless of the completeness of their representation, sidewalk trip injury claims are proof that there are hazards on the sidewalk that prevent safe navigation by pedestrians.

The methodology developed in this research illustrates the magnitude of the discrepancy between the number of trip injury events and the number of submitted claims. Using the 2001 resident population statistics for Saskatoon (Statistics Canada 2002a) and the probability of a trip injury event occurring (Statistics Canada 2001a; Statistics Canada 2003; Statistics Canada 2005a; U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994), an estimated 435 residents per year experience a trip injury event, not involving a vehicle, on a sidewalk, street, or highway. The direct impact of those injuries is the loss of quality of life equivalent to more than 48 person-years. Conversely, in the ten years around 2001, the City of Saskatoon defended approximately 10 sidewalk injury claims per year paying an average of more than $50,000 per year.

Even though complete facts are not available, there is a perceived concern for the safety of sidewalk users. The City of Saskatoon has identified a need to complete the formalization of sidewalk management policies ensuring that sidewalk service is delivered effectively and demonstrating due diligence with a clear defence for operational decision-making. It is recommended here that decision-making consider key characteristics indicating the magnitude of potential risk of sidewalk users, specifically pedestrian volume and pedestrian age and gender. These characteristics provide the foundation for the development of an objective methodology for the prioritization of trip hazard locations identified for repair or replacement.

An extensive literature search was unable to find an objective prioritization methodology for the removal of trip hazards at specific sidewalk locations. Much on the topic of managing deteriorated sidewalk infrastructure discussed field collection of sidewalk defect information and the geographic representation and analysis of these unsafe locations as a first step in dealing with similar sidewalk management issues as those in Saskatoon. Research on sidewalk management did not address the prioritization of sidewalk locations for hazard removal. Therefore, there is a need to develop an objective prioritization policy that maximizes pedestrian safety by first repairing those identified unsafe sidewalk locations where the risk of trip injuries is highest.

1.2 Research Objectives

The primary objective of this research was to develop a model for prioritizing a given list of unsafe sidewalk locations, aiding maintenance and rehabilitation decisions by providing critical information on the associated risk to pedestrian safety at each given location. Strategic removal of trip hazards would demonstrate due diligence in objective sidewalk management decision-making and result in preventative action to deliberately affect the number of actual pedestrian trip injury events on public sidewalks.

A secondary objective was to use only existing data for modelling. Most data used for this research are standard information essential for running municipal governments or commonly collected by federal statistics departments. This research did test three hypotheses related to the use of data: (1) that high quality data already exist, (2) that probabilities and estimations can be inferred from similar situations where data have already been collected and validated through research or federal agencies, and (3) that these data abstractions can be applied with sound logic and stated assumptions to produce value-added decision policy.

1.3 Scope of Research

This research includes the development of a prototype model that estimates the risk associated with a predicted pedestrian traffic volume at a specific sidewalk location. The magnitude of assessed risk prioritized competing locations previously selected for replacement or repair. The model was tested using specific scenarios from Saskatoon.

Development of a sidewalk classification system and inspection cycle is outside the scope of this research. However, the proposed methodology could be used as the basis for their development. Type of treatment, optimal length of replacement, design specifications, failure mechanisms, impact on asset condition, and life cycle are sidewalk management topics not included in this thesis. For this research, a list of specific unsafe sidewalk locations was given. Defect type and severity is evaluated before the point where this research applied.

This work did not separate the entire city sidewalk inventory into priority classifications. Rather, given a list of sidewalk locations already classified as unsafe, this work prioritized the list by the magnitude of assessed direct safety risk to pedestrians most probable to walk on the sidewalk at each location. An unsafe sidewalk is defined as a distressed sidewalk exceeding the threshold criteria for safe. For example, an unsafe sidewalk may be defined as one containing an 18 millimetre (mm) vertical displacement or a 20 mm crack width. Some may include a cross-slope threshold of, for instance, 6%.

The prototype model presented in this thesis is a first step toward isolating independent factors that represent risk to pedestrians. There were many assumptions made to account for or to represent missing information.

1.4 Methodology

The criteria for sidewalk prioritization must reflect the primary purpose of the infrastructure. That is, to provide a safe walking surface for pedestrians. The direct consequence associated with this function is that pedestrians might trip and injure themselves. A direct measure of this risk at an unsafe sidewalk location is the loss of quality of life for those injured. Health organizations and government regulators use this measure to evaluate or predict the impact of decisions on health. Applying this measure to the field of sidewalk management provides a direct safety measure to assist with maintenance and rehabilitation decisions. Once sidewalks are objectively differentiated, treatment can be executed effectively, minimizing overall risk to society and maximizing the value of expenditures. The cost becomes the result of service delivery. The pallet of treatment options to meet a service level reflects resource constraints.

The modelling process for prioritizing unsafe sidewalk followed these steps for each specified location: (1) estimation of the average daily pedestrian volume by age and gender, (2) prediction of probable trip injury events, (3) risk assessment of the consequence of trip injury events and measured as quality-adjusted life years lost per year, and (4) prioritization of the given list of competing unsafe sidewalk locations facilitated by the order of magnitude of estimated risk. The largest number represents the highest potential risk.

Throughout the steps of this process, total quantities for various physical attributes were identified for the entire city. Based on some known and related indicator of the desired attribute, estimates for each location were proportioned from the total estimate. This strategy ensured that each location was treated equally relative to another.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The objective of this research was to develop a risk-based model for prioritizing a given list of unsafe sidewalk locations for maintenance or rehabilitation. Previous prioritization studies were limited to municipal publications. These studies focused on the development of methodologies to prioritize new pedestrian facility construction projects and did not apply to existing sidewalk maintenance and rehabilitation actions. Further, these previous studies did not explicitly consider pedestrian traffic volume as well as age and gender proportions. Gallagher (Frank Cowan Company Limited 1997) recommended that sidewalk maintenance and repairs be based on location and type of usage rather than sidewalk defect size.

The prototype developed in this research estimated the probable risk associated with trip hazard locations on public sidewalks. The complete modelling process was theoretical in nature but demonstrated a decision analysis approach to aid with prioritizing sidewalk repairs given the amount of uncertainty related to the problem. Assumptions were made to deal with uncertainty and to reduce the complexity of the problem. Research from different areas was incorporated into the proposed process to address inputs and techniques needed for a decision analysis model. Areas of research included methods for estimating pedestrian traffic volume, measurement of quality of life using health utilities indexes and the application of decision analysis.

2.2 Research Areas

2.2.1 Estimating Pedestrian Traffic Volume

To estimate the probability of types of trip injury events, the pedestrian traffic volume at a location must be determined. Not only the volume but also the age and gender distributions are required because different types of injury are more common among certain age and gender groups (Eilert-Petersson and Schelp 1998).

Various fields of study propose methods to estimate pedestrian volume for use in assessing costly initiatives. Some of the initiatives include proposed construction projects for pedestrian facilities, design of new pedestrian facilities, network connectivity, urban design, urban planning, transportation planning, allocation of funds for non-motorized transportation investment decisions, and health promotion. To predict pedestrian volume, researchers have identified many variables that correlate with pedestrian traffic volume.

Porter et al. (1999) reviewed current methods and identified research needed to forecast bicycle and pedestrian travel. Current methods were broadly categorized as aggregate-level methods, attitudinal surveys, discrete choice models, and regional travel models. Forecasted demand is used to assess competing proposals for construction projects by predicting impact on the non-motorized modal split of the affected area. Physical, social, economical, attitudinal, and personal factors were identified as general groups of indicators that influence the decision to walk versus other modes of transportation.

From the perspective of health promotion, Moudon and Lee (2003) reviewed factors related to people, the environment, and route characteristics that influence the decision to walk or bike. Aspects of the behaviour-environment were grouped into spatiophysical, spatiobehavioural, spatiopsychosocial, and policy. General classes of environmental factors associated with each group were identified. Roadway characteristics, environment along roadway, network and area were factors identified for spatiophysical. Spatiobehavioural environmental factors were classified as non-motorized traffic, vehicular traffic, and safety. Perceptions of environments were identified as factors for spatiopsychosocial. Policies affecting environments were identified as the policy environmental factor. Moudon and Lee claimed this information is integral in the creation of activity-friendly communities that promote walking and biking as routine activities easily integrated into most people's daily life as well as reduce vehicular traffic congestion and air pollution. The paper tabulates research findings for measures of the environment that affect non-motorized modal choice.

Parks and Schofer (2006) focused on the use of secondary data to predict pedestrian environment assessments. Six factors they associated with good pedestrian design that can be measured remotely were sidewalks, parking lots, building setbacks, block length, intersection type, and census block density representing network design, pedestrian facilities, and roadside built environment.

Other research that identified factors used to predict pedestrian volume include land use effects and the impact of personal attitude toward walking (Kitamura et al. 1997), the relationship between site design (land use and urban form) and pedestrian travel (Hess et al. 1999), and the effect of block size on circulation performance (Siksna 1997).

Matlick (1998) identified the necessity for a prioritization tool to evaluate the need for sidewalks based on the volume of predicted pedestrian traffic. Pedestrian trip variables were classified as the mode of arrival at the start node, personal variables of influence, trip purpose, path variables, and land use at the end node.

Moudon and Sohn (2005) described concepts relating land use to travel behaviour and illustrated effects on transportation efficiency of individual variables using map layers. The purpose of this mapping tool was for use in transportation and urban planning to assess transportation efficiency and monitor progress toward goals over time. Variables used to predict travel behaviour were residential and employment densities, land use mix, connectivity, parking supply, pedestrian environment, and affordable housing.

Rodriguez and Joo (2004) studied the relationship between the local physical environment and non-motorized mode choice and suggested that measures of the built environment should be included when modelling the choice to bike or walk. The presence of sloping terrain, sidewalk availability, residential densities, and employment densities were suggested to improve non-motorized modal estimation models.

Chapleau and Morency (2005) demonstrated various spatial representations of data collected by a large sample household travel survey conducted in the Greater Montreal Area in 1998. Trip purposes identified in the paper include work, study, shopping, leisure, and returning home. The Georgia Guidebook for Pedestrian Planning (Georgia Department of Transportation 2006) chose to graph school or church or civic, earning a living, social or recreational, personal or family business as trip purposes for the transportation mode, walking. Horowitz and Farmer (1999) stated that trip purposes are incorporated in some of the urban travel forecasting methods. Matlick (1998) grouped trip purpose variables into work, shop, business, cultural, social, and other. The 2003 Canadian Travel Survey (Statistics Canada 2005b) identified trip purposes to visit friends or relatives, for pleasure, for personal or not stated, and for business and conventions. The U.S. Department of Transportation (2000) identified sources of trip purpose data and indicated that the Nationwide Personal Travel Survey (NPTS) has a large sample size and is publicly available.

Raford and Ragland (2003) calculated pedestrian risk from an estimation of pedestrian volume. The method of volume prediction generated pedestrian movement potentials considering layout and connectivity of urban streets, compared outputs to sampled pedestrian counts at key locations and factored in land use indicators such as population and employment density.

In these cases, pedestrian-vehicle collisions were the critical concern for assessing pedestrian risk. Predicted pedestrian volume prioritized new construction projects for pedestrian facilities, mainly at sites where sidewalks were missing. Because of the lack of research on prioritizing maintenance of sidewalks, the literature review had not found a documented measure of risk reflecting the potential for sidewalk trip injuries.

The method used for estimating pedestrian traffic volume in this research incorporated suitable components from the literature to fit the need of a municipal environment and to fit the purpose of prioritizing existing sidewalk locations for repairs, not new sidewalk construction projects for influencing the choice to walk. The purpose was not to predict future demands on sidewalks but to approximate the current traffic flow.

2.2.2 Measuring Quality of Life

Quality-adjusted life years (QALYs) measures quality and quantity of health. QALYs has been extensively researched and widely applied in the areas of medical decision analysis (Miyamoto et al. 1998), cost utility analysis of health care programs (Bleichrodt et al. 1997), environmental impact assessment of alternatives (Cohen et al. 2003) and outcome measures of clinical studies and in population health surveys (Feeny et al. 2002) . QALYs combine into one measure two important outcomes of health, namely quality of life and quantity of life. Bleichrodt and Miyamoto (2003) identified that the measurement of QALYs belongs to the general field of multi-attribute utility theory.

Extensive research has been performed on the characterization, robustness, limitations and implications of QALYs for axioms defining expected utility. Some authors include Bleichrodt and Miyamoto (2003), Miyamoto et al. (1998), Bleichrodt et al. (1997) and Loomes and McKenzie (1989). Evaluation and comparison of different health measures for specific applications have been documented: Elvik (1995) for describing traffic injury consequences for public health, Dickie and List (2006) for economic valuation of health for environmental policy, Morrow and Bryant (1995) for measuring disease burden due to disability and premature mortality, Chancellor et al. (1997) for economic evaluations of cancer therapies that includes quality of life consideration, and Gold et al. (2002) for measures of population health.

Smith and Kenney (2005) provided a prescriptive model for health, safety and consumption decisions. The model allowed the study of tradeoffs between income and health risks under uncertainty by integrating financial tradeoffs and consumption decisions made to either improve health or risk health loss.

The use of QALYs in decision analysis and Markov modelling was described by Inadomi (2004) and applied to a clinical scenario for the evaluation of screening strategies to decrease mortality from cancer. A health-related quality of life measure

(HRQL) for chronic health states called a health utility index (HUI) was developed by Fenny et al. (1998) to assess the quality of life for children on cancer therapy and afterward for their long-term evaluation. In a cost-effectiveness analysis, Cohen (2003; 2005) quantified resulting health damages in terms of lost QALYs from the reduction of emissions for three fuel alternatives for school buses. Coyle et al. (2003) estimated the health impact from potential changes in sulphate air pollution within Canada using QALYs in a decision analytic model applying Monte Carlo simulation techniques.

For non-chronic health profiles, the assumption of additive separability over discrete time intervals was added so that Markov models could be applied (Bleichrodt et al. 1997). Additive separability means that separate utilities evaluating each time period can be added together without overlap. QALYs lost or gained are calculated by multiplying the health utility index (HUI) describing a discrete health state by the duration of that health state. The generic multi-attribute preference-based measure of health status was developed by Feeny et al. (2002) using results of two preference surveys of the general Hamilton, Ontario population age sixteen years and older. This Health Utilities Index Mark 3 (HUI3) consists of eight measured attributes of health status, which include vision, hearing, speech, ambulation, dexterity, emotion, cognition and pain. There are five or six levels per attribute distinguishing 972,000 unique health states (Table B-1).

The decision to use QALYs as the outcome measure of the decision model used in this research was based on its proven extensive use and varied application as an accepted measurement of health in many fields of research. The scope of this thesis does not include validating the use of QALYs measurement for this application.

2.2.3 Decision Model Methodologies

The problem studied contains an extensive amount of uncertainty, has complex consequences, needs to consider community values and satisfy multiple objectives, and has little existing data to validate the magnitude of decision consequences. Objectives include optimizing life cycle cost, maximizing pedestrian safety, providing excellent customer service, and managing budget and resource constraints. Decision analysis facilitates evaluation of decision alternatives for highly uncertain and complex problems with sensitive decision outcomes.

To review decision model methodologies that are pertinent to the specific application of sidewalk maintenance and rehabilitation prioritization decisions, the following assumptions are stated:

- There is one group of decision makers with consistent values and objectives.
- There are multiple interested stakeholders.
- Multiple conflicting objectives influence the decision alternatives.
- There is limited directly relevant data.
- There exist uncertainties that pose significant organizational risks.
- The decision alternatives are discrete.

Jaszkiewicz and Slowinski (1999) stated that many psychological studies indicate that a decision-maker has limited capability to process multi-criteria information when making a decision. Choosing the best solution from a set of alternatives is a psychologically difficult task. Wierzbicki (1983) stated that psychological experiments have found that the human mind can process between five and nine objectives. These research findings substantiate the need for a decision aid such as the application of a decision model methodology for important decision-making.

Mussi (2002) stated that decision theory involves aspects of utility theory and probability theory. The maximum expected utility principle is the fundamental assumption of decision theory. That means that if a person were offered a choice among lotteries, the person would choose the one with the maximum expected utility. Mussi identified that consequence types are linked to evidence along with probabilistic inferences using Bayesian networks. The visual representation of this relationship is an influence diagram. The fundamental rule for probabilities on which this network is based is Bayes' Rule:

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)} \qquad [2.1]$$

Multicriteria decision models (MCDM) are used to merge assessment methods with judgement methods to perform decision analysis (Vreeker et al. 2002). Methods can incorporate multiple dimensions into evaluation of problems such as social, cultural, ecological, technological, and institutional and can consider conflicting stakeholder objectives (Vreeker et al. 2002). In MCDM, the decision maker must fulfill conflicting goals while satisfying constraints of the problem. In many cases, decision-making criteria are generally incompatible with each other.

Providing support for the use of decision analysis, Aven and Sandve (1999) clearly outlined the problems with classic maintenance optimization models and the benefits for using decision analysis for real world applications. Classic models attempt to objectively represent the truth whereas decision analysis considers observable quantities and subjective probabilities to make decisions about policy, alternative solutions, and the effect of measurement. An interesting difference was noted for defining uncertainty in the two fields. In the classic statistical approach, uncertainty means the accuracy of estimated probabilities and values used whereas in the fully Bayesian approach, uncertainty is the degree of belief or probability of the values used.

Aven and Pörn (1998) provided a supportive argument for the Bayesian approach rather than classical statistical approach to assess risk consequences for real world decisions. In practice, some quantities are unobservable such as hazard rates whereas other quantities that can be observed and predicted, such as accident events, can effectively represent these unobservable quantities. They viewed risk analysis as a tool to debate and argue safety policy, not as a representation of actual future events.

Siskos and Spyridakos (1999) identified four theoretical trends that have progressed over the last twenty-five years improving multicriteria analysis. The value systems approach quantitatively represents the preferences of the decision-maker to assess decision alternatives providing comparative information to make a choice. The outranking relations approach provides a qualitative non-comparably measured assessment of the decision-maker's preferences to construct a relation between and ranking of decision alternatives. The disaggregation-aggregation approach analyzes the decision-maker's behaviour and cognitive style and incorporates these findings into a value system to provide knowledge to the decision-maker. The multiobjective optimization approach or multiple objective linear optimization programming (MOLP) (Chen and Lin 2003) is used to solve problems that do not have discrete alternative decisions (Siskos and Spyridakos 1999). The MOLP approach was not a candidate for this problem. The value system approach was incorporated in this decision analysis.

At least four types of evaluation styles were identified by Vreeker et al. (2002) upon their review of transportation planning literature. These were the single criteria monetary decision approach using cost-benefit or cost-effectiveness principles, utility theory approach using quantitative evaluation of decision-maker preferences, learning approach where the decision-maker's views are referred to throughout the decision process and collective decision approach using multi-person negotiation techniques. The first style was not considered because there is not a single economic objective. Vreeker et al. stated that cost benefit analysis is inappropriate when qualitative criteria influence the decision choice and when there are information shortages. The utility theory approach was chosen for evaluating this decision model.

Chen and Lin (2003) stated that a multiattribute utility function (MAUF) can represent decision-maker preference as well as normalize evaluation criteria so they become compatible. The most common functions used are additive, multiplicative, and multilinear. The health utility index used in this research is a multiplicative MAUF.

Corner and Kirkwood (1991) stated that:

> …many decision analysis applications address decisions with strategic or policy implications. These are generally characterized by one or more of the following characteristics: multiple conflicting objectives, limited directly relevant data, multiple interested stakeholders, alternatives that differ from each other qualitatively as well as quantitatively, uncertainties that pose significant organizational risks, and long time horizons.

2.3 Current Prioritization Strategies

The City of Portland (1998) used two indices that were combined to prioritize new construction projects by evaluating the potential of these new facilities to increase walking opportunities. The Oregon Department of Transportation and the Oregon

Department of Land Conservation and Development were responsible for their development. The indices, pedestrian potential index and deficiency index, were used by some cities in British Columbia including Kamloops (City of Kamloops 2002), Kelowna (Geddes et al. 2005), and Prince George (Geddes et al. 2005). The pedestrian potential index identifies which physical improvements would most likely increase walking trips because other environmental factors that favour walking are already in place. The deficiency index identifies places where construction improvements might fix insufficiencies of pedestrian environments. Geddes et al. (2005) proposed a modification to this prioritization method for the development of a priority index for existing sidewalk repairs identified in the City of Prince George.

There was not a standard table of pedestrian traffic volumes by land use compared to the standard tables provided by the Institute of Transportation Engineers (ITE) for vehicular traffic by land use attractors. In practice, there are many automatic ways to obtain actual vehicular traffic counts. There are few automatic methods for counting pedestrian traffic on sidewalks. Manual counting plus determining age and gender of pedestrians is extremely difficult as well as labour intensive. Adding to the complexity, unlike automobiles on roads, pedestrians enter and exit the sidewalk at almost any point and there are no mandated rules for sidewalk navigation (Beltz and Huang 1998).

Considering the complexities of actual measurement, this research applied a collection of concepts from documented methods that were used for theoretically predicting future or current pedestrian traffic volumes. Many researchers used an aggregating method of pedestrian estimation considering adjacent land use attractors, other physical attributes associated with land design and existing structures, and resident population characteristics found within a specified distance from the location under investigation.

This research extended this method by estimating the mix of age cohort and gender of this pedestrian traffic. In the test application, travel statistics, resident population count, and commuter statistics were added together to give an estimated total daily population for the city. Variables describing the city were quantified and totalled. Each location under assessment attracted a proportion of this total daily population. Relative determination ensured that the pedestrian volume at each location was calculated considering its ability to attract people in relation to the entire city.

2.4 Literature Search Summary

Public sidewalks function primarily as a safe right-of-way for pedestrians to travel from their origin to destination for utilitarian or recreational purposes. The removal of trip hazards is primarily a mitigating action to improve safety for pedestrians or in other words, to reduce pedestrian risk of trip injury during sidewalk use. A direct measure of this risk consequence is the reduction in the quality of life for a pedestrian who has unsuccessfully navigated the sidewalk or tripped. Quality of life was estimated quantitatively using the well-researched utility index called quality-adjusted life years (QALYs). Probabilities for trip injuries as well as the type of injury and length of recovery were predicted from existing data collected by various government agencies as well as from documented research results. Assuming a trip injury event is a stochastic process, Monte Carlo simulation can be applied during sensitivity analysis. A stochastic process is a process of random events that can be described by a probability distribution. Because of the high amount of uncertainty, decision analysis was the method of choice to model the problem addressed in this thesis.

CHAPTER 3

MODEL DESIGN

3.1 Introduction

Prioritization processes for sidewalk maintenance and rehabilitation work in the City of Saskatoon use varied criteria, result from subjective decision-making and consider available funding and sidewalk condition as primary factors. City Council had allocated additional funding for sidewalk rehabilitation with the directive to improve sidewalk safety. To demonstrate the effectiveness of operational decisions, measures must be used to assess decisions for safety improvements made to sidewalks.

Many decisions are made before a list is generated of trip hazard locations identified for maintenance or rehabilitation. The proposed decision model prioritizes a given list of locations so that removal of trip hazards is most probable to minimize the overall risk to pedestrians using public sidewalks in the city. This process adds to the defence of due diligence supporting reasonableness of response times and proving consistent decision-making for the removal of known trip hazards.

Objective and equal assessment of each location, problems of small numbers and accuracy of estimations were dealt with by quantifying physical variables that describe the entire city. Each location was assessed equally, using ratios of measurable common variables of influence. For example, pedestrian traffic volume at a sidewalk location was relatively represented by apportioning the total daily population in the city to a location using observable attributes of the physical environment that attract people taking trips for specific purposes in the local area versus total city.

Prioritization was performed by comparing the magnitude of risk for sidewalk use at each location considering local pedestrian characteristics. Four factors influenced the magnitude of risk. First, pedestrian traffic volume quantified the use of a sidewalk or the arrival rate of pedestrians at a trip hazard. Second, the proportion of age groups and gender influenced the frequency of trip events, the distribution of injury types, and the duration of recovery from injury. Third, probabilities for trip injury events by gender and age group and estimates for the duration of recovery by age group and injury type provided information about the overall impact on quality of life for the injured individuals. Last, the loss of quality of life was predicted by estimating the health utility index for each combination of injury type and body part affected for three stages of recovery: bed days, restricted activity days, and reduced activity days. The magnitude of quality-adjusted life years lost provided a theoretical risk used to rank competing unsafe sidewalk locations. This assessment supports objective decision-making related to repair actions and response times that maximize safe pedestrian navigation of all public sidewalks. Figure 3.1 illustrates the general concepts of the methodology developed in this research. Figure 3.2 identifies the input variables used in the model.

To clarify, trip event or trip injury event refers to the physical act of falling down after stumbling. Only trip events resulting in an injury with a recovery duration that lasts for more than half of a day are considered. A trip refers to the transport of a person from an origin to a destination. A trip purpose is the person’s motive for taking the trip. Wherever possible, Statistics Canada data have been used to reflect actual representation of Canada, Saskatchewan or Saskatoon.

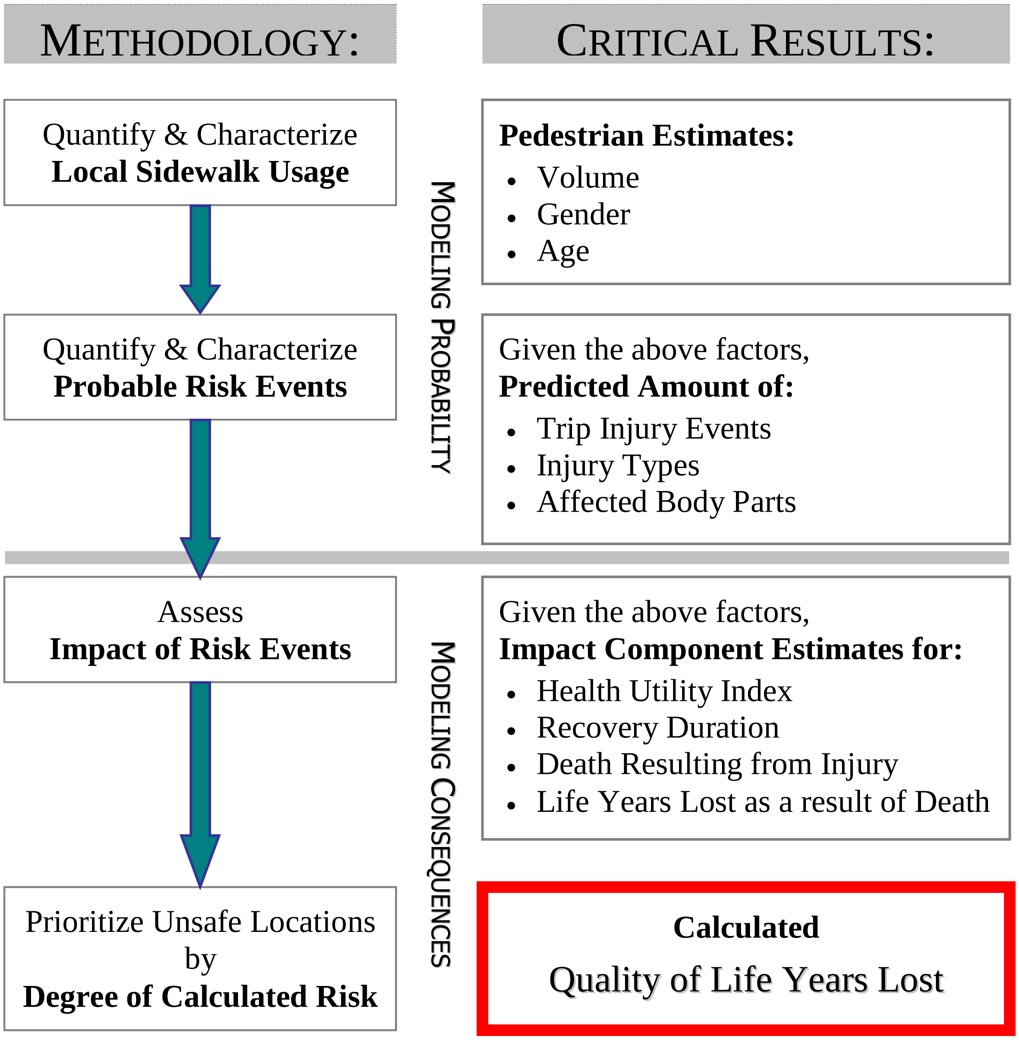

Figure 3.1 Risk-Based Prioritization Methodology and Critical Results

3.2 Input Estimation Methodologies and Sources

Figure 3.2 identifies all general input variables and modelling function (diagram grouping) used in the decision policy for sidewalk prioritization.

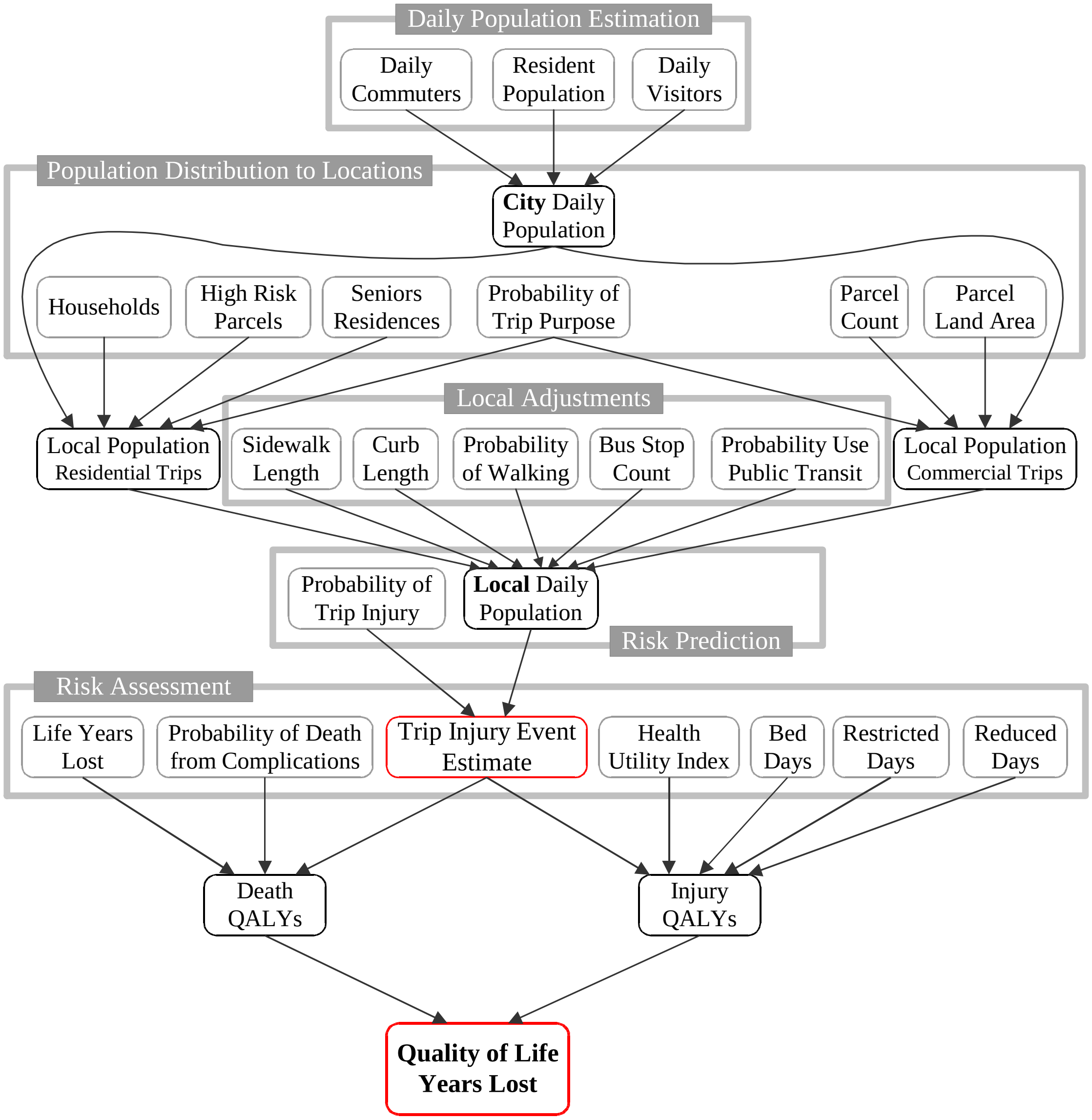

Figure 3.2 Decision Model Variables and Group Functions

3.2.1 Estimating the Total Daily Population of Saskatoon

In this model, predicted average daily pedestrian traffic volume at a sidewalk location was a proportion of the entire city’s total daily population estimate. Three significant sources contributed to the city’s daily population: (1) travellers and (2) commuters to Saskatoon, and (3) residents of Saskatoon. Estimates were determined using various sources of Statistics Canada data. The top group box shown in Figure 3.2 identifies the three significant contributors to the average city daily population.

The quantity, age, and gender of travellers to Saskatoon were estimated from the 2003 Canadian Travel Survey data (Statistics Canada 2005b). These visits were divided into time primarily spent in residential areas and time spent primarily in commercial areas. Commuter contribution to the total daily population was loosely approximated for residential and commercial purposes because a data source was not found for commuter travel to Saskatoon. The population base used for this approximation was the Saskatoon Health Region (Statistics Canada 2001a). Resident population counts for Saskatoon were provided by Statistics Canada 2001 census data (2002a). The sum of each source by gender-age group provided the total daily population estimate for the city. The omission of estimated residents travelling out of Saskatoon was intentional to simplify the estimation process. The resulting population was accepted as somewhat over-estimated.

3.2.2 Estimating Local Sidewalk Traffic and Pedestrian Characteristics

This research differs from previous studies that estimated pedestrian traffic volume because it predicted the pedestrian characteristics, age and gender. Researched evidence indicated that the frequency of trip events as well as the type of trip injury varies by gender and age group (Eilert-Petersson and Schelp 1998).

To assess each location consistently, first the daily population was estimated for the entire city. By apportioning the total population to various locations in the city, relative assessment was maintained even though the total, absolute or actual pedestrian traffic volume may be significantly different from the calculated value.

The data collected by Statistics Canada for trip injury events estimated actual events experienced by the Canadian population that year. Yearly time spent as a pedestrian on public sidewalks or sidewalk exposure was not included in the survey. In this research, exposure was assumed similar throughout the Canadian population. Therefore, during one year of residing in Canada, a certain number of trip, slip or stumble events on a sidewalk, street or highway did result in a fall injury of a certain type affecting a certain part of the body. In this research, trip injury events were calculated from the total daily population-equivalents estimate, not duration of the year spent walking on public sidewalks or pedestrian traffic volume. The assumption was, if a group of people are nearby a location, they are the most probable group to walk on the sidewalk at that location.

To illustrate the concept of population-equivalents, a person living in neighbourhood A, is downtown for 9 hours, and in neighbourhood B for 3 hour. This person would contribute 0.5 person-equivalents to the daily population of neighbourhood A, 0.375 person-equivalents to downtown, and 0.125 person-equivalents to the daily population of B. The probability of taking a trip for a certain purpose uses this same underlying principle whereby the probability reflects the proportion of trips taken for a certain purpose in a year compared to the number of trips made for any purpose in that year.

Sidewalk traffic was relatively estimated by identifying the portion of the total daily population attracted to the influence area of the sidewalk location. Assessing the location’s ability to attract pedestrians involved measuring the proportion of physical variables found in the influence area that also contribute to the city total. Table 3.2.2.1 provides the measurement units of physical features used to quantify the feature’s ability to attract a trip purpose.

Building area may be a more accurate measure to assess attraction rates for most of the commercial variables but this information may not be readily available in municipal databases. In the City of Saskatoon, parcel counts and land area are standard data fields that are linked to property use codes standard in the city planning profession. Counts are a simple understandable measure used for weighting. In Saskatoon, due to the large variance in parcel size at hospitals and medical offices or schools, other educational institutions, and daycares, land area was chosen as the measure for these trip attractors.

Table 3.2.2.1 Variables used to Distribute Daily Population by Trip Purpose

Trip Purpose	Physical Feature	Measurement
Home	Household	count
Visiting at Households	Household	count
Business	Land Parcel	count
Shopping or Buying	Land Parcel	count
Restaurants or Eating Out	Land Parcel	count
Entertainment or Recreation	Land Parcel	count
Education or Daycare	Land Parcel	land area
Spiritual	Land Parcel	count
Medical	Land Parcel	land area

Parcel information including property use identification exists in a municipal database. There were, however, some inconsistencies for property use identification. For example, some commercial parcels identified only one property use even though the property contained multiple businesses. Businesses situated in a multi-storey building on one land parcel were not identified separately. Investigation of these inconsistencies and finding a resolution was beyond the scope of this research. This lack of detail may affect accuracy of the model especially at locations where there was a concentration of business-unit to parcel-unit ratios greater than one.

Combined with attraction rate estimations, trip purpose probabilities for each gender-age group distributed the city population to the area nearby sidewalk locations. Probabilities were calculated using the proportion of trips taken for a specific purpose compared to all trips taken. Further adjustments to population-equivalents reflected expected local sources of influence such as sidewalk availability, high bus stop concentrations, gender-age characteristics linked to transportation mode choice, and high-risk pedestrian source considerations. The remainder of this section provides a detailed explanation of the methodology for estimating local pedestrian traffic.

Estimating the Probability of Trip Purpose Given an Age and Gender Group

A detailed Canadian source for trip purpose data was not found so the 2001 National Household Travel Survey was utilized (U.S. Dept. of Transportation Federal Highway Administration 2002). To apply the U.S. data, it was assumed that Canadians manage life by taking care of daily needs in the same way as Americans. For example, trips made in normal daily living include going to get food, buying items, visiting friends and relatives, going to school, going to work, going out for entertainment, going to a place of worship, taking care of business, looking after personal health needs, and returning home.

The U.S. travel data was confined to comparably sized cities with the same available modes of transportation as those available in Saskatoon. Thirty-six trip purpose identifiers were combined to produce nine groups of generalized trip purposes (Table C-3) that were assumed attracted to a set of property use codes (Tables C-4 to C-9). The resulting conditional probability estimates are found in Tables 4.2.2.2. A redistribution of the probabilities was calculated to apply to non-residents where trips to home and trips to educational facilities and daycares were assumed not applicable. The resulting probabilities for visitors are located in Table 4.2.2.3. During model development, it was determined that the probability associated with trips to educational facilities and daycares needed further detail. These probabilities are identified in Table 4.2.2.4. Details of the process used to extract trip purpose probabilities from the travel data and calculations for resident trip purpose probabilities as well as the confinement and groupings for non-resident probabilities are explained in Appendix A starting at Estimation Details - Trip Purpose Probability Given Gender-Age Group.

Pedestrian Traffic Area of Influence

Two distances were used for modelling attractors that affect a location. Hess et al. (1999) defined a radius of 800 metres for a pedestrian travel catchment area. Randal and Baetz (2001) stated that a reasonable walking distance was 400 metres. IBI Group (2005a) defined a transit-oriented development area of 400 to 800 metres diameter from a bus station or bus stop. The National Guide to Sustainable Municipal Infrastructure (NRC-CNRC 2004) referenced research suggesting that seniors normally walk within two blocks of their homes. For this study, a circle of radius 400 metres centered over the sidewalk location, called **influence area**, identifies local land characteristics and bus stops. A 300-metre radius captures specific seniors' residences nearby the location.

The use of radius to identify attributes in close proximity to a location was a compromise to the preferred option of sidewalk length. For example, in a neighbourhood with standard 40 X 60 ratio block size, sidewalk lengths within 400 metres of a location is a diamond shape, not a circle. In addition, the use of radius ignores any barriers to pedestrian routes. Identifying possible sidewalk routing from a location was beyond the scope of this research. Due to the preliminary nature of this research, identifying attributes using a lineal distance of 400 metres radius was easily accomplished with available geographic tools as shown in Figure 3.3. The circle identifies the area of influence. The different colour land parcels reflect dissimilar groups of property uses.

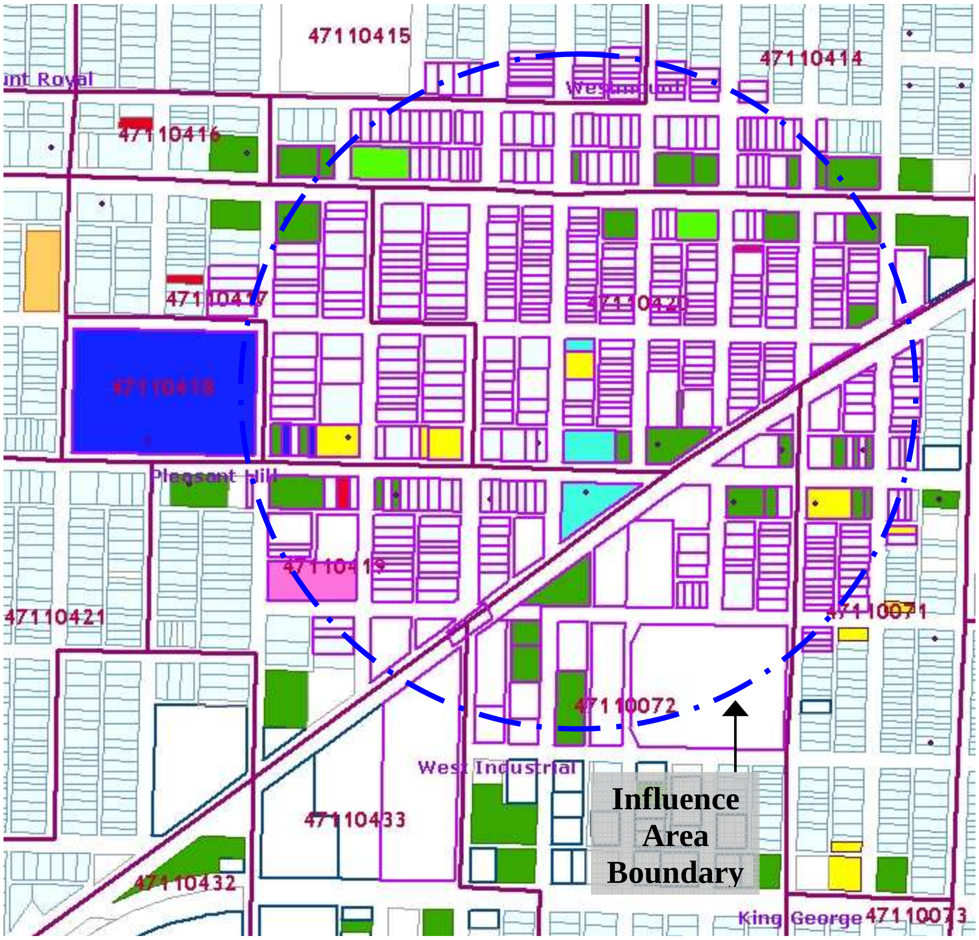

Figure 3.3 Area of Influence Used for Summary Statistics by Property Use

Physical characteristics identified as person attractors within the specified radius of a location were measured in parcel counts and land area by property use type. Measurements were taken for bus stop counts, identified seniors residences, household counts, and sidewalk versus curb lengths. Property use types were grouped by those generally indicative of attracting people due to various trip purposes such as residence, business, shopping or buying, restaurant, entertainment, education or daycare, spiritual, medical and high risk. Property use types included in each group are listed at the end of Appendix C in Tables C-4 to C-9.

Estimating Local Population and Household Counts

To understand differences in the total daily population at sidewalk locations, population estimates by gender-age groups as well as household counts were required with more accuracy. For 2001, population counts and household counts were provided by dissemination area (Statistics Canada 2001b; Statistics Canada 2001d; Statistics Canada 2002a; Statistics Canada 2002b). Dissemination area (DA) is a relatively stable geographic unit composed of one or more blocks and usually contains a population of 400 to 700 (Statistics Canada 2002c).

Figure 3.4 illustrates the general inputs for determining the number of residents and households within the influence area surrounding a sidewalk location using dissemination area (DA) statistics, non-private household counts and land area. The detail shown in Figure 3.4 is not included in the main variable diagram, Figure 3.2.

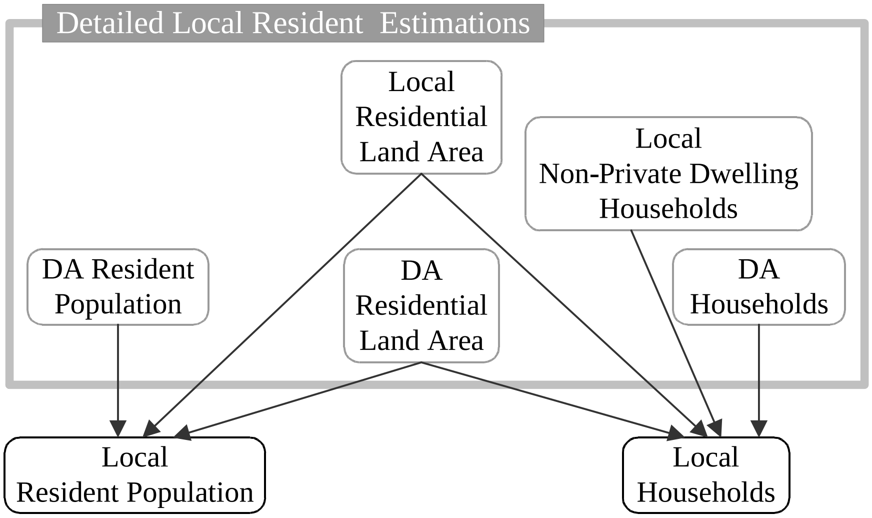

Figure 3.4 Inputs to Estimate Local Resident Population and Households

Statistics Canada stated that households in non-private dwellings were not included in the DA household data. These include households residing in dwellings classified as institutional, communal or commercial. Some seniors' complexes were not accounted for based on this definition so non-private household estimates were added to the local and total number of households in the city to account for this exclusion. The locations and estimates for specific seniors' complexes were gathered from an online directory

(Saskatoon Public Library 2006). Conversely, Statistics Canada stated that populations residing in non-private dwellings were reported in the counts provided by DA.

Local Population Detail

Population counts in the area of influence surrounding a sidewalk location were estimated using a weighting process. Weights represented the proportion of residential land area found within the influence area and dissemination area compared to the total residential land area in the DA. Figure 3.5 is the bottom left dissemination area extracted from the influence area identified in Figure 3.3. Shaded in purple, this diagram shows the residential land parcels that are contained by the area of influence as well as the dissemination area. The remainder of the outlined parcels are residential land parcels within the dissemination area but not within the influence area.

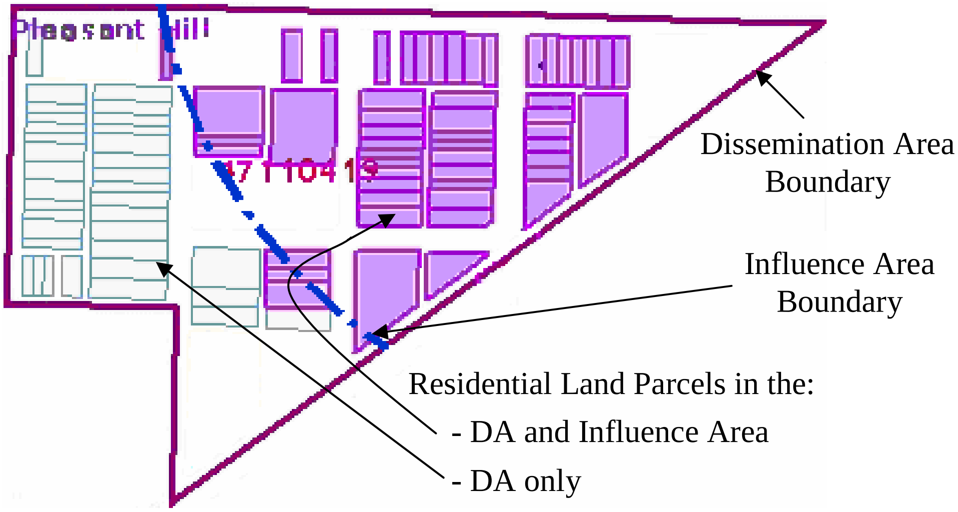

Figure 3.5 Residential Land Parcels in the Influence Area vs. Dissemination Area

Converting the concepts from this diagram to logic, if Λ_{rDA_x} stands for the residential (r) land area (Λ) within a dissemination area x (DA_x), then $\Lambda_{rL\cap rDA_x}$ represents the residential land area in the influence area (L) and ($\cap$) DA_x. The weight, Λ_{rDA_x} divided by $\Lambda_{rL\cap rDA_x}$, is used to apportion population counts by DA to those residing in the area of influence.

Gender and ages were grouped into 20 categories. Let i and j express, respectively, gender categories and age cohorts. Then ij is a gender-age pairing. If P_L corresponds to the local resident population, then P_{Lij} identifies the division of local resident population by gender-age group. Categories for gender groups are i = 1 (male) and 2 (female). Age groupings include j = 1 (ages 0 to 11 years), 2 (12-14), 3 (15-19), 4 (20-24), 5 (25-34), 6 (35-44), 7 (45-54), 8 (55-64), 9 (65-74), and 10 (75 years or older).

A weighted sum of each population count by DA ($P_{DA_x ij}$) identified with some portion within the influence area provides an estimate of local resident population within 400 metres of a sidewalk location. This estimation procedure is symbolized by

$$P_{L\,ij} = \sum_x \left[\left(\frac{\Lambda_{rL \cap rDA_x}}{\Lambda_{r\,DA_x}} \right) P_{DA_x\,ij} \right] \quad \forall \text{ x with some portion in L.} \qquad [3.1]$$

In words, the local daily population count by gender-age group within 400 metres of a sidewalk location is equal to the sum of weighted population counts for each group in each dissemination area having some portion of land area in the influence area. The weighting is determined from the proportion of the dissemination area's residential land area in the influence area compared to the entire DA residential land area.

LOCAL HOUSEHOLD DETAIL

The local household (H_L) estimation process uses the same residential land area weights described previously for determining local population counts. H_{DA_x} signifies the household count by dissemination area provided by Statistics Canada. These counts did not include households in non-private dwellings. $H_{\alpha L}$ denotes the household count in non-private dwellings within a smaller influence area of 300 metres radius. Typically, residents in non-private dwellings are elderly or high-risk so, because mobility reduction is assumed, a shorter distance of 300 metres radius was used to estimate their influence. The estimate for local household count is equal to the summation of weighted private household counts for each DA found within the influence area plus the non-private household count. The following equation estimates the household count within 400 metres that is expected to influence the sidewalk location:

$$H_L = \sum_x \left[\left(\frac{\Lambda_{rL \cap DA_x}}{\Lambda_{r\,DA_x}} \right) H_{DA_x} \right] + H_{\alpha L} \quad \forall\ x \text{ with some portion in } L. \qquad [3.2]$$

Estimating the Local Total Daily Population

Land parcel counts and parcel areas were summarized by attractor type for those contained by the 502,655 square metres surrounding the sidewalk location (Equation A-12), called influence area, as well as the total contained by the city limits. These land parcel statistics were inputs to calculate weights reflecting the influence area's contribution to the entire city for ability to attract people.

RESIDENTIAL ATTRACTION

People are attracted to residential areas to visit friends and relatives or to return home. Any city resident or non-resident can enter the influence area to visit people in a household and every person living in the area of influence will enter to return home. It is prudent to add extra consideration for the elderly and other high-risk groups residing in the influence area. Figure 3.6 shows the general inputs needed to distribute the city daily population attracted to local residential areas.

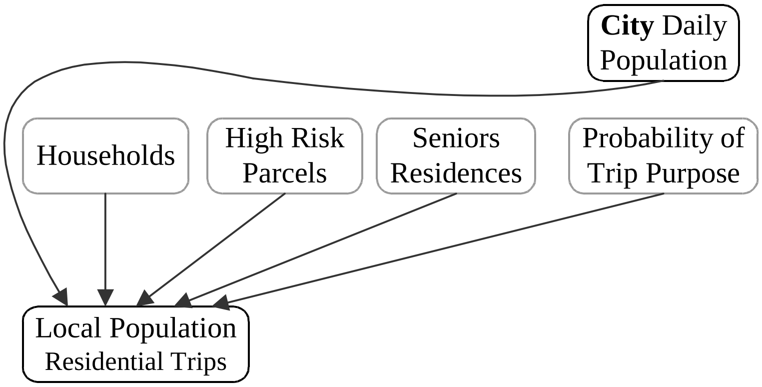

Figure 3.6 Inputs to Estimate Population-Equivalents Attracted to Residential Areas

The first component to assess residential attraction considers trips for the purpose of visiting friends and relatives. If H_T indicates the total number of households in the city then H_L designates the household count in the area of influence (L). The ratio of local households versus total city households provides the attraction weight of the influence area representing its ability to attract visiting trips to residences.

There were two sources of visitors. Any non-resident and city resident can visit a household in the area of influence. First, if V_{rij} signifies the number of non-resident visitors in the city with the primary purpose of visiting friends and relatives, then the household attraction weight can be applied directly to these visitors to estimate the number attracted to the influence area. Second, if $P_{\theta ij}$ identifies the city resident population and $þ_{v|\Phi_{ij}}$ corresponds to the probability of a city resident, given their gender-age group (Φ_{ij}), taking a trip for the purpose of visiting friends and relatives (v), then the product $P_{\theta ij}\, þ_{v|\Phi_{ij}}$ estimates the contribution of all city residents who are on trips to visit friends and relatives in the city. When this contribution is multiplied by the household attraction weight, the result is the estimate of population-equivalents attracted to the influence area for the purpose of visiting friends and relatives who are city residents.

The second component to assess residential attraction considers trips to return home. Therefore, this applies only to the population residing in the influence area. If P_{Lij} characterizes the local population and $þ_{h|\Phi_{ij}}$ stands for the probability of a city resident given their gender-age group taking a trip to return home, then the product $P_{Lij}\, þ_{h|\Phi_{ij}}$ estimates population-equivalents attracted to the influence area to return home.

These two components, trips to visit friends and relatives and trips to return home, determine the contribution to the daily population attracted to residences in an influence area. These base contributions are embodied in each of the equations 3.3, 3.4, and 3.5.

The following equation calculates the estimated daily population-equivalents by gender and age group (λ_{rij}) including city residents and non-residents ages less than 25 years old entering an influence area because they are attracted to households for the purpose of visiting friends and relatives (v) or because they are local residents returning home (h):

$$\lambda_{rij} = \left[\left(\frac{H_L}{H_T}\right)\left[\left(P_{\theta ij}\ \text{þ}_{v|\Phi_{ij}}\right) + V_{rij}\right]\right] + \left(P_{Lij}\ \text{þ}_{h|\Phi_{ij}}\right) \quad \forall\, i, j<5. \qquad [3.3]$$

Extra deliberation was performed for residents who are elderly or in high-risk groups by implementing two weights that increase the local resident contribution to return home. Since it is assumed that the probability of injury increases for elderly or high-risk groups, the model provides some compensation by simply increasing the population-equivalents for residents returning to their home who are in the gender-age groups thought to contain persons living in parcels identified as high-risk or seniors' residences.

Assume that parcels with the land use designation 'high-risk' apply to residents in the age groups 25 years or older (j=5, 6, 7, 8, 9, 10). Let N_z symbolize the total number of high-risk land parcels in the city and n_z denote the count of high-risk land parcels within the influence area. Then the ratio of local count versus total number produces a high-risk group weighting used to increase those eligible resident age groups returning home.

The following equation calculates the estimated daily population-equivalents (λ_{rij}) including city residents and non-residents ages 25 to 54 years old entering an influence area. They are attracted to households for the purpose of visiting friends and relatives or they are local residents returning home with added consideration for high-risk groups residing in the influence area:

$$\lambda_{rij} = \left[\left(\frac{H_L}{H_T}\right)\left[\left(P_{\theta ij}\ \text{þ}_{v|\Phi_{ij}}\right) + V_{rij}\right]\right] + \left[\left(P_{Lij}\ \text{þ}_{h|\Phi_{ij}}\right)\left(1 + \frac{n_{zL}}{N_z}\right)\right] \quad \forall\, i,\ j = 5,6,7. \qquad [3.4]$$

Additional concern for seniors' residences is assumed to apply to ages 55 years and older (j=8, 9, 10). Let H_{gT} represent the total number of seniors' households in the city and H_{gL} stand for the seniors' household count in the influence area. Then the ratio of the seniors' household count for the influence area to the total city count generates a senior's residence weight to be applied to eligible resident age groups returning home.

The following equation calculates the estimated daily population-equivalents (λ_{rij}) including city residents and non-residents ages 55 and older entering an influence area. They are attracted to households for the purpose of visiting friends and relatives or they are local residents returning home. Additional weighting is included to be sensitive to high-risk groups and the elderly residing in seniors' residences in the influence area:

$$\lambda_{rij} = \left[\left(\frac{H_L}{H_T} \right) \left[\left(P_{\theta ij}\, \text{þ}_{v|\Phi_{ij}} \right) + V_{rij} \right] \right] + \left[\left(P_{Lij}\, \text{þ}_{h|\Phi_{ij}} \right) \left(1 + \frac{n_{zL}}{N_z} + \frac{H_{gL}}{H_{gT}} \right) \right] \quad \forall\, i, j > 7. \qquad [3.5]$$

Refer to Figure 3.6 for a diagrammatic representation of the last three equations.

COMMERCIAL ATTRACTION

Generally, land parcel counts are a simple effective measure of trip attraction in Saskatoon. Due to the large variance in parcel size associated with hospitals and medical offices or schools, other educational institutions, and daycares, land area was alternatively chosen as the measure for these trip attractors in this city. Figure 3.7 illustrates the general inputs needed to distribute the city daily population attracted to local commercial areas.

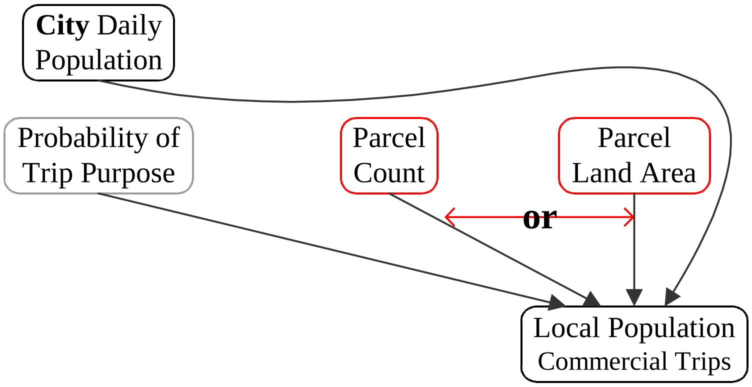

Figure 3.7 Inputs to Estimate Population-Equivalents Attracted to Commercial Areas

People are attracted to commercial land parcels for various purposes. For those attractors assessed using land parcel count, corresponding commercial trip purposes (k) include the following classifications: for work or personal business (b), to shop or buy (a), to eat out (f), for entertainment (e) and for spiritual purposes (w). If N_k indicates the total number of the commercial land parcels in the city that attract trip purpose k, then n_{kL}

denotes only those parcels found within the area of influence. The ratio of the local count versus total number is the proportion of the total number of land parcels people taking a trip for the purpose k can be attracted to in the area of influence. This commercial attraction weight was used to apportion the total population-equivalents in the city taking a trip for purpose k to only those taking that trip within the influence area surrounding a sidewalk location.

City residents and non-residents contribute to the total number of population-equivalents in the city taking a trip for commercial purpose k. Let $P_{\theta ij}$ embody the city resident population and let $\text{þ}_{k|\Phi_{ij}}$ represent the probability of a city resident, given the gender-age group, taking a trip for commercial purpose k. Then the product $P_{\theta ij}\,\text{þ}_{k|\Phi_{ij}}$ estimates the population-equivalents contributed by city residents attracted to commercial areas within the city for trip purpose k. In addition, let V_{cij} identify non-residents primarily in the city for commercial purposes and let $\text{þ}'_{k|\Phi_{ij}}$ indicate the probability of a non-resident, given the gender-age group, taking a trip for commercial purpose k. Then the product $V_{cij}\,\text{þ}'_{k|\Phi_{ij}}$ estimates the population-equivalents contributed by non-residents attracted to commercial areas of the city for trip purpose k.

The sum of city residents and non-residents attracted to commercial areas within the city for trip purpose k is multiplied by the commercial attraction weight for that purpose contributed by the influence area. The result is an estimate of the daily population-equivalents (λ_{kij}) by gender-age group on a trip for the commercial attraction purpose k within the area of influence surrounding a location. This calculation is symbolized by

$$\lambda_{k\,ij} = \left(\frac{n_{kL}}{N_k}\right)\left[\left[P_{\theta\,ij}\;\text{þ}_{k|\Phi_{ij}}\right] + \left[V_{c\,ij}\;\text{þ}'_{k|\Phi_{ij}}\right]\right] \quad \forall\ i, j. \qquad [3.6]$$

Distribution of the city daily population on a trip for the purpose of education or to daycare employed land parcel area, not parcel count, to determine local attraction weighting. Three distinct attractors were identified for educational land uses including elementary school (E), high school (Y), and trade school or college (U). No land parcels were identified for daycare so it was assumed that most daycares were in educational facilities.

Let Λ_{ET} represent the total elementary school land area in the city. Let Λ_{dT} stand for all educational land area in the city where d includes all elementary school, high school, and trade school or college land areas. Then Λ_{EL} and Λ_{dL} designate the land areas within the influence area (L) that are elementary schools (E) and that are any educational (d) land areas, respectively. The weight used to estimate attraction in the influence area for elementary schools is the ratio of $\Lambda_{EL} \div \Lambda_{ET}$ and for all educational parcels is the ratio of $\Lambda_{dL} \div \Lambda_{dT}$. These two weights are combined with two trip sub-purposes to determine the total number of population-equivalents having an age less than 15 years entering into the influence area for the trip purpose for education and to daycare (d).

Trips for the purpose for education or to daycare were also separated into two sub-purposes: either as a student ($d_{+\varepsilon}$) or not as a student ($d_{-\varepsilon}$). Let $\text{þ}_{d_{+\varepsilon}|\Phi_{ij}}$ signify the probability that, given the gender-age group, a person takes a trip for the purpose for education or to daycare as a student. Then $\text{þ}_{d_{-\varepsilon}|\Phi_{ij}}$ is the probability that, given the gender-age group, a person takes a trip for the same purpose except not as a student. Because any age can go on a trip as a non-student for the purpose of education or to daycare, there is no need to separate distinct land use areas for this sub-purpose. Compromising for the age groups used, assumptions were made for going on a trip for education or to daycare as a student: only those ages less than 15 years old go to elementary schools, only those ages 15 to 19 go to high schools, and only those greater than 19 years of age go to trade schools or colleges.

The daily population-equivalents ($\lambda_{d\,ij}$) for ages less than 15 years old on a trip for the purpose for education or to daycare as a student ($d_{+\varepsilon}$) or not ($d_{-\varepsilon}$) within an influence area is estimated by multiplying the total city resident population by the sum of two influences. These influences are expressed as the following: (1) the attraction weight for the proportion of elementary school land areas in the influence area multiplied by the probability of a student, given the gender-age group, going on a trip for education or to daycare; and (2) the attraction weight representing the proportion of all educational land areas found in the influence area multiplied by the probability of a non-student, given the gender-age group, going for education or to daycare. The product, total city resident population multiplied by the sum of the student and non-student influences, estimates the daily population-equivalents for the age groups less than 15 years old on a trip for the purpose of education or to daycare ($\lambda_{d\ ij}$) and is calculated by

$$\lambda_{d\ ij} = P_{\theta\, ij} \left[\left(\left(\frac{\Lambda_{EL}}{\Lambda_{ET}} \right) \text{þ}_{d_{+\varepsilon}|\Phi_{ij}} \right) + \left(\left(\frac{\Lambda_{dL}}{\Lambda_{dT}} \right) \text{þ}_{d_{-\varepsilon}|\Phi_{ij}} \right) \right] \quad \forall\ i, j < 3. \qquad [3.7]$$

The daily population-equivalents ($\lambda_{d\ ij}$) in the age group 15 to 19 on a trip into the influence area for the purpose for education or to daycare as a student or not as a student is estimated in exactly the same manner as above except for this age group, students are attracted to high schools (Y) instead of elementary schools. Therefore, let Λ_{YL} divided by Λ_{YT} characterize the weighting used to estimate attraction of students to the influence area because of high schools. Substituting this weight for the elementary school weight in the previous equation provides the estimate of the daily population-equivalents in the age group 15 to 19 years old on a trip for the purpose for education or to daycare ($\lambda_{d\ ij}$) and is symbolized by the following equation:

$$\lambda_{d\ ij} = P_{\theta\, ij} \left[\left(\left(\frac{\Lambda_{YL}}{\Lambda_{YT}} \right) \text{þ}_{d_{+\varepsilon}|\Phi_{ij}} \right) + \left(\left(\frac{\Lambda_{dL}}{\Lambda_{dT}} \right) \text{þ}_{d_{-\varepsilon}|\Phi_{ij}} \right) \right] \quad \forall\ i, j = 3. \qquad [3.8]$$

Last, the daily population-equivalents ($\lambda_{d\ ij}$) in the age groups greater than 19 years on a trip for the purpose of education or to daycare as a student or not as a student in the area of influence is conceptually estimated in the same manner as the other age groups except for the student weighting. In these age groups, students are attracted to trade schools or colleges (U) instead of elementary or high schools. Therefore, let Λ_{UL} divided by Λ_{UT} embody the weighting used to estimate attraction of students to the influence area because of trade schools or colleges. Then the equation to estimate the daily population-equivalents for age groups greater than 19 years old on a trip for the purpose of education or to daycare ($\lambda_{d\,ij}$) is expressed by the following equation:

$$\lambda_{d\,ij} = P_{\theta\,ij}\left[\left(\left(\frac{\Lambda_{UL}}{\Lambda_{UT}}\right)\text{þ}_{d_{+\varepsilon}|\Phi_{ij}}\right)+\left(\left(\frac{\Lambda_{dL}}{\Lambda_{dT}}\right)\text{þ}_{d_{-\varepsilon}|\Phi_{ij}}\right)\right] \quad \forall\ i, j > 3. \qquad [3.9]$$

Trips for medical purposes also used attraction weights based on land area instead of land parcel count. For example, a dentist's office is expected to be much smaller than a general hospital so count is not representative of each facility's ability to attract people. The parcel land areas where the services in this example are located are more representative of each attraction capability.

Let Λ_{mT} correspond to the total medical (m) land area in the city and Λ_{mL} denote the medical land area within the influence area (L). Then Λ_{mL} divided by Λ_{mT} is the weighting used to determine the ability of the influence area to attract people for the purpose of medical services. When this weight is multiplied by the population-equivalents in the city on a trip for medical purposes, the result estimates the number of people who are in the influence for medical purposes.

There are two contributors to the total number of persons on trips for medical purposes: city residents and non-residents. First, let the city resident population be designated by $P_{\theta ij}$ and let $\text{þ}_{m|\Phi_{ij}}$ characterize the probability of a city resident, given the gender-age group, taking a trip for medical purposes. Then the product $P_{\theta ij}\,\text{þ}_{m|\Phi_{ij}}$ estimates the population-equivalents contributed by city residents attracted to medical facilities within the city for trip purpose m. Second, let $V_{c\,ij}$ indicate non-residents primarily in the city for commercial purposes and let $\text{þ}'_{m|\Phi_{ij}}$ identify the probability of a non-resident, given the gender-age group, taking a trip for medical purposes. Then the product $V_{c\,ij}\,\text{þ}'_{m|\Phi_{ij}}$ estimates the population-equivalents contributed by non-residents attracted to commercial areas of the city for medical purposes. The sum of city residents and non-residents on a trip for medical purposes multiplied by the weight describing the ability of the influence area to attract people for medical purposes provides the estimated daily population-equivalents (λ_m) related to trips for medical purposes (m) nearby a location:

$$\lambda_{m\,ij} = \left(\frac{\Lambda_{mL}}{\Lambda_{mT}} \right) \left[\left[P_{\theta\,ij}\ \text{þ}_{m \left| \Phi_{ij} \right.} \right] + \left[V_{c\,ij}\ \text{þ}'_{m \left| \Phi_{ij} \right.} \right] \right] \quad \forall\ i, j. \qquad [3.10]$$

Figure 3.7 is a visual representation of the above equations used to estimate the local population-equivalents attracted to all types of commercial areas.

Further Refinement of the Daily Population Estimate at a Location

Three final adjustments were made to the relative pedestrian traffic volume estimate. Particular physical attributes identified for special consideration were, in this research, suspected to influence traffic volume and risk. These adjustments were made to the local total population-equivalents estimate to account for special physical circumstances in the influence area. Figure 3.8 identifies the components of these local adjustments.

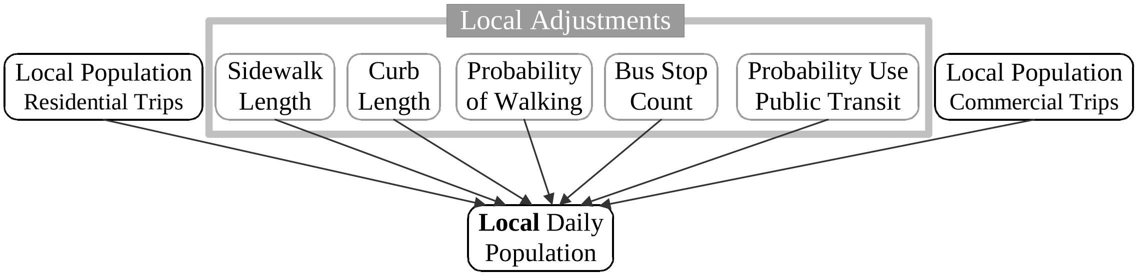

Figure 3.8 Inputs for Final Adjustment of Local Population-Equivalents Estimate

An adjustment was made for sidewalk availability (δ_S) which was assumed to affect the decision to walk including to walk to use public transportation. It was assumed that curb length provides the complete potential length of sidewalk that can exist in non-industrial established areas of the city as well as in the influence area. The ratio of sidewalk (S) length versus curb (C) length for established non-industrial neighbourhoods in the entire city identifies the average accepted ratio for Saskatoon assuming that Saskatoon residents are generally content with the current sidewalk availability. Let ℓ_{ST} represent the total sidewalk length measured in metres in these areas and let ℓ_{CT} stand for the total curb length measured in metres in the corresponding areas. Then the quotient, $\ell_{\mathrm{ST}} \div \ell_{\mathrm{CT}}$, characterizes the average sidewalk versus curb length ratio typical for established non-industrial areas of the city. Now, for an influence area (L), let ℓ_{SL} identify the sidewalk length and let ℓ_{CL} indicate the curb length. Then the quotient, $\ell_{\mathrm{SL}} \div \ell_{\mathrm{CL}}$, embodies the sidewalk versus curb ratio for an influence area.

Assuming that 1 is the perfect sidewalk to curb ratio, then 1- ($\ell_{\mathrm{ST}} \div \ell_{\mathrm{CT}}$) is the accepted tolerance for missing sidewalks in non-industrial established areas of the city. If this tolerance is added to the sidewalk versus curb ratio calculated for an influence area, $\ell_{\mathrm{SL}} \div \ell_{\mathrm{CL}}$, and the outcome is greater than the average ratio, $\ell_{\mathrm{ST}} \div \ell_{\mathrm{CT}}$, the amount of missing sidewalk is assumed to have no affect on the choice to walk in the influence area. Otherwise, if the outcome of the local ratio plus tolerance is still less than or equal to the average sidewalk-to-curb ratio, the absence of sidewalk in the influence area is assumed to deter people from choosing to walk. In this case, the resulting ratio is used to reduce the local total daily population estimate. Stated in the form of equations, the sidewalk availability adjustment (δ_S) is calculated whereby

$$\delta_S = \begin{cases} 1 & \text{if } \left[\left(1-\left(\dfrac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\dfrac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] > \dfrac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}} \\ \left[\left(1-\left(\dfrac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\dfrac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] & \text{otherwise.} \end{cases} \qquad [3.11]$$

For example, in Saskatoon, if the average sidewalk to curb ratio is 0.8, this ratio is considered normal and therefore it is acceptable in this city to have 20% of the potential sidewalk network missing in non-industrial established areas. Consider an influence area that has a sidewalk ratio, $\ell_{\mathrm{SL}} \div \ell_{\mathrm{CL}}$, equal to 0.7. Then (1-0.8)+0.7 is 0.9 which is greater than the average of 0.8 so this area is not expected to deter people from choosing to walk. Now, consider an influence area that has a sidewalk to curb ratio of 0.5. The result of (1-0.8)+0.5 is 0.7 which is less than the average ratio of 0.8. In this case, the decision to walk is discouraged by the lack of sidewalk connectivity. As a result, each gender-age group estimate for all trip purposes (η), $\sum_{\eta}\lambda_{\eta ij}$, is multiplied by $\delta_S = 0.7$. Further explanation and a sample calculation for sidewalk availability is found in Appendix A – Adjustment for the Impact of Sidewalk Availability.

Research had identified that different modes of transportation are used more frequently by certain segments of the population (Kitamura et al. 1997). A national household travel survey conducted in the U.S. in 2001 provided evidence that not only mode of transportation but also trip purpose had different gender and age distributions (U.S. Dept. of Transportation Federal Highway Administration 2002). Two adjustments for transportation mode choice were considered: walking and public transport. The gender and age group distribution for these transportation modes add further weight to groups representing the young and the elderly. Probabilities for transportation mode choice given the gender-age group are identified in Table A-4.

For these mode choice adjustments, the existing local daily population estimates were inflated for walking and bus use without corresponding adjustments for the reduction of the other mode choices, personal motorized vehicles and bicycles. The decision to ignore corresponding reductions was made to exclude additional complexity in the model and because of the fact that, for a short duration, a person using the latter two modes are likely to walk on public sidewalks.

The U.S. sourced transportation mode choice conditional probabilities were transformed to be representative of Saskatoon’s modal split. A detailed explanation of the transformation process is located in Appendix A starting at Adjustment for Mode Choice Affect on Sidewalk Usage.

First, adjustment for choosing to walk is performed by using the probability of a person choosing to walk given the gender-age group. The probability of choosing to walk, $\text{þ}_{W|\Phi_{ij}}$, is added to the other weighted mode adjustment representing the use of public transportation. The addition assumes this mutually exclusive mode choice is not affected by the availability of physical features except for sidewalk availability (δ_S), which is considered. This assumption was made knowing that research had analyzed the impact of factors on the choice to walk such as climate (U.S. Department of Transportation Bureau of Transportation Statistics 2000) and elevation change (Moudon and Sohn 2005) but these factors were not considered in this model.

Describing trips in terms of origin-destination, a pedestrian on a sidewalk may have originated from a previous destination or from another mode of transportation such as a personal or hired vehicle or a transit bus. The latter mode will significantly increase sidewalk usage in close proximity to bus stops and other bus facilities so adjustments for this modal factor must be considered.

To determine if bus use is encouraged or discouraged in an area, the city average number of bus stops in a 502,655 square metre area, the area of a circle with 400 metre radius, must be calculated. Let N_{Ξ} symbolize the total number of bus stops in the city. Let ∂ designate the land parcel attraction groups which include the following: to shop or buy (a), for work or personal business (b), for education or to daycare (d), for entertainment or recreation (e), to eat out (f), for medical purposes (m), and for spiritual purposes (w), and residential land parcels (r). If $\Lambda_{\partial T}$ denotes the total parcel land area in the city for any attraction group in ∂, then $\sum_{\partial} \Lambda_{\partial T}$ is the sum of land area for all attractor types in the city. If the total number of bus stops in the city (N_{Ξ}) is divided by the outcome of the sum of land area for all attractor types in the city ($\sum_{\partial} \Lambda_{\partial T}$) divided by the area of a 400 metre radius circle (Λ_L = 502,655 m^2), the result is the average number of bus stops in an area equivalent in size to an influence area. Assume that this result is the average bus stop density that neither encourages nor discourages the decision to choose public transit as a transportation mode choice. Therefore, any more or less dense areas either encourage or discourage the choice to take a bus.

If $n_{\Xi L}$, signifying the bus stop count in the area of influence, is divided by the average number of bus stops in a similar sized city area, the result is the weight representing local bus stop availability. If the weight is less than 1, bus stop availability discourages this mode choice, otherwise public transit use is encouraged. The equation summarizing the derivation of bus stop availability (δ_{Ξ}) follows:

$$\delta_{\Xi} = \frac{n_{\Xi L} \; \sum_{\partial} \Lambda_{\partial T}}{\Lambda_{L} \; N_{\Xi}} \qquad \forall \, \partial. \tag*{[3.12]}$$

Bus stop availability (δ_{Ξ}) affects the decision to use public transport (Γ) as a mode choice. Let $\text{þ}_{\Gamma|\Phi_{ij}}$ represent the probability that given the gender-age group, a person chooses to use public transport. Then the product $\delta_{\Xi} \, \text{þ}_{\Gamma|\Phi_{ij}}$ called local bus use weight represents the joint probability that bus stops are readily available and that a person chooses to use the bus given the gender-age group. The local bus use weight is added to the probability of choosing to walk, $\text{þ}_{W|\Phi_{ij}}$.

Let η include all trip purposes: to shop or buy (a), for work or personal business (b), for education or to daycare (d), for entertainment or recreation (e), to eat out (f), to return home (h) or to visit friends and relatives (v), for medical purposes (m), and for spiritual purposes (w). Together, local adjustments, for sidewalk and bus stop availabilities as well as for probabilities for choosing to walk or use public transport, are made to the sum of all estimated local population-equivalents contribution by trip purpose ($\sum_{\eta} \lambda_{\eta ij}$). The sum of all estimated daily population-equivalents by gender-age group within 400 metres of a sidewalk location is adjusted to produce the final estimate of local daily population-equivalents, $\tilde{\lambda}_{Lij}$, such that

$$\tilde{\lambda}_{Lij} = \left[\sum_{\eta} \lambda_{\eta ij} \left[1 + \left(\delta_{\Xi} \; \text{þ}_{\Gamma|\Phi_{ij}} \right) + \text{þ}_{W|\Phi_{ij}} \right] \right] \delta_{S} \quad \forall \, \eta. \tag*{[3.13]}$$

The adjusted local daily population estimate is equal to the sum of population-equivalents entering into the influence area for all trip purposes adjusted for two modal choices and multiplied by the sidewalk availability adjustment. The two modal choice adjustments include the added effect of bus stop availability multiplied by the probability of choosing to use public transport given the gender-age group and the added effect for the probability of choosing to walk given the gender-age group.

At this point, the first step of Figure 3.1 is complete. This population-equivalent estimate proportionally characterized the local pedestrian traffic on the sidewalk including pedestrian volume, age and gender.

3.2.3 Estimating Trip Injury Events

Quantifying the frequency of trip injury events is an illusive task. Currently, the number of claims against the City of Saskatoon for sidewalk trip injuries is assumed anecdotal. A central repository for health care providers to record injury statistics in Saskatoon has not been located for this study. Researchers have found that in order to properly collect this data, they must get agreement from various participants in the health care field to record information needed for a research project. These projects collect data for at least one year. Even still, incomplete and missing information are identified as problems in the data collected (Li et al. 2006).

Viscusi (1994) found that wealthy individuals would select lower levels of risk. An assumption related to this was that higher income individuals are more likely to submit a claim. In addition, affluent individuals may have better access to legal assistance, have more knowledge of their legal rights and therefore be more likely to submit claims. Conversely, when a vehicle is involved in a qualifying accident in Saskatoon, the reporting process is taken care of because Saskatchewan Government Insurance (SGI) and the city police collaboratively record events in a database for motor vehicle crashes. This process ensures consistent and unbiased recording of most accident events. Therefore, trip injury claims submitted to the city does not represent the actual number of trip events or the impact on public safety.

There are also problems with self-reporting injuries. Li et al. (2006) referenced, in his research related to outdoor falls among older adults, a finding that incidents that occurred in previous years were likely to be underreported by 13% to 32%. Li et al.

(2006) also stated that there was little research or public attention focused on outdoor falls. This may be the result of the lack of available information or evidence on trip injury events.

To get logical and fact-based approximations, trip injury event types by gender and age were estimated using the Canadian Community Health Survey (CCHS) data for 2001, 2003 and 2005 (Statistics Canada 2001a; Statistics Canada 2003; Statistics Canada 2005a). Because this health survey only included those ages 12 years and older, an alternate source was used for estimating trip injuries for ages less than 12.

In 1987, the United States collected information through a household survey that identified similar but not exactly the same type of information collected in the CCHS (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994). For the purposes of this model, the probability of trip injury events for the ages eleven years and younger was estimated using this data source.

Probabilities for individuals' ages 12 years and older living in private occupied dwellings were estimated where the individual was injured in the past 12 months, because of a fall due to a slip, trip or stumble on any surface but not on ice or snow and not from an elevated position on a street, highway or sidewalk. An example of falling from an elevated position is falling down stairs. As noted before, some seniors' residences were not classified as private dwellings so elderly injuries were likely underrepresented by these trip injury probabilities. This is a source of concern for model accuracy due to the increased impact of injury and length of recovery as people age.

General input variables for the prediction of risk events, trip injuries, are identified in Figure 3.9. A detailed explanation of this process is found in Appendix A – Method of Estimating the Probability of Trip Injury Events.

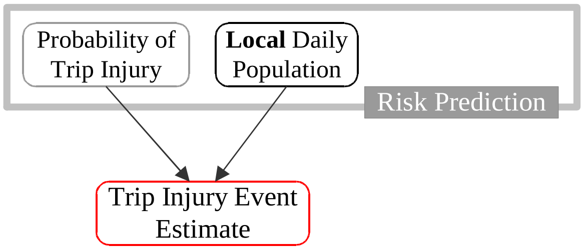

Figure 3.9 Inputs for Risk Event Prediction

Quantification and characterization of trip injury events concludes the second step of the methodology illustrated in Figure 3.1. Up to this point, the model proportionally predicts the probable yearly number of risk events that occur at a given unsafe sidewalk location.

3.2.4 Estimating Injury Recovery Rates

Recovery rates were needed for the calculation of quality-adjusted life years lost. The number of disability days for each recovery stage by injury type and body part affected was estimated where information was found (Nationwide Publishing Company Inc. 2004; Statistics Canada 2006a; Work Loss Data Institute 2003). The Work Loss Data Institute (2003) provided an adjustment factor for each working age group reflecting differences in disability duration. Interpolation extended adjustment factors for the young and elderly age groups. It was assumed that recovery rates were similar for each gender so recovery days were estimated for only the age groups under study (Tables 4.2.4.1 to 4.2.4.4). The estimates generated from this data were deemed coarse but were accepted due to the inability to find a more detailed source. Specifics of this estimation procedure are explained in Appendix A – Determining the Difference in Total Recovery Rates by Age Group.

There is a possibility that a person does not recover from a fall injury. The probability of death was estimated using counts from Canadian Vital Statistics and CCHS trip injury counts. To arrive at the probability of death, it was assumed that an average of yearly incidents could be used as the basis for calculating the average yearly death rates even though the years may not be exactly correlated. The resulting probabilities found in Table 4.2.4.5 are very rough estimates and likely high for the prediction of death resulting from fall injuries during the navigation of unsafe sidewalk. No data was available for some gender and age groups so these groups were assumed to have insignificant contribution. The steps taken to calculate the probability of death were documented in Appendix A – Determining Death Rates caused by Fall Injuries.

Two scenarios were included in the risk assessment for pedestrian navigation of sidewalks. The injured fully recovers from the trip injury or the person dies from complications caused by a trip injury. A third scenario where a pedestrian never fully recovers from a trip injury was not considered in this model even though there was evidence in literature that this may occur especially in the elderly population. For the purposes of this study, this omission was an accepted deficiency.

3.2.5 Estimating the Health Utilities Index for Each Recovery Stage

Quality-adjusted life years lost is a measure that uses the Health Utilities Index Mark 3 (HUI3) Multi-Attribute Utility Function on Dead-Health Scale developed at McMaster University and, for non-chronic injuries, duration of recovery (Feeny et al. 2002). Statistics Canada collected information from survey participants in 32 health regions during the 2003 Canadian Community Health Survey or CCHS (2003) which was used to calculate the health utility index to represent the population overall functional health. Eight attributes identified as important to and representative of health quality were measured in the survey and include vision, hearing, speech, mobility, dexterity, cognition, emotion, and pain and discomfort (Table B-1).

The model presented in this thesis assumed that the health state of an individual directly before a trip injury event was equal to one representing perfect health and the QALYs lost was an estimate of the trip injury effects only. In other words, the estimate of QALYs lost was the relative decrease in functional health status of an individual from immediately before a single trip injury event. The health utility score was estimated without support from research (Table 4.2.5.1). This may be a source of error in the model accuracy.

For deaths, the number of life years lost was estimated using complete life tables for Saskatchewan for the time interval of 2000 to 2002 (Statistics Canada 2006d; Statistics

Canada 2006e). The number of life years lost was the remainder of a statistical life that was expected, given a person's age at death. Because death occurs at a point in time, the total number of life years lost was attributable to that year only. Life years lost due to death are tabulated for those groups where death probabilities were estimated (Table 4.2.4.5).

Figure 3.10 summarizes the final set of inputs needed to assess the risk of probable trip injury events at a sidewalk location. Quality-adjusted life years (QALYs) lost per year was the resulting measure used to prioritize a given list of unsafe sidewalk locations for aiding decisions for effective hazard removal minimizing the risk to all sidewalk users.

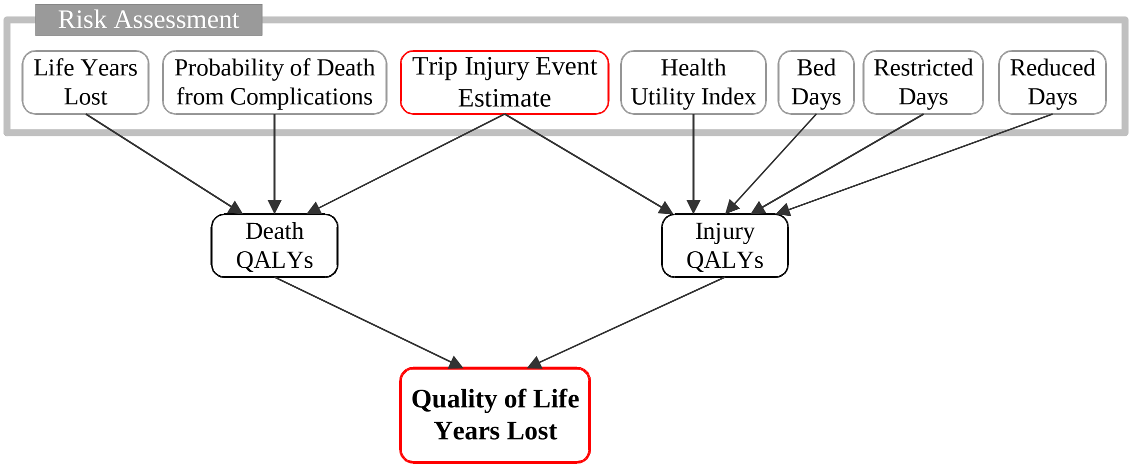

Figure 3.10 Inputs for Risk Assessment at a Given Sidewalk Location

Estimating injury recovery rates and health utility indexes for each stage of recovery are included in the fourth step shown in Figure 3.1. This data along with the predicted trip injury events provided the inputs necessary to model the consequence of probable risk events at a sidewalk location.

3.3 Model Methodology and Output Predictions

3.3.1 Calculating Quality-Adjusted Life Years Lost per Year

The output of the model is quality-adjusted life years lost (QALYs lost) per year. This measure was chosen because it is a direct measure of the impact on individual health associated with the existence of unsafe sidewalk and subsequent risk to public safety.

Let I represent injury type groups used in this model where I is equal to 1 (fracture or dislocate), 2 (sprain or strain), 3 (bruise, scrape, cut or puncture), 4 (concussion or internal injury), and 5 (multiple or other injuries). Let B stand for the grouping of injured body parts where B is equal to 1 (head, neck, back or spine), 2 (shoulder, arm or elbow), 3 (wrist or hand), 4 (hip, leg, ankle or foot), 5 (chest or abdomen), and 6 (multiple sites).

Let τ correspond to the discrete recovery stages that were chosen for this model where τ is equal to 1 (bed days), 2 (restricted activity days), and 3 (reduced activity days). To clarify, bed days are characterized as those days when the injured spends more than half of each day in bed, restricted activity days are days that the injured is inhibited from performing activities, and reduced activity days correspond to days that the injured cuts down on usual activities performed.

Let $HUI_{IB\tau}$ indicate the health utility index during recovery stage τ for an injury type I and affected body part B. Then the loss of health utility, assuming the pedestrian is in perfect health immediately before the trip injury event, is expressed by $1\text{-}HUI_{IB\tau}$. Let $D_{IB\tau j}$ signify the duration of recovery measured in days for recovery stage τ and let D_Y symbolize the number of days in a year. Then the quotient, $D_{IB\tau j} \div D_Y$, identifies the proportion of the year in recovery stage τ.

For each combination of injury type (I), body part affected (B), and age group (j), QALYs lost per year ($Q_{IB\,j}$) is the sum of three products for health loss due to the injury at each of three stages of recovery multiplied by the recovery duration expressed as the proportion of a year for that stage. $Q_{IB\,j}$ is calculated using the following formula:

$$Q_{IB\,j} = \left[\sum_{\tau} \left(\left(1 - HUI_{IB\tau}\right) \frac{D_{IB\tau j}}{D_Y} \right) \right] \ \forall\ \tau. \qquad [3.14]$$

$HUI_{IB\tau}$ designates the health utility index (Feeny et al. 2002) for injury type (I) and body part affected (B) for recovery stage (τ). It is comprised of measurements for 8 attributes identified by Canadians as important to health. Let β_φ denote multi-attribute utility functions related to scores for each of the eight attributes (φ) where 1 = vision, 2 = hearing, 3 = speech, 4 = ambulation, 5 = dexterity, 6 = emotion, 7 = cognition, and 8 = pain. Table B-1 identifies the attributes, level descriptions and scores used for assessing health status. The multi-attribute utility functions for each score are detailed in Table B-2. This calculation of Health Utility Index was provided by Feeny et al. (2002):

$$HUI_{IB\tau} = 1.371\left(\beta_1 \beta_2 \beta_3 \beta_4 \beta_5 \beta_6 \beta_7 \beta_8\right) - 0.371. \qquad [3.15]$$

For each combination of injury type and body part affected, the health scores for each stage of recovery were approximated with no support from references detailing research. Most research found used QALYs to measure the health status of different populations at a point in time, one population at subsequent time intervals, or to assess treatment options for the chronically ill. The HUI scores provided by Statistics Canada in the community health surveys (CCHS) were a measure of health at the time of the interview but did not isolate the sole affect on health because of a recorded trip injury event.

3.3.2 Prioritizing Unsafe Sidewalk Locations

The output of the model is a direct measure of risk to pedestrians. Total QALYs lost per year was predicted for an unsafe sidewalk location (Q_L). The magnitude of this risk assessment was used to rank a given list of unsafe sidewalk locations as information considered during operational decision-making for sidewalk repair.

Q_L is the sum of two components: (1) the summation of health loss for local total daily population-equivalents within the influence area of an unsafe sidewalk location who were predicted to sustain trip injury events; and (2) the summation of permanent life years lost due to the probability that some of those injured would suffer complications from their trip injuries, resulting in death.

Local QALYs Lost per Year Due to Injury

Let $þ_{IBij}$ identify the probability that, given a gender-age group ij, a person sustains a trip injury event of a certain injury type (I) to a certain body part (B). Let P_{Lij} signify the local population-equivalents in the area of influence (L) surrounding an unsafe sidewalk in gender-age group ij. Then $þ_{IBij}$ multiplied by P_{Lij} predicts, for a gender-age group ij, the number of trip events that occur at an unsafe sidewalk location that result in an injury type (I) affecting a body part (B). Let Q_{IBj} represent the measure of loss of quality of life related to the specific injury for the specified age group. Then the product $þ_{IBij}$ P_{Lij} Q_{IBj} corresponds to the health loss assessment for a unique combination of injury type and body part affected as well as gender-age group predicted to occur at a specific sidewalk location. The summation of all predicted trip events causing injury types that affect body parts for all gender-age groups is one of two components that quantify Q_L.

Local QALYs Lost per Year Due to Death

Statistics Canada (2006c) defined a stationary population as one where the number of persons living in any age group does not change over time. This stationary population is used to provide standardizes statistics for wide application. Complete Life Tables are an example of data sets using a stationary population. Life years lost due to death was calculated from data provided by the 2000 to 2002 Complete Life Tables for Saskatchewan (Statistics Canada 2006d; Statistics Canada 2006e).

For a gender, if T_u denotes the total number of life years lived by the stationary population beyond age u, then R_u identifies the average remaining lifetime at age u. For the gender-age groups set for this research, the average life years lost due to death must represent an average estimate of all ages within the group. Therefore, the summation of the product T_uR_u divided by the summation of T_u for every u equal to the single ages within the group j provides the average life years lost due to death for the gender-age group ij expressed as LYL_{ij}:

$$\mathrm{LYL}_{ij} = \frac{\sum_{u} \left(T_u R_u \right)}{\sum_{u} T_u} \; \forall\, u \in \; j \text{ in } \Phi_{ij}\,. \qquad [3.16]$$

Let $þ_{\Delta | ø \cap \Phi_{ij}}$ signify the conditional probability that death (Δ) results given the underlying cause was complication from a previous trip injury event (ø) sustained by a person in a gender-age group Φ_{ij}. Let LYL_{ij} stand for the estimated average life years lost due to death given a gender-age group ij. Then the product, $þ_{\Delta | ø \cap \Phi_{ij}} \mathrm{LYL}_{ij}$, determines, for a gender-age group, the life years lost due to death resulting from complications of a previous trip injury event.

The sum of all predicted injury types affecting all body parts for a gender-age group ij calculated by $\sum_{IB} \left(þ_{IBij} P_{Lij} \right)$ provides the quantity for predicting probable death due to complication. This quantity multiplied by the product $þ_{\Delta | ø \cap \Phi_{ij}} \mathrm{LYL}_{ij}$ estimates, for each gender-age group, the total life years lost at a location due to complications from previous trip injury events predicted to occur at a sidewalk location. The summation of this result for all gender-age groups is the second component in the calculation of Q_L.

Predicted QALYs Lost per Year for an Unsafe Sidewalk Location

Figure 3.10 is a visual of the variables used in Equation 3.17 that follows. The symbolization of the estimation of quality-adjusted life years lost per year at an unsafe sidewalk location (Q_L) is

$$Q_L = \left[\sum_{IBij} \left(þ_{IBij} P_{Lij} Q_{IBj} \right) \right] + \left[\sum_{ij} \left[\left(\sum_{IB} \left(þ_{IBij} P_{Lij} \right) \right) þ_{\Delta | ø \cap \Phi_{ij}} \mathrm{LYL}_{ij} \right] \right] \forall\, I, B, i, j. \qquad [3.17]$$

Sidewalk locations were prioritized by ordering the associated QALYs lost per year (Q_L) with the largest number suggesting the highest potential risk to users if not repaired and the smallest number implying the location with the least risk to overall pedestrian safety.

3.4 Model Design Summary

The decision model described in this chapter used a comprehensive and logic-based approach to estimate and distribute a total daily population confined within the city boundaries to locations within an influence area. This non-traffic approach was the result of the absence of actual sidewalk pedestrian traffic data. As well, accepted standard tables used for predicting pedestrian traffic volume did not exist at the time.

The potential for sidewalk use was assumed proportional to the number of people situated in the area. The more people living or visiting an area, the more potential there is for sidewalk use. In theory, if in one day a person takes one trip to work and one trip back home, the individual contributes 0.5 of a person-equivalent in the area of employment and 0.5 person-equivalents at home. Probabilities for taking different trip purposes and the probable attraction of those people to destinations having certain land use characteristics were used to distribute the total population to specified areas of influence surrounding a location. This was the underlying logic behind the distribution of the total daily population to identified sidewalk locations needing repair prioritization.

Once the local pedestrian traffic was estimated, probable trip injury events were predicted to determine potential risk due to the sidewalk hazard. Trip injury events are random events that can occur at any sidewalk location but are more probable to occur at sidewalk hazards. Events were predicted for the daily population situated in the influence area and who were most likely to walk over the unsafe sidewalk. For each gender-age group, probabilities for pedestrian trip injury events where an injury of a certain type results to a certain body part were used to predict these events.

Last, the consequences of probable risk events were assessed by estimating the impact of trip injuries on quality of life. Quality-adjusted life years lost per year was the output measure chosen for assessing the direct risk associated with pedestrian navigation of unsafe sidewalk. This single measure depicts not only the impact on quantity of life but also quality of life based on criteria identified by Canadians as important to health. The output measure was calculated for each of the identified unsafe sidewalk locations listed.

Quality-adjusted life years lost per year facilitated location prioritization to aid decision-making for sidewalk maintenance and rehabilitation actions.

CHAPTER 4

RESEARCH RESULTS

4.1 Introduction

This research proposes a non-monetary evaluation of pedestrian safety risk during sidewalk usage. Benefits of this approach are time independence, cost independence and the ability to add transparency to decision-making based on community values.

Time independence means that the measure of quality-adjusted life years lost does not change with time compared to monetary measures that are dependent on economic factors. The distribution of injury types caused by a trip event and the duration of recovery for those trip injuries are assumed to remain relatively constant over time.

Cost independence means that a decision-maker bases the removal of an unsafe sidewalk hazard on a measure reflecting the direct impact on the lives of users and not the direct or societal monetary cost of the impact. The concern for using cost as a measure is that comparison of theoretical cost implications of trip injury events to the actual cost of sidewalk treatment options may be attempted. This is an incorrect association with respect to this model because the former is a theoretical calculated cost accepting many sources of uncertainty and the latter is the real cost of treatments. In a discussion with colleagues about this research, this comparison was attempted which verified the need to find a non-monetary measure of safety. The intention of the cost first used in this model was solely for comparing a list of sidewalk locations to facilitate their prioritization. The decision-making information provided by this research assessed the potential risk to pedestrians at hazardous sidewalk locations, not the cost for hazard removal.

Measures that reflect community values for assessing the impact of decision alternatives provide clarity for City Council when approving policies. Specifically, the main purpose of council member appointment is to represent their community's interests. Using a non-monetary evaluation tool to describe sidewalk decisions provides a direct safety measure to compare to community values and to set levels of accepted risk.

In municipal environments, departments compete for funding of various initiatives. The competition is for funding but the decisions should reflect community values and community attitudes toward risk. Consequences for not funding upgrades to a water treatment facility or police services are supported by real life events publicized by the media. No such media event exists for sidewalk trip injuries. To facilitate equal funding competition, the impact of funding decisions should also include a measurable value-based indicator to compare the probable social consequence of decision alternatives for funding different public services. In the case of sidewalk maintenance and rehabilitation funding, the proposed safety indicator measured the direct health implications for sidewalk users. For consistent management decision-making, thresholds must be approved by city council to identify acceptable risk to pedestrian health during public sidewalk usage. Currently, an annual survey of civic services provides information on residents' satisfaction with past service delivery and order of importance to the respondent of current civic services.

4.2 Model Input Results

4.2.1 Average Daily Population Estimate for Saskatoon

Two significant contributors inflated the average daily population of Saskatoon. An influx of visitors and commuters added to the population on a daily basis at an estimated 12 % average rate of increase from the resident population.

The 2003 Canadian Travel Survey (Statistics Canada 2005b) provided domestic travel data for Saskatoon and Saskatchewan. Trips less than 80 kilometres one-way from home (commuter trips), trips not originating in Canada, trips taking longer than one year, travel in an ambulance, trips related to work or school, and relocation of residence were not included. A trip was defined as travel from home to a destination in Canada. A person-trip described a person who started a trip from home and measured the number of persons starting each trip from their home. A person-visit was a visit, overnight or same-day, made by a person taking a trip and measured as the number of visits made by each person on each trip. A visit-night was each night one person taking a trip was away from home in Canada.

In 2003, 1,888,000 person-trips were made with Saskatoon as the destination, person-visits were 2,025,000, and visit-nights were 2,786,000. Quarterly totals for person-visits to Saskatoon were not equally distributed. Because sidewalk usage was expected to be higher in the second and third quarters of the year, average daily person-trips were estimated based on these two quarters. This ensured visitor contribution was not underestimated (Equation A-1).

The travel survey identified five general areas describing trip purpose. One primary purpose was to visit friends or relatives. The proportion of trips made for this purpose over all person-visits was used to represent the number of persons attracted to residential households (Equation A-2). The remainder was the number of persons attracted to commercial units (Equation A-3). Age and gender groups for person-trips, not person-visits, were provided only at the provincial level. Saskatchewan gender-age group proportions were assumed representative of the person-visits to Saskatoon because 78% of person-visits to Saskatoon originated in Saskatchewan. Gender distribution by age group for Saskatchewan from the 2001 census facilitated the distribution of person-visits into groups. Appendix A provides further explanation of the estimation procedure.

Table 4.2.1.2 contains the resulting estimate of the domestic visitor contribution to the average daily population of Saskatoon. In total, the daily population increase in residential areas was approximately 1,900 persons and the increase in commercial areas was about 4,000 persons.

Commuters travelling for employment into Saskatoon were common. Information from the 2001 Census on Commuting Flow for Employed Labour (Statistics Canada 2001c) identified that of the 11,500 persons who were employed in Saskatoon but did not reside there, 11,040 lived somewhere in Saskatchewan. Conversely, 8,100 Saskatoon residents did not work in Saskatoon. On average, if the number of workdays per year was 208 and time spent per day was about 10 hours, there was a net daily inflow of approximately 1,200 person-equivalents with slightly more females. The age groups with net outflow from Saskatoon were males ages 55 to 64, both genders ages 65 or more and females ages 15 to 24. Overall, the Saskatoon residents leaving the city to work was less than the number of incoming workers. These research findings were abandoned as a separate commuter estimation component in the model.

A broader method of estimation was chosen even though this method was not derived from survey data or substantiated by research. This component of estimating the total number of commuting trips was logic-based because no such information was located for Saskatoon. The Saskatoon Health Region or SHR (Table A-1) was the population base for calculating commuting trips even though the region extended further than 80 kilometres from Saskatoon. The assumption was that Saskatchewan Health considered population demographics and reasonable travel distances in the choices made for locating central services for the community and that the population was concentrated around Saskatoon. Gross estimates by age groups were set for the number of days a commuter visits Saskatoon in a one-year period for each of commercial and residential purposes with an average of 8 out of 16 hours of available trip time spent in Saskatoon (Table 4.2.1.1).

Table 4.2.1.1 Estimated Commuter Visit Days per Year

Age	Residential	Commercial
0-14	26	52
15-24	52	156
25-54	52	208
55-64	26	104
65+	12	46

From this, the estimated daily population increase due to commuter trips was approximately 18,500 including 14,300 in commercial areas and 4,200 in residential areas (Equations A-4, A-5). Estimated population increase due to commuter trips to Saskatoon are tabulated below (Table 4.2.1.2).

Table 4.2.1.2 Estimated Daily Saskatoon Population contributed by non-Residents

	Travel Person-Visits (2003)				Commuter Person-Visits			
	Residential		Commercial		Residential		Commercial	
Age	Male	Female	Male	Female	Male	Female	Male	Female
0-14	130	130	380	370	400	300	600	600
15-24	130	130	300	200	400	300	1,200	1,100
25-34	100	100	300	300	300	200	1,400	700
35-44	100	200	300	300	400	600	1,500	2,200
45-54	200	200	400	400	400	400	1,700	1,500
55-64	90	100	200	200	100	100	500	500
65-74	50	50	100	100	100	100	200	200
75+	40	60	90	100	50	100	150	200

Saskatoon residents also take trips out of the city. This fact was ignored in the model. The omission increased the model output but increased proportionally for each location.

For 2001, the Saskatoon resident population estimate was 196,800 (Table A-1). The daily population estimate including approximately 24,400 visitors and commuters totalled to 221,200 person-equivalents (Figure 4.1). By percentage for each gender, the largest non-resident contributions were males ages 45 to 54 and females ages 35 to 44. The smallest non-resident contributions were males ages 65 to 74 and females older than 74 years of age. Generally, non-residents increased the proportion of the total population in the age groups included in 35 to 54 plus males ages 25 to 34.

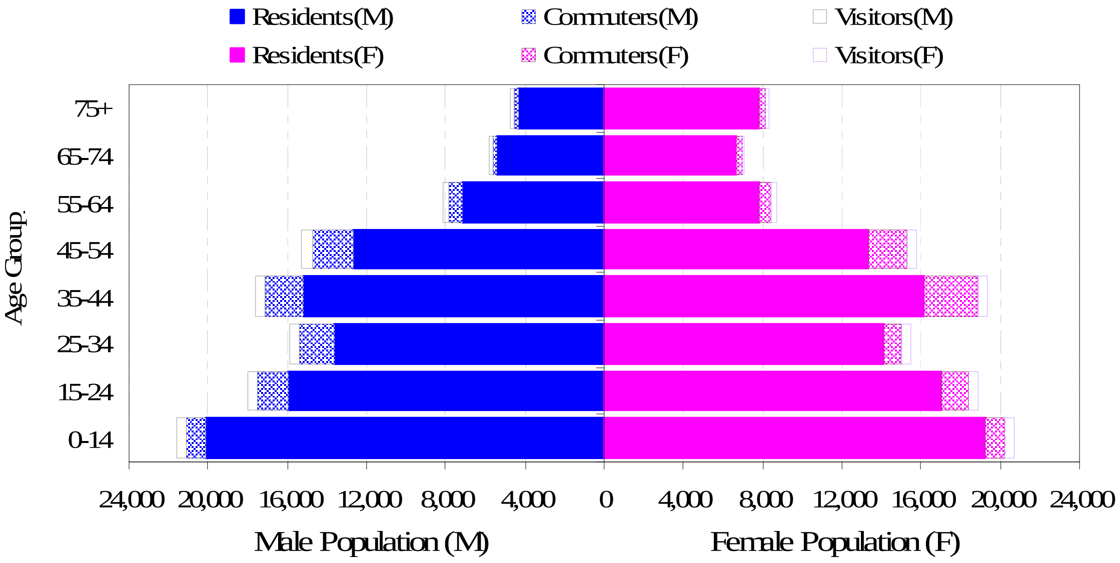

Figure 4.1 Saskatoon Total Daily Population Estimate (2001)

4.2.2 Distribution of Saskatoon's Daily Population to Sidewalk Locations

To test the model, 12 sidewalk locations were assessed. Locations in Saskatoon were selected from city records of customer requests identifying unsafe sidewalks. Criteria describing the selected locations are summarized in Table 4.2.2.1 along with some unique characteristics.

Table 4.2.2.1 Test Sidewalk Location Characteristics

ID	Direction	Area	Neighbourhood	Characteristics	Adjacent Building Type
CBD	central	business district	CBD	high density commercial, elderly	store, discount CBD/ Broadway 10,000-49,999
Core_W	west	core	Pleasant Hill	hospital, low income, young	rectory
Core_E	east	core	Varsity View	hospital, university	single family, detached residence
Inter_W	west	intermediary	Mayfair	mixed land use	mixed residential <4 and other present use
Inter_E	east	intermediary	Buena Vista	residential	mixed residential <4 and other present use
SC_W	west	suburban centre	Confederation SC	multi-residential, younger	condo townhouse
SC_E	east	suburban centre	Nutana SC	multi-residential, low income, elderly	office building
Out_W	west	outlying	Fairhaven	multi-residential younger	low rise multi-residential
Out_N	north	outlying	River Heights	low density residential	single family, detached residence
Out_EN	northeast	outlying	Forest Grove	low density residential, young	single family, detached residence
Out_E	east	outlying	Wildwood	multi-residential	mixed, multi-residential and other present use
Ind	east	industrial	Exhibition	industrial	commercial

It was necessary to provide a mechanism that could distribute the total daily population to locations throughout the city along with age and gender group proportions that reflected the unique demographics of the area surrounding a location. Distribution of the total by age and gender group based on the contribution of some physical feature to the entire city would over simplify the inputs key for model prioritization. Research confirmed that there were known critical differences in fall injury types characteristic for certain age and gender groups resulting in varying degrees of quality of life lost.

To be more reflective of the area, residents within the area of influence were estimated by age and gender group using the 2001 census population data by dissemination area (Equation 3.1). Household counts were also provided by dissemination area adding more detail for distributing the total population (Equation 3.2).

The mechanism used to distribute the total daily population to locations identified for prioritization combined two related factors. First, the probability that an individual takes a trip for a certain purpose, given that they are in a specified gender and age group, provided composition differences for attraction to destinations based on the trip's purpose. Second, summary statistics for physical features that influence sidewalk traffic at a location compared to the total for the entire city quantified the contribution to the total amount of trip destinations in the city for a given trip purpose. For each trip purpose, formulas were constructed to distribute the daily population to a location in a way that quantified the influence of expected trip patterns to generalized parcel destinations (Equations 3.3 through 3.10). Additional considerations for physical situations that have a significant influence on the calculated risk were included in the distribution formulas (Equations 3.11, 3.12 and the probability of walking given the gender-age group; all summarized in 3.13). The resulting gender-age group quantities and distribution of the local average daily population provided logical and adequate uniqueness related to each sidewalk location assessed.

The derived formulas contain many assumptions. The hypothesis was that the model would maintain relative and equal assessment of each location. The basis of this claim was that variables describing the location were quantified using consistent and objective methods of measurement from city owned and maintained databases that identify physical attributes of the city. These variables as well as the total daily population estimate were bounded by the total quantity for the city. In addition, population-related statistics came from the most reliable and standard unbiased source, Statistics Canada.

Probabilities of gender-age groups taking trips for various purposes were estimated from the 2001 U.S. National Household Travel Survey (U.S. Dept. of Transportation Federal Highway Administration 2002) summarized below in Table 4.2.2.2. Details of the estimation process are provided in Appendix A. For residents, between 30% and 40% of all trips taken were to return home, 9% to 32% were for business purposes and 10% to 27% of trips were to shop or buy. The remainder were other categories of trip purposes.

Table 4.2.2.2 Estimated Probability of Trip Purpose for Residents

	Conditional Probability(Person in Group *ij* is on a Trip with a certain Purpose)								
Group *ij*	Home	Busi-ness	Shop Buy	Restaur-ant	Entertain-ment	Visit	Education Daycare	Spiritual	Medical
M 0-11	0.4	0.1	0.2	0.05	0.09	0.09	0.1	0.03	0.01
M 12-14	0.4	0.06	0.09	0.05	0.1	0.06	0.2	0.04	0.003
M 15-19	0.3	0.2	0.08	0.07	0.1	0.09	0.1	0.02	0.009
M 20-24	0.3	0.3	0.1	0.1	0.07	0.05	0.04	0.01	0.005
M 25-34	0.3	0.3	0.2	0.06	0.07	0.04	0.01	0.009	0.009
M 35-44	0.3	0.3	0.1	0.07	0.05	0.03	0.005	0.02	0.005
M 45-54	0.3	0.3	0.2	0.07	0.06	0.03	0.005	0.02	0.009
M 55-64	0.3	0.3	0.2	0.08	0.06	0.03	0.002	0.02	0.007
M 65-74	0.4	0.2	0.2	0.09	0.08	0.03	0.004	0.02	0.02
M 75pl	0.4	0.1	0.2	0.09	0.08	0.03	0.005	0.03	0.03
F 0-11	0.4	0.1	0.2	0.06	0.07	0.08	0.1	0.02	0.006
F 12-14	0.3	0.1	0.1	0.05	0.1	0.08	0.2	0.03	0.004
F 15-19	0.4	0.1	0.1	0.06	0.08	0.09	0.1	0.03	0.005
F 20-24	0.3	0.2	0.2	0.06	0.05	0.06	0.09	0.01	0.007
F 25-34	0.3	0.3	0.2	0.05	0.06	0.05	0.009	0.02	0.01
F 35-44	0.3	0.3	0.2	0.06	0.05	0.03	0.01	0.02	0.02
F 45-54	0.3	0.3	0.2	0.07	0.05	0.03	0.01	0.02	0.02
F 55-64	0.3	0.2	0.2	0.07	0.06	0.04	0.005	0.03	0.02
F 65-74	0.4	0.1	0.3	0.07	0.05	0.05	0.009	0.03	0.03
F 75pl	0.4	0.1	0.3	0.09	0.06	0.05	0.009	0.03	0.03

Note: The sum of probabilities for each gender-age group = 1.
Reporting requirements for use of the source data specify one significant digit only.

These probabilities could only be applied to the city resident population. Probabilities for trips taken by visitors and commuters excluded trips to go home because they do not live in the city. Trips to go to educational facilities or daycares were assumed to have little relevance so these trips were also excluded. Excluding the latter trip purposes may be only partially correct because there are instances where visitors and commuters can make such trips. Separating the daily population increases for non-residents into those making trips into primarily residential or commercial areas also, to some extent, violated reality. Both were known and accepted omissions to prevent additional complexity in the model. Because non-residents making trips to visit friends and relatives were already separated, the adjusted set of probabilities found in Table 4.2.2.3 was applied to the daily population for non-residents attracted to commercial areas only.

Table 4.2.2.3 Estimated Probability of Trip Purpose for Non-Residents

	P(Person in Group *ij* is on a Trip for the Purpose of …)					
Group *ij*	Business	Shop or Buy	Restaur - ant	Entertain -ment	Spiritual	Medical
M 0-11	0.2	0.4	0.1	0.2	0.06	0.03
M 12-14	0.2	0.3	0.2	0.3	0.1	0.009
M 15-19	0.4	0.2	0.1	0.2	0.05	0.02
M 20-24	0.5	0.2	0.2	0.1	0.02	0.009
M 25-34	0.5	0.3	0.1	0.1	0.02	0.01
M 35-44	0.5	0.2	0.1	0.09	0.03	0.007
M 45-54	0.4	0.3	0.1	0.1	0.03	0.01
M 55-64	0.5	0.3	0.1	0.1	0.03	0.01
M 65-74	0.3	0.4	0.1	0.1	0.03	0.03
M 75pl	0.2	0.4	0.1	0.1	0.05	0.05
F 0-11	0.2	0.4	0.1	0.2	0.05	0.01
F 12-14	0.2	0.3	0.1	0.3	0.08	0.009
F 15-19	0.3	0.3	0.1	0.2	0.07	0.01
F 20-24	0.5	0.3	0.1	0.1	0.02	0.01
F 25-34	0.4	0.3	0.09	0.09	0.03	0.02
F 35-44	0.5	0.3	0.1	0.08	0.03	0.03
F 45-54	0.4	0.3	0.1	0.09	0.04	0.03
F 55-64	0.3	0.4	0.1	0.09	0.05	0.03
F 65-74	0.2	0.5	0.1	0.09	0.06	0.05
F 75pl	0.2	0.5	0.2	0.1	0.05	0.06

Note: The sum of probabilities for each gender-age group = 1.
Reporting requirements for use of the source data specify one significant digit only.

During model testing, it was discovered that the distribution of trips for the purpose of education and daycare did not reflect the expected. Two problems were clear: (1) The university land area was a significant contribution to the total for this attractor group; and (2) The age group proportions were expected to vary with each stage of education.

To deal with these problems, inputs for the distribution method were revised. For trip attraction, property use codes attached to these parcels separated the original group into elementary schools, high schools, and colleges and trade schools. For the original trip purpose group, education and daycare, the probabilities were recalculated for two subgroups: go to school as a student; and school/religious activity, go to library - school related, and daycare. As well, probabilities for the second age group were recalculated for the subgroups 15 to 19 and 20 to 24. The resulting set of probabilities for trip purposes (Table 4.2.2.4) and land area by detailed property use type provided differentiation as a student or as a non-student to elementary schools or daycares, to high schools, or to trade schools and colleges.

Table 4.2.2.4 Estimated Probability of an Education or Daycare Trip

	P(Person in Group *ij* is on a Trip for the Purpose of …)	
Group *ij*	School as a Student	School or Daycare as a Non-Student
M 0-11	0.09	0.04
M 12-14	0.2	0.02
M 15-19	0.09	0.01
M 20-24	0.03	0.003
M 25-34	0.01	0.002
M 35-44	0.002	0.003
M 45-54	0.001	0.004
M 55-64	0.00008	0.002
M 65-74	0.002	0.002
M 75pl	0.002	0.003
F 0-11	0.09	0.05
F 12-14	0.1	0.02
F 15-19	0.1	0.01
F 20-24	0.07	0.02
F 25-34	0.006	0.004
F 35-44	0.005	0.007
F 45-54	0.005	0.005
F 55-64	0.002	0.003
F 65-74	0.002	0.007
F 75pl	0.002	0.007

A standard land area, called influence area, facilitated the uniform objective identification of land parcels in the city geospatial database. All land parcels having any portion within 400 metres from the centre of the parcel site adjacent to the hazardous sidewalk location were identified as influencing the sidewalk traffic and included in the calculations (Figure 3.3). To get the location specific inputs needed for the model, information associated with these parcels was summarized by trip attractor type.

By using a standard land area, many other variables that influence sidewalk traffic were automatically considered. For example, household income can be associated with household density. Households are commonly less expensive in multi-residential or in small lot areas which result in high population densities and greater potential for sidewalk usage. On the other hand, warehouse style stores surrounded by large parking lots attract many people who are likely to travel there by private vehicle, causing little public sidewalk usage. The standard land area revealed these density differences and therefore naturally reflected sidewalk usage.

Upon review of household counts in dissemination areas, an omission was discovered. For modelling purposes, an additional 1,435 households were added to the total number of private households in Saskatoon to account for seniors' residences that, by definition, were assumed institutional, communal or commercial households. The data provided by dissemination area was for private household counts only. Conversely, the population data provided by dissemination area included residents in non-private households.

There were 3 areas of concern in the modelling process for estimating the total daily population-equivalents in the area of influence: (1) the method of and source for estimating excluded non-private households, (2) the compromise for using land parcel count or land area instead of building floor area to determine the influence of commercial properties to attract people, and (3) the use of commercial property use codes linked to land parcels instead of the more indicative attribute, commercial units.

4.2.3 Trip Injury Events on Sidewalks

To get logical and fact-based approximations, trip injury event types by gender and age were estimated using the Canadian Community Health Survey (CCHS) data for 2001, 2003 and 2005 (Statistics Canada 2001a; Statistics Canada 2003; Statistics Canada 2005a). The information was filtered to represent those individuals across Canada who were injured in the past twelve months because of a fall on a street, highway or sidewalk where they had slipped, tripped or stumbled on any surface but not due to snow or ice and not from an elevated position. Burn, scald, chemical burn and blister injuries were excluded. The resulting probabilities were summarized into a three-year average (Tables 4.2.3.1 through 4.2.3.4). The estimation procedure is detailed in Appendix A.

To reduce the number of conditional probability estimates, the following variables were combined. Injury types combined include (1) fracture or dislocate, (2) sprain or strain, (3) bruise, scrape, cut or puncture, (4) concussion or internal injury, and (5) multiple or other injuries. Combined affected body parts were (1) spine = head, neck, back or spine, (2) arm = shoulder, upper arm, elbow or lower arm, (3) hand = hand or wrist, (4) leg = hip, thigh, knee, lower leg, ankle or foot, (5) trunk = chest or abdomen, and (6) multi = multiple sites. Even still, for some groups there were no data representing some combinations of injury type and body part affected. It was assumed that these combinations had insignificant contribution to probable fall injuries.

Because this health survey included only those ages 12 years and older, an alternate source was used to estimate trip injuries for those younger. Data collected by a United States household survey in 1987 was filtered to identify individuals injured as a result of a fall on a highway, street, or sidewalk but not involving a vehicle (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994). Injury incident information, although somewhat inconsistent with the CCHS data, provided an approximation for use in this model. Estimation details are explained in Appendix A.

The resulting conditional probability estimates indicated that for females, the most probable injury for age groups within the range 12-64 was a sprain or strain to the lower extremity. The lower extremity starts at the hip downward to the foot. Children, younger than 12, were most likely to fracture or dislocate an upper extremity. The upper extremity extends from the shoulder to lower arm. The age group 65-74 was most probable to fracture or dislocate a lower extremity. Those 75 or older were most likely to fracture or dislocate a wrist or hand.

For males, the age group less than 12 were most likely to bruise, scrape, cut or puncture a head, neck, back or spine. The age groups 12-14 and 25-34 were most probable to sprain or strain a lower extremity. The age groups 15-19, 20-24 and 45-54 were most likely to bruise, scrape, cut or puncture a lower extremity. Fracturing or dislocating an upper extremity not including the hand or wrist was most probable for the age groups 35-44 and 55-64. Those ages 65 or older were most likely to sustain multiple or other injuries to one or more sites. Overall, the three most probable gender-age groups predicted to have a trip injury event follow (comparing CCHS data only): a female 75 years or older, a female in the age group 65-74, and a female in the age group 12-14.

Table 4.2.3.1 Given Group ij, Probability of Fracture or Dislocate

Body Part	Spine	Arm	Hand	Leg	Trunk	Multi
Group $_{ij}$						
M 0-11	0.0004	•	0.0001	0.0008	•	•
M 12-14	0.00006	0.0005	0.0003	0.0003	•	•
M 15-19	•	0.0001	0.0001	0.0001	•	•
M 20-24	0.00001	0.00009	•	•	0.00006	•
M 25-34	0.000008	0.00002	0.00003	0.00006	0.00002	•
M 35-44	•	0.0002	0.0001	0.00004	0.00002	•
M 45-54	0.00002	0.0001	0.0001	0.00008	0.0001	•
M 55-64	•	0.0002	0.00002	0.0001	0.000009	•
M 65-74	•	0.00005	•	0.0002	•	•
M 75pl	0.00006	0.0003	0.0001	0.00009	0.0001	•
F 0-11	•	0.001	•	0.0001	•	•
F 12-14	•	•	0.0001	0.0005	•	•
F 15-19	0.00004	0.000004	0.0002	0.0002	0.00005	•
F 20-24	0.00003	•	0.0001	0.0003	•	•
F 25-34	0.00002	0.0001	•	0.0001	0.000008	•
F 35-44	0.00007	0.00007	0.00008	0.0003	•	•
F 45-54	0.00007	0.0003	0.0002	0.0004	•	•
F 55-64	0.00002	0.0002	0.0004	0.0005	0.00006	•
F 65-74	0.0002	0.0003	0.0002	0.0007	0.00006	•
F 75pl	0.00009	0.0006	0.0009	0.0004	•	0.0001

• no data available

Table 4.2.3.2 Given Group ij, Probability of Sprain or Strain

Body Part	Spine	Arm	Hand	Leg	Multi
Group $_{ij}$					
M 0-11	•	•	•	•	•
M 12-14	•	•	0.0003	0.0005	•
M 15-19	•	•	0.0002	0.0004	•
M 20-24	0.0002	0.00008	•	0.0005	•
M 25-34	0.00005	•	0.00002	0.0007	•
M 35-44	0.00005	0.0001	0.00003	0.0002	•
M 45-54	0.000002	0.00009	0.000002	0.0002	•
M 55-64	0.00002	0.00002	•	0.0001	•
M 65-74	0.00003	•	0.00007	0.0002	•
M 75pl	•	0.0003	•	0.0002	•
F 0-11	•	•	•	•	•
F 12-14	•	•	0.0007	0.001	•
F 15-19	0.00006	•	0.00007	0.001	•
F 20-24	0.00003	0.00003	0.0003	0.002	•
F 25-34	0.00002	0.00008	0.00002	0.001	•
F 35-44	0.00005	0.00001	•	0.0005	0.00003
F 45-54	0.00002	0.00006	0.00005	0.0005	0.00002
F 55-64	0.00007	0.00003	0.0002	0.001	•
F 65-74	0.00003	0.0002	0.0002	0.0006	0.00009
F 75pl	0.00004	0.0003	0.0002	0.0004	0.00004

• no data available

Table 4.2.3.3 Given Group ij, Probability of Bruise, Cut, Scrape, Puncture

Body Part	Spine	Arm	Hand	Leg	Trunk	Multi
Group $_{ij}$						
M 0-11	0.001	•	•	•	0.0004	•
M 12-14	0.00004	0.00002	0.0002	0.0005	•	•
M 15-19	0.00003	0.00002		0.0005	•	0.00002
M 20-24	0.0001	•	0.00003	0.0007	•	0.0002
M 25-34	0.00002	•	•	0.00009	•	0.00003
M 35-44	•	•	0.00002	0.0001	•	•
M 45-54	•	•	•	0.0002	0.000004	•
M 55-64	0.00001	•	•	•	0.00005	•
M 65-74	0.00004	•	0.00007	0.00008	0.0001	0.00005
M 75pl	0.0004	0.0001	0.00008	0.0005	0.0002	•
F 0-11	0.0002	•	•	•	•	•
F 12-14	0.000007	•	•	0.0004	•	•
F 15-19	0.0008	0.0003	0.00004	0.0002	•	•
F 20-24	•	0.0004	•	•	•	•
F 25-34	0.000009	•	•	0.0001	•	0.00008
F 35-44	0.00007	0.00002	0.00002	0.0002	•	0.00007
F 45-54	0.00003	0.00006	0.00007	0.0002	•	•
F 55-64	0.00008	0.00002	0.00002	0.0002	•	0.0001
F 65-74	0.0001	•	•	0.0004	•	0.00006
F 75pl	0.0007	0.00004	0.0002	0.0005	•	0.00006

• no data available

Table 4.2.3.4 Given Group ij, Probability of Injury to any Body Part

Injury Type	Concussion	Multiple Injuries and other
Group $_{ij}$		
M 0-11	•	•
M 12-14	•	•
M 15-19	0.0001	0.00006
M 20-24	•	0.0003
M 25-34	•	•
M 35-44	•	0.00001
M 45-54	•	•
M 55-64	•	0.0001
M 65-74	•	0.0004
M 75pl	0.00004	0.0005
F 0-11	•	•
F 12-14	•	0.0004
F 15-19	•	•
F 20-24	•	•
F 25-34	•	0.00007
F 35-44	•	0.0001
F 45-54	•	0.0001
F 55-64	0.00003	0.0001
F 65-74	•	0.0004
F 75pl	0.0001	0.0006

• no data available

4.2.4 Injury Recovery Rates

The decision to combine genders for recovery rate estimations removed some complexity in modelling and increased sample data points for each age group. At first, recovery days were estimated from the United States 1987 household survey and filtered to identify individuals who had sustained an injury (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994). The data was also reduced to include injury records where only one injury type was recorded, occurred near home, on a street, highway or sidewalk, or adjacent to a building or other place not inside buildings or at workplaces. Injuries thought to be inconsistent with unintentional injuries were removed. Examples include bullet wound, dog bite, or hit by an object. The assumption was that intentional injury events and extreme trauma events involving excessive force would generally be unrepresentative of fall injury events.

Genders were combined for recovery rate estimations because recovery days were assumed similar for each gender given the age group. Estimates for the number of disability days for each recovery stage by injury type alone and not considering the affected body part were determined to lack sensitivity. For example, a fractured back is very likely to have a different number of disability days than a fractured arm. Due to the lack of data points when separating out the body part affected for each injury type, the first estimations were abandoned and another source was located.

Again, the disability duration by injury type and body part affected were estimated where information could be found (Nationwide Publishing Company Inc. 2004; Work Loss Data Institute 2003). The Work Loss Data Institute (2003) provided an adjustment factor to reflect differences in disability duration for each working age group. Interpolation was performed to extend adjustment factors for the excluded young and elderly age groups. Tables 4.2.4.1 through to 4.2.4.4 summarize the estimated days of recovery for five different injury types by body part affected by age group.

Table 4.2.4.1 Estimated Recovery Days for Fractures and Dislocates

Body Part	Spine			Arm			Hand			Leg			Trunk			Multi		
Age	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
0-11	5	54	21	3	30	10	3	43	10	3	41	15	3	25	16	3	38	14
12-14	7	54	22	5	29	10	5	42	10	5	40	15	6	24	17	6	38	15
15-19	9	58	24	6	31	11	6	45	11	6	43	17	7	25	18	7	40	16
20-24	10	64	27	7	34	12	7	50	12	7	48	19	8	28	20	8	45	18
25-34	11	71	30	8	37	13	8	55	13	8	52	21	9	30	22	9	49	20
35-44	13	105	43	9	57	19	9	83	19	9	79	30	10	47	32	10	74	29
45-54	15	108	44	10	58	20	10	84	20	10	80	31	11	47	33	11	75	29
55-64	17	133	54	12	72	24	12	104	24	12	99	38	13	59	41	13	93	36
65-74	19	163	66	12	89	30	12	129	30	12	122	46	14	73	49	14	115	44
75+	21	188	76	14	103	34	14	149	34	14	141	53	16	85	57	16	133	51

Where τ_1 - bed days; τ_2 – restricted activity days; τ_3 - reduced activity days.

Table 4.2.4.2 Estimated Recovery Days for Sprains and Strains

Body Part	Spine			Arm			Hand			Leg			Multi		
Age	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
0-11	4	7	7	2	7	10	3	9	11	4	11	15	3	9	11
12-14	4	8	8	2	8	10	3	9	12	4	12	15	3	9	11
15-19	4	8	8	2	8	11	3	10	13	4	13	17	3	10	12
20-24	5	9	9	3	9	12	3	11	14	5	14	19	4	11	14
25-34	5	10	10	3	10	13	4	12	16	5	16	21	4	12	15
35-44	7	15	15	4	15	19	5	18	23	7	22	30	6	18	22
45-54	8	15	15	4	15	20	5	18	24	8	23	31	6	18	22
55-64	9	19	19	5	19	24	6	23	29	9	28	38	8	22	28
65-74	11	23	23	7	23	30	8	28	35	11	34	46	9	27	33
75+	13	26	26	8	26	34	9	32	41	13	40	53	11	31	39

Where τ_1 - bed days; τ_2 - restricted activity days; τ_3 - reduced activity days.

Table 4.2.4.3 Estimated Recovery Days for Bruise, Cut, Scrape and Puncture

Body Part	Spine			Arm			Hand			Leg			Trunk			Multi		
Age	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
0-11	1	3	5	2	4	6	2	3	6	2	6	7	1	2	10	1	4	7
12-14	1	3	6	2	4	7	2	7	18	2	6	8	1	2	10	2	4	7
15-19	1	3	6	2	4	7	2	11	4	2	7	8	1	2	11	2	4	8
20-24	1	3	7	2	5	8	4	6	29	3	7	9	1	3	12	2	5	9
25-34	1	4	7	2	5	9	7	8	11	3	8	10	1	3	13	2	5	10
35-44	2	5	11	3	7	13	6	7	12	4	12	15	2	4	19	3	7	14
45-54	2	6	11	3	8	13	5	6	19	4	12	15	2	4	20	3	7	15
55-64	3	7	14	4	9	16	3	9	15	5	15	19	3	5	24	4	9	18
65-74	3	8	16	5	11	20	2	19	14	7	18	23	3	7	30	5	11	22
75+	4	9	19	6	13	23	16	16	16	8	21	26	4	8	34	5	13	26

Where τ_1 - bed days; τ_2 - restricted activity days; τ_3 - reduced activity days.

Table 4.2.4.4 Recovery Days for Concussions, Multiple and Other Injuries

Injury Type	Concussion			Multiple		
Body Part	Head			Multi		
Age	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
0-11	7	26	4	4	42	16
12-14	8	27	4	6	41	16
15-19	8	29	4	7	45	18
20-24	9	33	5	9	49	20
25-34	10	36	5	10	54	22
35-44	15	52	7	11	82	32
45-54	15	54	8	12	83	32
55-64	19	66	9	14	103	40
65-74	23	80	11	15	127	48
75+	26	93	13	17	147	56

To account for the possibility that a person does not recover from their injuries, the probability of death plus life years lost due to death were estimated. Information on death rates for 2001, 2002 and 2003 provided by the Canadian Vital Statistics death database (Statistics Canada 2006b) included those deaths caused by a fall on the same level from slipping, tripping and stumbling but did not specify where the fall occurred. This cause of death was one of many classifications set by the World Health Organization, International Statistical Classification of Diseases and Related Health Problems (ICD-10 classification W01). Probabilities for death caused by a fall on the same level from slipping, tripping and stumbling were estimated by including data provided by the CCHS database (Statistics Canada 2001a; Statistics Canada 2003; Statistics Canada 2005a). It was assume that, on average, each subsequent year would provide similar events so that using fall injury data in similar years as those for the cause of death data should approximate the estimates needed for this study (Table 4.2.4.5). It is understood that this was a very rough estimate and was most likely high for the injuries under study. However, it would be inappropriate to exclude the possibility of death due to a fall injury (Li et al. 2006).

A person who dies because of a fall injury has an immediate health utility index of zero. Conversely, the health utility index lost is 1. The equivalent recover rate for death was estimated as the average remaining years of life predicted for the individual given the gender and age group. For example, if a female who experienced a trip injury event died because of the event at an age between 55 and 64, the average life years lost that year is an estimated 26 years. Table 4.2.4.5 provides a summary of estimated average life years lost per year upon death. Life years lost were only determined for gender and age groups that had an associated probability of death.

Even though males ages 75 or older were the sixth most likely group to have a trip injury event, an injured male from this group was most likely to die because of the event. An injured female from the same age group was the second most likely but yet half as likely as the male counterpart was.

Table 4.2.4.5 Statistics for Death Resulting from a Fall Injury

	P(Death | Group)		Life Years Lost | Group	
Age	Male	Female	Male	Female
20-24	0.00001	•	56	•
25-34	0.000006	•	49	•
35-44	0.00003	0.00002	39	44
45-54	0.00005	0.00002	30	35
55-64	0.0001	0.00005	22	26
65-74	0.0004	0.0001	14	18
75+	0.002	0.0008	8	10

• no data available

4.2.5 Measurement of the Impact of a Trip Injury on Quality of Life

Once the number of deaths and injuries by injury type and body part affected were estimated for each gender-age group, measurement of the impact of these events could be performed. This measurement assessed the relative state of health as a direct result of a trip injury event. An approximation of health utility index (HUI) score was made for each injury type and body part affected.

For example, referring to Table B-1, immediately after sustaining a fractured ankle, a person who is in perfect health (HUI=1) just before the incident, would not experience any affect to vision, hearing, speech, or dexterity but is predicted to be at stage 5 for ambulation, 4 for emotion, and 5 for pain. For a fractured wrist, ambulation would be 3, dexterity 6, emotion 4, and pain 5.

With all combinations approximated, the associated health utility index score was identified and used in Equation 3.15. These approximations were calculated for three stages of recovery: bed days, restricted activity days, and reduced activity days. Averages were then taken for each injury related group used in this research. The results are found in Table 4.2.5.1.

Table 4.2.5.1 HUI Score Loss Approximations for Fall Injuries

Injury	Recovery Stage		
Fracture or Dislocate:	τ_1	τ_2	τ_3
Spine	1.19	0.86	0.28
Arm	1.14	0.74	0.26
Hand	1.14	0.83	0.34
Leg	1.06	0.64	0.28
Trunk	1.09	0.72	0.28
Multi	1.25	0.91	0.36
Sprain or Strain:			
Spine	1.06	0.60	0.28
Arm	1.14	0.64	0.26
Hand	1.14	0.83	0.26
Leg	1.06	0.60	0.28
Multi	1.20	0.87	0.29
Bruise, Scrape, Cut or Puncture:			
Spine	0.96	0.53	0.28
Arm	0.92	0.44	0.20
Hand	0.94	0.48	0.20
Leg	0.96	0.51	0.28
Trunk	0.96	0.51	0.28
Multi	1.01	0.55	0.29
Concussion or Internal Injury	1.20	0.73	0.37
Multiple Injuries	1.10	0.80	0.28

Where τ_1 - bed days; τ_2 – restricted activity days; τ_3 - reduced activity days

Finally, equation 3.14 provides the quality-adjusted life years lost for each injury type and affected body part for each age group. The calculation considers HUI as well as disability duration. The disability duration estimations have a direct affect on the QALY calculation for each age group. The graphs in Figures 4.2 to 4.7 illustrate the effect of recovery rates on the QALY estimates for the injury type, fracture or dislocate, for each group of body parts affected (Q_{IB}). Generally, the graphs show that for each group of affected body parts (B), Q_{IB} increases with age.

QALYs Lost per Year Caused by a **Fracture or Dislocate** to a Part of the Body

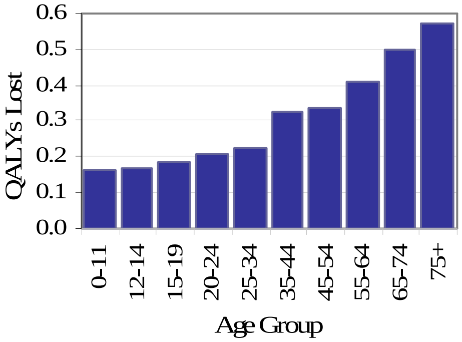

Figure 4.2 QALYs Lost for Head, Neck, Back, or Spine Injury

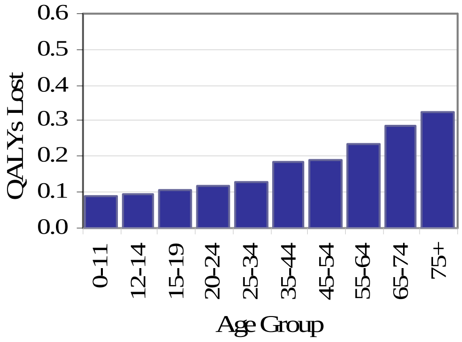

Figure 4.5 QALYs Lost for Hip, Leg, Ankle, or Foot Injury

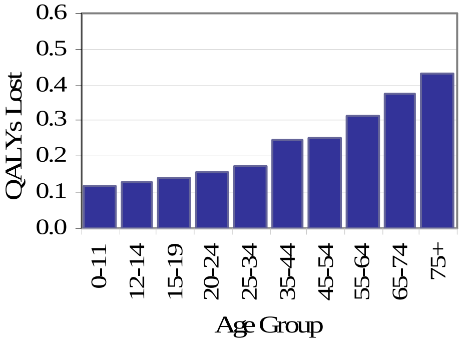

Figure 4.3 QALYs Lost for Multiple Sites Injury

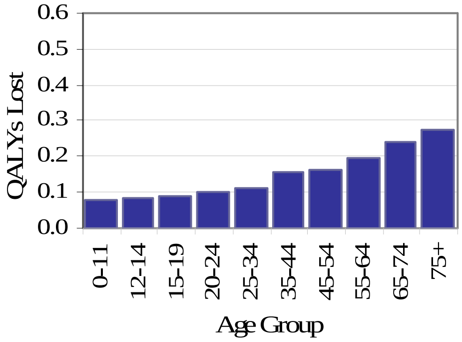

Figure 4.6 QALYs Lost for Shoulder, Arm, or Elbow Injury

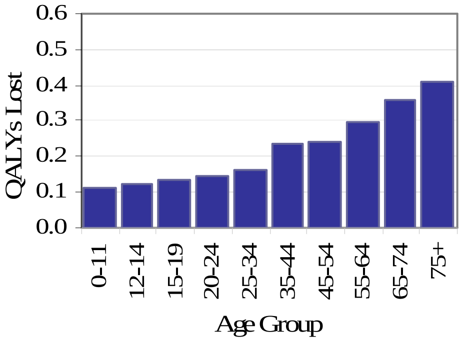

Figure 4.4 QALYs Lost for Wrist or Hand Injury

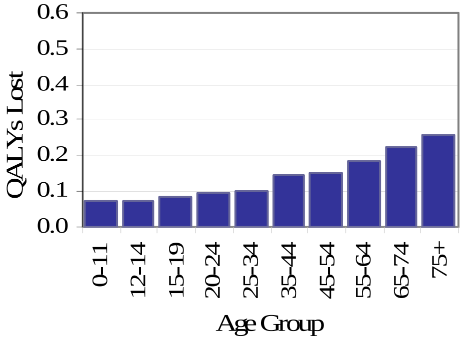

Figure 4.7 QALYs Lost for Chest or Abdomen Injury

4.3 Model Output Results

4.3.1 Decision Model - Prioritization of Unsafe Sidewalk Locations

The result of equation 3.17 assesses the magnitude of risk per year. This risk (Q_L) is measured for each given unsafe sidewalk location and is used for prioritizing a list of locations. Table 4.3.1.1 provides the summary of risk assessment results for a test list of unsafe sidewalk locations. For comparison of intermediate calculation results, this table also identifies estimates for number of persons injured, number of deaths, local daily population percent contribution to the total, population proportional increase from the local resident count and age group counts for the total local daily population.

Table 4.3.1.1 Resulting Prioritization of Unsafe Sidewalk Locations

Sidewalk Location	**QALYs Lost**	Persons Injured	Deaths	% Daily Population	Increase in Resident Population	Age Groups		
						0-34	35-44	55 plus
CBD	**3.46**	30	0.06	6.0%	16	6,589	3,914	2,868
Core_W	**1.32**	11	0.02	2.3%	4.4	2,485	1,579	1,084
Core_E	**1.14**	12	0.02	2.1%	3.2	3,206	751	662
Inter_W	**1.04**	9.3	0.02	1.9%	2.3	2,150	1,155	824
SC_E	**0.81**	5.6	0.02	0.99%	1.2	957	504	729
Out_E	**0.52**	4.5	0.008	0.87%	0.59	992	491	444
SC_W	**0.46**	4.3	0.007	0.85%	1.1	1,071	472	341
Inter_E	**0.42**	3.7	0.007	0.77%	1.3	869	513	332
Out_EN	**0.34**	4.2	0.003	0.81%	0.73	1,283	341	165
Out_W	**0.33**	3.2	0.005	0.62%	0.63	797	328	247
Out_N	**0.17**	1.6	0.002	0.33%	0.61	398	197	130
Ind	**0.14**	1.3	0.002	0.29%	1.8	317	208	108

The following discussion refers to neighbourhoods and functional areas of the city strictly for ease of discussion. There is no intention to prioritize an entire neighbourhood or city area based on these results. Each test sidewalk location in this list is situated at a specific street address.

The central business district location (CBD) had the highest risk associated with the decision to leave a trip hazard on public sidewalks. Two points suggest that the assessment of this location was underestimated: (1) there are many multi-level buildings which had only been assessed by parcel count or parcel area resulting in under representation for the attraction rate; and (2) property use codes are attached to the parcel and not the commercial unit so, in many cases, the number and diversity of businesses is not accurately reflected for the central business district area.

The sidewalk location, Core_W, situated in the core neighbourhood, Pleasant Hill, has a young resident population, low-income neighbourhood status and high population density. Commercial attractors influenced about 80% of the daily population, increasing the daily total to more than 4 times the number of residents, mostly adding weight to the working class age groups. One of the three main hospitals is located in the influence area. No seniors' complexes were identified within 300 metres. As a result of commercial trip attraction and high residential density, this location had the second highest risk.

The third highest risk was calculated for the Varsity View sidewalk location (Core_E). Also situated in a core neighbourhood, this location is influenced by another of the main hospitals, is adjacent to the University of Saskatchewan, and is influenced by more than 6% of the total number of seniors' households. Its ranking compared to the other core sidewalk location may be due to the 53% increase in daily population attracted to the university. The increase was mostly younger age groups, diluting the affect of the older resident population. Unique to this location, predicted injuries identified more sprains or strains than fractures or dislocates.

Comparing the two sidewalk locations in intermediary areas, Inter_W in the Mayfair neighbourhood and Inter_E in the Buena Vista neighbourhood, resident population counts and group compositions are very similar. Trip attraction due to the mixed land use in the Mayfair location increased the daily population. The daily population for Inter_W was 2.3 times the resident population compared to only 1.3 for Inter_E. The daily group composition shifted, to older in Mayfair and to younger in Buena Vista, from the resident group distribution.

Influence from residents at the sidewalk locations in the suburban centre (SC) neighbourhoods, Confederation SC (SC_W) and Nutana SC (SC_E), have very different group compositions. SC_W has a young resident population whereas SC_E is influenced by 7.4% of the total seniors’ residences. Both had similar population count increases. The daily composite group age became older in Confederation SC and younger in Nutana SC compared to the average resident age. For SC_E, almost 40% of the resident population is more than 74. This influence remained dominant even with the addition of daily non-resident population due to commercial trip attraction.

The four outlying area sidewalk locations in Wildwood (Out_E), Forest Grove (Out_EN), Fairhaven (Out_W) and River Heights (Out_N) neighbourhoods each have different average age and household density. These differences are characterized in Table 4.2.2.1. Each of these locations shared a unique affect; the daily population estimate was less than the resident population count. Low influx of non-residents plus high outflux of residents for commercial trip purposes resulted in a daily population count less than the resident count. The daily group composite age became younger at each of these locations. Comparing amongst each of these locations, the magnitude of the population count ranked the locations in the same order as QALYs lost. Therefore, the magnitude of daily population would produce equal ranking amongst these locations.

The daily population count was estimated to be double the resident population count in the influence area surrounding the industrial sidewalk location (Ind) because of the number of commercial attractors that are present. The model reduced the total daily population estimate by 50% because the lack of sidewalks in this area discourages the decision to walk and encourages other transportation modes to arrive at the intended destination. This sidewalk location was the only test location that lacked sidewalk availability discouraging the choice to walk on public sidewalks.

4.4 Summary of Results

The results of this research demonstrate an effective risk-based decision model that prioritizes a given list of unsafe sidewalk locations for aiding decisions related to maintenance and rehabilitation actions. This is a non-monetary evaluation of pedestrian safety that is time and cost independent as well as transparent in reflecting community values that guide decision-making for the strategic removal of trip hazards.

By estimating the average daily population, relative traffic flow was predicted thus providing differences in potential risk to sidewalk users at given unsafe sidewalk locations. On average, there was an estimated 12% increase in the Saskatoon daily population due to contributions from non-residents with the largest changes to group proportions experienced in the age groups in the range from 35 to 54 (Figure 4.1).

Selected from actual public sidewalk locations in Saskatoon, the unsafe locations used to test the prioritization model provided a cross-section of demographic areas, population densities, land use mix, sidewalk availability, average age of resident populations, and low-income neighbourhood designation (Table 4.2.2.1). Statistics were gathered for physical characteristics found within 400 metres of each sidewalk location as well as within the entire city. These statistics, the local resident population, and conditional probabilities for various trip purposes were used to distribute the total daily population to the unsafe sidewalk by probable attraction to the location.

Estimated trip events causing an injury type that affects a body part were calculated for gender-age groups using conditional probabilities derived from a historical 3-year average of self-reported statistics collected in Canadian Community Health Surveys for the years 2001, 2003 and 2005. Estimated recovery rates, death rates, life years lost and health utility index scores were inputs into the calculation that assessed the quality-adjusted life years lost (QALYs lost) because of a trip injury event. QALYs lost is a measure of the direct risk associated with a trip injury event.

The resulting output separated and evaluated key demographic differences for each location. The outcome was an acceptable and justifiable prioritization of the sidewalk locations tested (Table 4.3.1.1). In addition, most data used in the model are high quality, reliable, readily available, and routinely maintained by various municipal and federal government agency sources.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Introduction

The primary objective of this research was to develop a model for prioritizing a given list of unsafe sidewalk locations, aiding maintenance and rehabilitation decisions by providing critical information on the direct risk to pedestrian safety at each location. A secondary objective was to use only existing data for modelling. These high quality existing data are standard information essential for running municipal governments or commonly collected by federal statistics departments. It was shown that estimations could be inferred from similar situations where data have already been collected and validated through research or federal agencies. Data abstractions can be applied using decision analysis methodology to produce value-added decision policy.

The modelling process for prioritizing unsafe sidewalk included estimating the average daily population-equivalents at the location by gender and age, and predicting the probable number of trip injury events there. Risk associated with the impact of these trip injury events was assessed by calculating the quality-adjusted life years lost. Prioritization of competing unsafe sidewalk locations was facilitated by ordering the magnitude of calculated risk. A general strategy, found to be effective in this model to ensure that each location was assessed relatively equal to the others, was to determine the location’s contribution of some physical factor to the total city quantity.

5.2 Model Performance

The prioritization model successfully ranked the given list of sidewalk locations creating a separation that can be explained by considering unique characteristics of each location. Model vulnerabilities were identified for areas where there exist a number of multi-storey commercial buildings or strip malls. Both examples share a single land parcel but may have different business functions that attract people for different trip purposes. Model strengths include the ability to predict the average daily population density by gender-age group so that estimations of trip events causing injuries to certain body parts can be assessed for loss of quality of life. Generally, the key success of this model is the number of factors considered reflecting unique attributes associated with each location.

The local daily population was estimated in a complex manner. Three contributors were considered to estimate the average daily population count separated into 20 gender-age groups. Another set of 20 gender-age groups represent a more detailed estimate of the local resident population in close proximity to a sidewalk location. Two hundred different probabilities distinguishing 10 trip purposes for each of the 20 gender-age groups were used along with 10 ratios to distribute the total resident population to a test location. An additional 120 probabilities for trip purposes were used with six ratios to distribute non-residents of Saskatoon to a test location. The ratios used along with each set of trip purpose probabilities described some physical land use characteristic. Final adjustments were made for the influence of bus availability and sidewalk availability. Additional weighting accounted for those gender-age groups most likely to walk (one for each of the 20 gender-age groups) as well as for noted risk associated with high-risk land parcels within 400 metres and seniors’ residences within 300 metres of the location.

Once the local average daily population was estimated, risk was calculated. The total loss of quality-adjusted life years calculation considered 57 health utility index scores along with 540 disability days estimates as well as 222 predicted trip injury types by affected body part. To add loss of quality-adjusted life due to death because of a trip and fall injury, 12 probabilities for death were considered along with 12 estimates for life years lost.

Each stage of estimation was accompanied by logic and stated assumptions of which most justified the use of sourced data and researched methodology. The process of exploring different data sources and paths of logic has provided a robust link between uncertainty and known physical properties. The resulting risk assessment provides information for consideration when making an objective decision from a discrete set of alternatives. These are fundamental principles in decision analysis.

5.3 Data Sources

This model is successful because of its ability to estimate relative pedestrian traffic at a sidewalk location and to predict the risk associated with its use. The outcome of this research, a risk-based decision model for prioritizing a given list of unsafe sidewalk locations, made use of a vast amount of existing data and previous research. As an analogy, the expert opinion in the decision analysis process was data. To make more than 1,320 estimations, many data sources were consulted and analyzed.

The secondary objective of this research was to prove three hypotheses related to the value of existing data. If each piece of data considered in this model had to be collected, validated and summarized by the researcher, the topic would not have been attempted. With stated assumptions, only existing data were used, most inferred from similar situations and abstracted for use in the sidewalk prioritization model.

Conditional probabilities were used as a method of minimizing population dependent influences in source data. To infer statistics from one population to another, conditional probabilities for a set of gender-age groups were estimated from the source population and then applied to the same groupings of gender and age ranges in the study population. Examples of the application of other population statistics to Saskatoon are Canadian fall injury statistics, U.S. fall injury statistics, U.S. trip purpose statistics and Canadian deaths caused by a previous fall injury statistics.

Using a technique of relative contribution to the total, this model can be relied upon to treat each location consistently and objectively. The output value may not be accurate but is very likely to be precise. This concept must be understood to determine the limitations for possible applications of this model. The model has been tested for the prioritization of a given list of sidewalk locations needing maintenance and rehabilitation action in Saskatoon only. Because of the relative techniques used, in physically similar cities, the model is expected to work effectively. Effectiveness depends on the accuracy and completeness of the data inputs characterizing the physical land attributes. Local government databases may not be scrutinized with the same care as federal statistics departments. Therefore, data validation and verification must be understood before it is used in this decision model.

Many existing data have been sourced and explored. Some statistics have been successfully inferred from similar situations and abstracted for used in the development of a decision model. The model prioritizes a given list of unsafe sidewalk locations based on the direct risk to pedestrians. The success is maximized by calculating probabilities such that the influence of gender-age group differences in the source and study populations are minimized. Further, sensitivity analysis would aid with understanding the importance of the precision needed for data inputs.

5.4 Model Limitations and Future Potential

This model is designed for assessing sidewalk locations in established areas only. It is unlikely that newly developed neighbourhoods contain unsafe sidewalk locations unless the sidewalk sustained abuse by non-pedestrian traffic. Additionally, new developing neighbourhoods will not have up-to-date and accurate Statistics Canada data.

To implement this model, input measures for physical attributes must be updated at a reasonable interval to adjust for new information that becomes available ensuring proper representation. Base estimations for population and probabilities should be reviewed as new information becomes available, typically every four years.

There is great potential to automate many of the physical data gathering processes. Automation can facilitate the extension of these concepts for aid in determining service level differentiation, inspection cycles, and as objective information to focus discussion of decisions for sidewalk repair requests from customers and politicians.

Three areas needing further investigation are identified. Most importantly, model sensitivity analysis is needed to explore the value of information. Depending on the findings, identification of business units versus property use identification for land parcels may improve the attraction rates. Improvements are predicted to impact modelling of dense commercial areas especially where multi-business units share a land parcel and where multi-storey buildings house multiple business units. A comprehensive source for documented trip injuries sustained by pedestrians on public sidewalks in Saskatoon may add validation to the current estimates. Sensitivity analysis would reveal whether further accuracy would add value. Even still, if the medical data were available, it would be somewhat incomplete only representing those injuries where medical treatment was sought. The most challenging sourcing of data in this research was the quest for disability days for injury types to certain body parts at the stages of recovery. This may be an area needing further validation depending on model sensitivity.

In addition to sensitivity analysis and automation of data summarization, there are other research opportunities. This research could be extended to develop sidewalk service levels, derive sidewalk safety thresholds, determine sidewalk inspection cycles, and develop risk-based sidewalk construction planning standards. Exploring the feasibility of extending concepts from this research to other infrastructure programs for assessing service impact or risk assessment may be worthwhile.

5.5 Summary

The primary and secondary objectives of this research have been fulfilled. A decision model was presented for the prioritization of a given list of unsafe sidewalk locations, aiding maintenance and rehabilitation decisions by providing critical information on the direct risk to pedestrian safety at each location. The model design and inputs used only existing data. Various sources were found from municipal governments and federal statistics departments. The federal statistics were high quality data. Estimations were inferred from similar situations where data have already been collected. Data abstractions were applied using decision analysis methodology to produce value-added decision policy on sidewalk maintenance and rehabilitation actions.

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APPENDICES

Appendix A

METHOD OF ESTIMATING THE TOTAL DAILY POPULATION OF SASKATOON

Three sources considered to contribute to the Saskatoon daily population were travellers, commuters and the resident population.

TRAVELLER CONTRIBUTION TO THE SASKATOON AVERAGE DAILY POPULATION

Let Ω represent the number of person-visits to the city in each quarter of the year. Let q_o signify the quarter of the year where o is equal to 2 for the quarter including the months from April to June and 3 for the quarter July to September. Let D indicate the number of days in the quarter. Then D_{q2} and D_{q3} stands for the number of days in the second and third quarter, respectively. To determine the total average daily person-visits in peak quarters of a year ($\overline{\Omega}$), the sum of person-visits in the second and third quarter of the year is divided by the number of days in each of the corresponding quarters of the year. The calculation for $\overline{\Omega}$ is

$$\overline{\Omega} = \frac{(\Omega_{q2} + \Omega_{q3})}{(D_{q2} + D_{q3})}. \qquad [A\text{-}1]$$

The 2003 Canadian Travel Survey (Statistics Canada 2005b) was used to estimate the contribution of travellers to Saskatoon's daily population such that

$$\overline{\Omega} = \frac{(482{,}000 \text{ person visits} / q_2 + 602{,}000 \text{ person visits} / q_3)}{(91 \text{days} / q_2 + 92 \text{days} / q_3)}$$

$$\approx 5{,}920 \text{ increase in daily population due to travellers.}$$

Let Ω_v correspond to the number of person-visits per year with the primary purpose of visiting friends and relatives. Let Ω_T embody the total number of person-visits per year. Then the total average daily person-visits with the primary purpose of visiting friends and relatives ($\overline{\Omega}_v$) is estimated by the quotient, Ω_v divided by Ω_T, multiplied by the total average daily person-visits in peak quarters of the year and is symbolized by the following equation:

$$\overline{\Omega}_v = \left(\frac{\Omega_v}{\Omega_T}\right) \times \overline{\Omega}. \qquad [A\text{-}2]$$

In 2003, the estimated average increase in the daily population in residential areas of Saskatoon due to travellers was:

$$\overline{\Omega}_v = \left(\frac{633{,}000 \text{ person} - \text{visits}_{\text{visit friends \& relatives}} / \text{ year}}{2{,}2025{,}000 \text{ person} - \text{visits} / \text{year}} \right) (5{,}920 \text{ person} - \text{visits} / \text{day})$$

$$\approx 1{,}850 \text{ person} - \text{visits} / \text{day with the primary purpose to visit friends \& relatives.}$$

Let $\overline{\Omega}_c$ denote the total average daily person-visits to the city with a primary purpose related to trips to commercial parcels. Then the total average daily person-visits for the purpose of visiting friends and relatives subtracted from the total average daily population visiting the city for any purpose, estimates $\overline{\Omega}_c$. The total average daily person-visits to the city with a primary purpose related to trips to commercial parcels, $\overline{\Omega}_c$, is calculated by

$$\overline{\Omega}_c = \overline{\Omega} - \overline{\Omega}_v . \qquad \text{[A-3]}$$

In 2003, the estimated average increase in total daily population for commercial areas of Saskatoon due to travellers was

$$\overline{\Omega}_c = 5{,}920 \text{ person} - \text{visits} / \text{d} - 1{,}850 \text{ person} - \text{visits}_{\text{ residential purposes}} / \text{ day}$$

$$\approx 4{,}070 \text{ person} - \text{visits} / \text{day with the primary purpose} - \text{for commercial purposes.}$$

Gender distribution by age group for Saskatchewan from 2001 census facilitates the distribution of person-visits into gender-age groups. Assume that Saskatchewan gender-age group proportions were representative of the person-visits to Saskatoon because 78% of these person-visits originated in Saskatchewan. The final visitor population-equivalents distribution is located in Table 4.2.1.2.

COMMUTER CONTRIBUTION TO THE SASKATOON AVERAGE DAILY POPULATION

Let the gender-age group be identified by ij where i and j signify the gender categories and age cohorts, respectively. Categories for gender groups are i = 1 (male) and 2 (female). Age groupings include j = 1 (ages 0 to 11 years), 2 (12-14), 3 (15-19), 4 (20-24), 5 (25-34), 6 (35-44), 7 (45-54), 8 (55-64), 9 (65-74), and 10 (75 years or older).

The population estimate for the Saskatoon Health Region (SHR) base population from which commuter travel was calculated (Statistics Canada 2001a) is in Table A-1. If P_{SHRij} represents the population of the SHR and $P_{\theta ij}$ stands for the city resident population, then subtracting the resident population from SHR population estimates the potential commuter population by gender-age group.

Let D_{vij} correspond to, for each gender-age group, the number of days per year spent commuting to the city to visit and let D_Y be the number of days per year. Then the yearly number of days spent visiting divided by the number of days in a year provides the proportion of the year that includes days with visiting trips by gender-age group.

Also, let t_v characterize daily hours spent on visiting trips and let t_D indicate the possible trip hours in a day. Then the daily hours spent on visiting trips divided by the possible trip hours in a day provides the proportion of potential daily time spent on visiting trips.

The product of these two quotients, proportion of year with days taking visiting trips by gender-age group multiplied by the proportion of daily time spent on visitor trips, provides the proportion of the yearly commuter trip time spent by gender-age group visiting friends and relatives in the city. If this yearly trip time proportion is multiplied by the estimate of the potential commuter population by gender-age group, the result estimates the contribution of commuter person-equivalents to Saskatoon's daily population in residential areas for the purpose of visiting friends and relatives, denoted by ς_{vij}:

$$\varsigma_{vij} = \left(P_{SHR\,ij} - P_{\theta ij}\right)\left(\frac{D_{vij}}{D_Y}\right)\left(\frac{t_v}{t_D}\right). \qquad \text{[A-4]}$$

For example, the estimate of daily commuter person-equivalents in the gender-age group, males ages 0 to 11 in Saskatoon is

$$\varsigma_{v11} = (23{,}350 - 15{,}900)\left(\frac{26\,\text{days}}{365\,\text{days}}\right)\left(\frac{8\,\text{hours}}{16\,\text{hours}}\right)$$

$$\approx 265 \text{ person} - \text{equivalents}.$$

The same logic that explains the estimation of commuter contribution of trips to visit friends and relatives is used for the contribution of commuters to commercial areas. Instead, let D_{cij} denote, for each gender-age group, the number of days per year spent commuting to city commercial areas. Also, let t_c embody the estimate of hours spent on daily trips to commercial areas of the city. Then the calculation for the commuter contribution to Saskatoon's daily population attracted to commercial areas (ς_{cij}) is

$$\varsigma_{cij} = \left(P_{SHR\,ij} - P_{\theta ij}\right)\left(\frac{D_{cij}}{D_Y}\right)\left(\frac{t_c}{t_D}\right). \qquad \text{[A-5]}$$

For example, the daily estimate of commuters in Saskatoon attracted to commercial areas is calculated as follows:

$$\varsigma_{c11} = (23{,}350 - 15{,}900)\left(\frac{52\,\text{days}}{365\,\text{days}}\right)\left(\frac{8\,\text{hours}}{16\,\text{hours}}\right)$$

$$\approx 531 \text{ person} - \text{equivalents}.$$

The resulting estimates for commuter population-equivalents are found in Table 4.2.1.2.

RESIDENT CONTRIBUTION TO THE SASKATOON AVERAGE DAILY POPULATION

The 2001 Saskatoon resident population estimate by gender-age group, $P_{\theta ij}$, was determined from single year gender-age data provided for each dissemination area, DA_x, summing for all x found within the city boundary by gender-age group ij. The Saskatoon resident population was estimated by

$$P_{\theta ij} = \sum_x P_{DA_x ij} \quad \forall \text{ x within the city.} \qquad [A\text{-}6]$$

Table A-1 contains the results.

Table A-1 Resident Population Estimates for 2001

Population	Saskatoon		SHR	
Age	Male	Female	Male	Female
0-11	15,900	15,190	23,350	22,100
12-14	4,215	4,095	5,895	5,655
15-19	7,245	7,505	10,805	10,720
20-24	8,705	9,480	10,755	11,320
25-34	13,690	14,105	18,585	16,705
35-44	15,235	16,135	20,645	23,945
45-54	12,665	13,365	18,505	18,675
55-64	7,170	7,800	10,900	11,385
65-74	5,405	6,680	8,475	9,835
75+	4,370	7,840	6,940	11,350

METHOD OF ESTIMATING PEDESTRIAN TRAFFIC AND CHARACTERISTICS

GENERAL CONCEPT – POPULATION DISTRIBUTION TO SIDEWALK LOCATIONS

Two measures were combined to distribute the city total daily population to sidewalk locations: (1) the probability of a person in a certain gender-age group taking a trip for a specified purpose and (2) the ability of the influence area to attract people taking trips.

To determine the distribution of residents throughout the city, two methods were used. First, the 2001 survey conducted in the U.S. provided estimates for composition differences for mode choices and trips to specific destinations for a certain purpose. These probabilities combined with the proportion of total land use attractors in the area distribute the city total daily population to the location under assessment. Second, resident population was estimated in the influence area surrounding the location.

Non-residents attracted to commercial parcels were distributed to sidewalk locations using adjusted trip purpose probabilities combined with land use attraction. Non-residents visiting friends and relatives were distributed by predicting attraction considering the number of local households versus the city total count.

Three assumptions were made to transform the mode choice and trip purpose probabilities to the Saskatoon population from the U.S. population. Assume that, given the gender-age group, mode choice is likely to vary by geographic region but the proportion of trip quantities per year and trip purpose gender-age distributions are consistent across these two regions. For example, the gender-age composition for trips for entertainment may vary in quantity across regions because of the number of people in the group but do not vary significantly by proportion of all trips taken for the gender-age group. The choice to take a trip by personal vehicle was considered a regional choice with many factors of influence. Therefore, mode choice probabilities must be adjusted for regional preferences.

To apply the U.S. probabilities to the Saskatoon population, probabilities were calculated from the number of trips made for a certain purpose by gender-age group. Because the probabilities were applied to a population with a different composition of gender and age, all probability estimations used were conditional given a gender-age group. This information was used to distribute the total daily population to locations attracting person-trips to medical facilities, schools, daycares and places of worship, etc.

The following trip purposes along with variable name were combined into groups to reflect consistent attraction to different land-uses:

- Home (h) includes trips to return home.
- Business (b) includes trips to go to work, return to work, attend business meetings/trips, other work related, buy gas, family personal business/obligations, use of professional services, use personal services, pet care, attend meetings, transporting someone, picking up someone, take and wait, dropping someone off and other reasons.
- Shop Buy (a) includes shopping and errands, buy goods and buying services.

- Restaurants (f) include trips to meals, social events, get/eat meals and coffee/ice cream/snacks.
- Entertainment (e) includes trips for social/recreational, go to gym/exercise/play sports, rest or relaxation/vacation, go out/hang out: entertainment/theatre/sports event/go to bar and visit public place: historical site/museum/park/library.
- Visit (v) includes trips to visit friends/relatives.
- Education Daycare (d) includes trips to school/religious activity, go to school as student, go to library: school related and day care.
- Spiritual (w) includes trips to go to religious activity and attend funeral/wedding.
- Medical (m) includes trips for the purpose of medical/dental services.

(Table C-3 provides the detailed list for each group.)

Probability estimates for Saskatoon residents, separated by gender-age group, taking trips for certain purposes are found in Table 4.2.2.2. Residents of Saskatoon travel throughout the city, making trips for various purposes. These probabilities facilitate the distribution of Saskatoon residents throughout the city based on predicted trips that they are most likely to take. Trips were transformed into person-equivalents. For example, one person who on average makes 0.4 of their total trips in a year to return home could also be viewed as 0.4 person-equivalents in the area of influence surrounding their home. The table identifies that the proportion of trips for a given purpose is most likely characteristic of and differs for each gender-age group.

To illustrate, the following two graphs compare the yearly trip probabilities of females in the age group 15 to 24 to that of females ages 65 to 74.

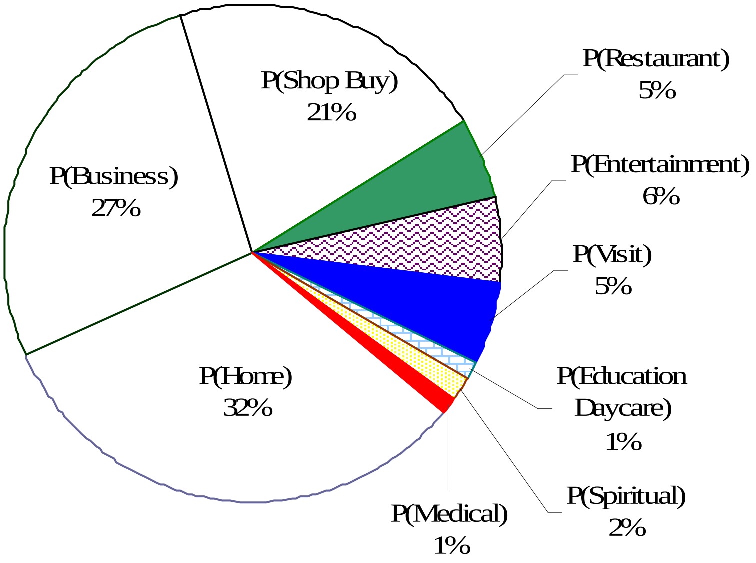

Figure A-1 Yearly Trip Distribution - Females Ages 25 to 34

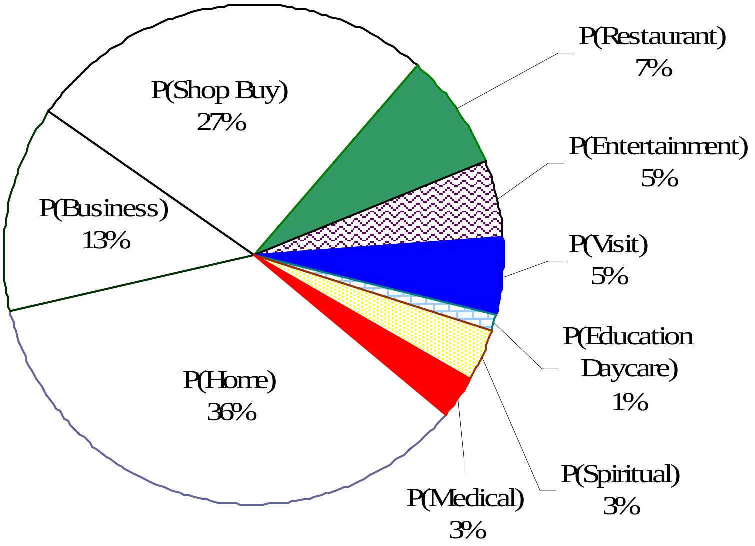

Figure A-2 Yearly Trip Distribution - Females Ages 65 to 74

ESTIMATION DETAILS – TRIP PURPOSE PROBABILITY GIVEN GENDER-AGE GROUP

Trip composition by purpose was estimated from the 2001 U.S. National Household Travel Survey (U.S. Dept. of Transportation Federal Highway Administration 2002). The data was filtered to include only metropolitan areas similar in size to Saskatoon, households in urban areas, only local trips and only those transportation modes that are also available in Saskatoon. There is more than one trip purpose field in this data but the field WHYTRP01 was identified as most appropriate for use in this research.

The following are sample SQL queries used to reduce the original survey data and summarize the information for trip purpose probability estimations.

(Constraint descriptions are in the form *// italic*)

QUERY - 2001 U.S TRIP PURPOSE AND MODE OF TRANSPORTATION TRIP COUNTS

A sample query used to determine the yearly number of trips taken by each gender-age group for a certain trip purpose and using a certain transportation mode follows:

```
SELECT      g.SexAgeGr,
            v.rTRPTRANS,          //Mode of Transportation Group
            p.rWHYTRP01,          //Trip Purpose Group
            Sum(t.WTTRDFIN) AS 'PurposeModeTotal'     //Yearly Trip Count
FROM    GroupGA.csv g,       purpGr.csv p,    travelD.csv t,    transGr.csv v
WHERE (g.Sex=t.R_Sex)
        AND (g.Age=t.R_Age)
        AND (v.TRPTRANS=t.TRPTRANS)
        AND (p.WHYTRP01=t.WHYTRP01)
        AND (t.URBRUR In ('1'))      //Household in urban area
        AND (t.MSACAT In ('3'))      //Metropolitan statistical area (MSA) < 1 million
        AND (t.MSASIZE In ('1','2'))
            //Population size of household MSA: 1=In an MSA of <250,000, 2=In an MSA
            of 250,000 to 499,999
        AND (t.OUTOFTWN Not In ('1'))    //Not out of town entire travel day
        AND (t.PUBTYPE Not In ('2','3'))
             //Mode of Public Transport not 2=subway/train/streetcar or 3=boat
        AND (t.TRPTRANS Not In ('-9','-8','-7','-1','08','09','15','19','21'))
            //Transportation mode on travel day trip not -9=not ascertained,-8=don’t know,
            -7=refused, -1=appropriate skip, 08=commercial/charter airplane,
            09=private/corporate airplane, 15=amtrack/inter city train, 19=ship/cruise,
            21=sailboat/motorboat/yacht
        AND (t.WHYTRP01 Not In ('-9','-8','-7','-1'))
            //Travel day trip purpose not -9=not ascertained, -8=don’t know, -7=refused,
            -1=appropriate skip
GROUP BY g.SexAgeGr,       v.rTRPTRANS,          p.rWHYTRP01
ORDER BY g.SexAgeGr,       v.rTRPTRANS,          p.rWHYTRP01
```

QUERY - 2001 U.S TOTAL TRIP COUNTS

The following sample query was used to determine the total number of trips taken in a year given each gender-age group:

```
SELECT      g.SexAgeGr,
            Sum(t.WTTRDFIN) AS 'TripTotal'      //Yearly trip total
FROM        GroupGA.csv g,        travelD.csv t
WHERE       (g.Sex=t.R_Sex)
            AND (g.Age=t.R_Age)
            AND (t.URBRUR In ('1'))
            AND (t.MSACAT In ('3'))
            AND (t.MSASIZE In ('1','2'))
            AND (t.OUTOFTWN Not In ('1'))
            AND (t.PUBTYPE Not In ('2','3'))
            AND (t.TRPTRANS Not In ('-9','-8','-7','-1','08','09','15','19','21'))
            AND (t.WHYTRP01 Not In ('-9','-8','-7','-1'))
GROUP BY    g.SexAgeGr
ORDER BY    g.SexAgeGr
```

QUERY - 2001 U.S. TRIP COUNT DETAILS FOR EDUCATION OR TO DAYCARE PURPOSES

Discovered during testing, further detail was needed for the original trip purpose group, for education or to daycare. The following codes were in the original trip purpose group: 21 = go to school as student, 20 = trips to school/religious activity, 23 = go to library/school related and 24 = daycare. Then probability estimates identify trips as a student (code=21) and trips not as a student (20,23,24). The following query determines the yearly total number of trips taken for each code for each gender-age group:

```
SELECT g.SexAgeGr,   v.rTRPTRANS,      p.WHYTRP01, Sum(t.WTTRDFIN) AS 'Tot'
FROM  GroupGA.csv g,         purpGr.csv p,   travelD.csv t,   transGr.csv v
WHERE (g.Sex=t.R_Sex)
        AND (g.Age=t.R_Age)
        AND (v.TRPTRANS=t.TRPTRANS)
        AND (p.WHYTRP01=t.WHYTRP01)
        AND (p.rWHYTRP01='d')
        AND (t.URBRUR In ('1'))
        AND (t.MSACAT In ('3'))
        AND (t.MSASIZE In ('1','2'))
        AND (t.OUTOFTWN Not In ('1'))
        AND (t.PUBTYPE Not In ('2','3'))
        AND (t.TRPTRANS Not In ('-9','-8','-7','-1','08','09','15','19','21'))
        AND (t.WHYTRP01 Not In ('-9','-8','-7','-1'))
GROUP BY g.SexAgeGr, v.rTRPTRANS, p.WHYTRP01
ORDER BY g.SexAgeGr, v.rTRPTRANS, p.WHYTRP01
```

CALCULATION – CONDITIONAL TRIP PURPOSE PROBABILITIES FOR CITY RESIDENTS

Let PurposeModeTotal be the SQL query variable that represents the yearly trip total for each unique combination of gender-age and trip purpose-transportation mode. Let η characterize any trip purpose type and let M be a symbol of any transportation mode which includes walk (W), bike (Ψ), public transit (Γ), and personal motorized vehicle (γ). Let TripTotal be the SQL query variable indicating the yearly total number of trips taken for each Φ_{ij} denoting gender-age group. Then $þ_{\eta|\Phi_{ij}}$ signifies the probability of taking a trip for a certain purpose given a gender-age group. Given a gender-age group, the probability of taking a certain trip is the sum of all yearly trips taken using any transportation mode but for the specific trip purpose and gender-age group divided by the yearly total number of trips taken for that gender-age group and is symbolized by

$$þ_{\eta|\Phi_{ij}} = \frac{\sum_{M} \text{PurposeModeTotal}\big|\Phi_{ij}}{\text{TripTotal}\big|\Phi_{ij}} \quad \forall\ M = W, \Psi, \Gamma, \gamma.$$

Let n_{eij} correspond to the total trip count for entertainment by the gender-age group ij. Let $n_{\eta ij}$ stand for the total trip count for Φ_{ij} with trip purpose η which designates any trip purpose including h (to return home), v (to visit friends and relatives), and k (all commercial trip purposes: a, b, d, e, f, m, w). Then the quotient of these two trip counts estimates the probability that given the group, a person goes on a trip for entertainment.

For example, the probability that a resident female in the age group 25 to 34 (Φ_{25}) is on a trip for entertainment, signified by $þ_{e|\Phi_{25}}$, is calculated by

$$þ_{e|\Phi_{ij}} = \frac{n_{eij}}{\sum_{\eta} n_{\eta ij}} \quad \forall \eta . \qquad \text{[A-7]}$$

$$þ_{e|\Phi_{25}} = \frac{n_{e25}}{\sum_{\eta} n_{\eta 25}}$$

$$= \frac{240{,}000{,}000}{4{,}300{,}000{,}000} \approx 0.056 .$$

The second Kolmogorov axiom from probability theory holds for each gender-age group. Specifically, for all trip purposes, the sum of the probabilities for a gender-age group is equal to 1. Trip purpose probabilities for distributing Saskatoon residents to locations throughout the city are found in Table 4.2.2.2.

To provide detailed conditional probabilities for residents who take trips for education and to daycare, each trip purpose code in this group was summarized. If d identifies trips for education and to daycare and +ε signifies trips as a student, then $n_{d_{+\varepsilon}\, ij}$ represents the number of yearly trips taken by gender-age group ij with trip purpose identified in the sample SQL query field p.WHYTRP01 as code 21, meaning to go to school as student. The probability, given gender-age group Φ_{ij}, that a city resident goes on a trip as a student for education or to daycare is indicated by $þ_{d_{+\varepsilon}|\Phi_{ij}}$. This probability is equal to the quotient of the yearly trip count taken by the gender-age group ij as a student for education or to daycare divided by the sum of all yearly trips taken by that same group:

$$þ_{d_{+\varepsilon}|\Phi_{ij}} = \frac{n_{d_{+\varepsilon}\, ij}}{\sum_{\eta} n_{\eta\, ij}} \quad \forall\, \eta\,. \qquad \text{[A-8]}$$

Continuing with the previous example, the calculation to estimate the probability that a female resident in the age group 25 to 34 (Φ_{25}) is on a trip as a student (+ε) for education or to daycare is

$$\begin{aligned} þ_{d_{+\varepsilon}|\Phi_{25}} &= \frac{n_{d_{+\varepsilon}\, 25}}{\sum_{\eta} n_{\eta\, 25}} \\ &\approx \frac{26{,}000{,}000}{4{,}300{,}000{,}000} \approx 0.006\,. \end{aligned}$$

Let -ε identify the sum of non-student yearly trips identified in the sample SQL query field p.WHYTRP01 with codes 20 (trips to school/religious activity), 23 (go to library/school related), and 24 (daycare). Using similar notation as above, the probability that a city resident on a trip for education or to daycare but not as a student (-ε), indicated by $þ_{d_{-\varepsilon}|\Phi_{ij}}$, is estimated by

$$þ_{d_{-\varepsilon}|\Phi_{ij}} = \frac{n_{d_{-\varepsilon}\, ij}}{\sum_{\eta} n_{\eta\, ij}} \quad \forall\, \eta\,. \qquad \text{[A-9]}$$

For instance, estimation of the probability that a female resident in the age group 25 to 34 (Φ_{25}) is on a trip for education or to daycare but not as a student is,

$$\begin{aligned} þ_{d_{-\varepsilon}|\Phi_{25}} &= \frac{n_{d_{-\varepsilon}\, 25}}{\sum_{\eta} n_{\eta\, 25}} \\ &\approx \frac{15{,}100{,}000}{4{,}300{,}000{,}000} \approx 0.004\,. \end{aligned}$$

NON-RESIDENT TRANSFORMATION OF CONDITIONAL TRIP PURPOSE PROBABILITIES

Non-resident visitors to residential households, identified by V_{rij} in equations 3.3, 3.4 and 3.5, were directly added to the number of daily person-equivalents predicted in the area of influence attracted to residential areas. Because visitor trips to Saskatoon were already separated by primary purpose into those who come to visit friends and relatives and those for other purposes, a new set of probabilities must be calculated for application to the latter group of visitors. To do this, trips for the purpose of visiting, trips to return home and trips for education and to daycare were excluded from the estimation of non-resident trip probabilities (Equation A-11). Table 4.2.2.3 provides the estimates for non-resident trip probabilities, denoted by $\text{þ}'_{k|\Phi_{ij}}$. Non-resident visitors to commercial parcels are dispersed using redistributed probabilities such that, for a given gender-age group of non-residents, the sum of all probabilities for trips attracted to non-excluded commercial areas is equal to 1:

$$\sum_k \text{þ}'_{k|\Phi_{ij}} = 1 \quad \forall\ k \neq d\ . \qquad \text{[A-10]}$$

Let þ_{eij} be the probability that a resident in the group Φ_{ij} takes a trip for entertainment and let þ_{kij} epitomize the probability that a resident in the same group Φ_{ij} takes a trip for a commercial purpose. Then the quotient of the probability for a given gender-age group, of taking a trip for entertainment over the sum of all commercial trips taken except those for education and to daycare results in the non-resident trip probability e for a given gender-age group, symbolized by

$$\text{þ}'_{e|\Phi_{ij}} = \frac{\text{þ}_{eij}}{\sum_k \text{þ}_{kij}} \quad \forall\ k \neq d\ . \qquad \text{[A-11]}$$

To continue with the previous example, the calculation to determine the probability that a non-resident female in the age group 25 to 34 (Φ_{25}) is on a trip for the purpose of entertainment ($\text{þ}'_{e|\Phi_{ij}}$) is:

$$\text{þ}'_{e|\Phi_{25}} = \frac{\text{þ}_{e25}}{\sum_k \text{þ}_{k25}}$$

$$\approx \frac{0.056}{(0.21 + 0.27 + 0.054 + 0.056 + 0.012 + 0.016)} \approx 0.09\ .$$

ESTIMATION DETAIL – PREDICTING ATTRACTION USING LAND USE STATISTICS

Land use characteristics were grouped using property use codes that describe land parcels. Details of these groupings are found in Tables C-4 to C-8 in Appendix C. For application in this model, assume that these land use groups attract certain trip purposes. These group identifiers are consistent with the categories used to group trip purposes: to return home (h), to visit people at their residences (v), for business purposes and work (b), to shop or buy (a), to eat out (f), for entertainment (e), for education and to daycare (d), for medical services (m) and to spiritual functions (w). The summary statistics for each test sidewalk location are found in Appendix C Tables C-2.

The land use group associated with the trip purpose, for education and to daycare, was sub-divided into elementary schools and daycares (E), high schools (Y) and colleges or trade schools (U). This additional detail was found to be necessary for Saskatoon due to the large variance in land area between the last attractor and the first two. As well, the probability of trip for education or to daycare was recalculated to distinguish those trips made as a student ($d_{+\varepsilon}$) or as a non-student ($d_{-\varepsilon}$) using equations A-8 and A-9 respectively. The resulting probabilities are found in Table 4.2.2.4.

Land area considered to influence a sidewalk location was set to the area included in a circle of radius 400 metres centered over the sidewalk location. This area, called **area of influence** or **influence area**, was fixed so that identification of local physical characteristics was consistent for each location. A 300-metre radius assumed reduced mobility of the elderly and captured specific seniors' residences nearby a location.

DEFINITION DETAIL - INFLUENCE AREA

Area of influence (L) was defined as the land area (Λ) in square metres (m^2) included in a 400 metre radius ($\Re$) centred on a sidewalk location and is calculated by

$$\begin{aligned}\Lambda_L &= \pi\Re^2 \\ &= \pi(400\text{m})^2 \quad = 502{,}655\text{m}^2 .\end{aligned} \qquad \text{[A-12]}$$

Influence area was used to gather physical statistics that describe the area in close proximity to a location. The local statistics gathered were used as a mechanism to predict attraction of pedestrian traffic volume at an unsafe sidewalk location. The proportion of local physical statistics compared to quantities for the entire city along with trip purpose probabilities assists with the identification of unique local pedestrian characteristics.

Using a standard area to assess locations also aided in reducing variables that may influence sidewalk usage. For example, building setback would seem to be a good indicator of sidewalk usage. In this model, if buildings are situated on larger parcels, there will be less commercial attractors and less pedestrian traffic. Therefore building setback is imbedded in the variable used and does not need to be considered separately.

If the test area is high density, there will be more households and therefore more residential attractors. Household income was not a separate variable considered in the model because the affordability associated with high household or population density in this city generally implies lower household income.

ESTIMATION DETAIL – LOCAL RESIDENT POPULATION COUNT

Population estimates by gender and single year of age for dissemination areas in Saskatoon were provided by Statistics Canada (2001b). Dissemination areas (DA_x) are relatively stable geographic units composed of one or more blocks and usually contain a population count of 400 to 700 (Statistics Canada 2002c).

Let $P_{DA_x ij}$ represent the population count in gender-age group ij residing in dissemination area DA_x. Let Λ_{rDA_x} stand for the sum of residential parcel (r) land areas situated with some portion in the dissemination area x. Let $\Lambda_{rL \cap DA_x}$ signify the sum of residential parcel areas located with some portion in not only the influence area (L) but also the dissemination area x. Then the residential land area quotient for DA_x, residential land area in both the influence area and DA divided by the total in the DA, provides the mechanism to apportion the total residential population reported in the DA to the number most likely residing in only the area of influence portion.

The product, residential land area quotient for DA_x multiplied by DA population count for the gender-age group ij estimates the local resident population in gender-age group ij for DA_x. Therefore, the sum of products for all DA_x with some portion in the influence area estimates the local resident population in gender-age group ij, symbolized by P_{Lij}. Equation 3.1, restated below, estimates the population count for each gender-age group ij residing in the influence area within 400 metres of a sidewalk location:

$$P_{L\,ij} = \sum_{x} \left[\left(\frac{\Lambda_{rL \cap DA_x}}{\Lambda_{r\,DA_x}} \right) P_{DA_x\,ij} \right] \ \forall \ x \text{ with some portion in L.} \qquad \text{[A-13]}$$

For example, the influence area centered on the test sidewalk location in the industrial area, identified as Ind, touches three dissemination areas. The calculation to determine P_{Ind11}, the approximate resident population for males ages 0 to 11 years within 400 metres of the sidewalk location, Ind, is as follows:

$$\begin{aligned} P_{Ind11} &= \left(\frac{20{,}620\,\mathrm{m}^2}{164{,}019\,\mathrm{m}^2} \right) 100 + \left(\frac{27{,}008\,\mathrm{m}^2}{63{,}456\,\mathrm{m}^2} \right) 40 + \left(\frac{2{,}355\,\mathrm{m}^2}{102{,}415\,\mathrm{m}^2} \right) 50 \\ &= (0.126)100 + (0.426)40 + (0.023)50 \\ &\approx 31 \text{ resident males in the age group } 0-11. \end{aligned}$$

The resident population estimates for influence areas surrounding test sidewalk locations are found in Appendix C Table C-1.

ESTIMATION DETAIL – LOCAL HOUSEHOLD COUNT

Household counts for each dissemination area in Canada were provided by Statistics Canada (2001d). In 2001, about 79,240 households in private dwellings existed in Saskatoon. Household counts in non-private dwellings, defined as institutional, communal or commercial, were excluded. In 2006, the exclusion missed about 1,435 households in senior's accommodations. A different source was used which identified each dwelling location and household capacity. The estimate for excluded households was added to the total count in private dwelling. When including seniors' households found in non-private dwellings, the total estimate in Saskatoon was 80,675 households.

Let H_{DAx} denote the household count for each dissemination area x with some portion in the influence area L. Consider that the residential land area quotient used to estimate the resident population within an influence area can also be used to estimate the household count in an influence area. Then the sum of the products for each DA_x of the residential land area quotient multiplied by the household count estimates the number of households in private dwelling within the influence area.

Let $H_{\alpha L}$ be the households in non-private dwellings at specified locations within 300 metres of the unsafe sidewalk location. Three hundred metres is chosen to reflect assumed reduced mobility of seniors in non-private dwellings. Then $H_{\alpha L}$ added to the households in private dwellings estimates the total household count in the influence area. Equation 3.2, restated below, estimates the influencing household count situated within 400 metres of a sidewalk location (H_L):

$$H_L = \sum_x \left[\left(\frac{\Lambda_{rL \cap DA_x}}{\Lambda_{r\,DA_x}} \right) H_{DA_x} \right] + H_{\alpha L} \quad \forall\ x \text{ with some portion in } L. \quad \text{[A-14]}$$

Continuing with the previous example, the estimate for local household count influencing the test sidewalk location, Ind, is

$$\begin{aligned} H_{Ind} &= \left[\left(\frac{20{,}620\,m^2}{164{,}019\,m^2} \right) 370 + \left(\frac{27{,}008\,m^2}{63{,}456\,m^2} \right) 205 + \left(\frac{2{,}355\,m^2}{102{,}415\,m^2} \right) 220 \right] + 0 \\ &= (0.126)370 + (0.426)205 + (0.023)220 + 0 \\ &\approx 139 \text{ households.} \end{aligned}$$

Household counts are used in equations 3.3, 3.4 and 3.5 to determine the daily population contribution at a sidewalk location due to trips taken to go home and to visit others at their residences. Assume that the proportion of total households better reflects visits to residences than the proportion of the Saskatoon residents living in the influence area surrounding a sidewalk location.

SAMPLE CALCULATION TO ESTIMATE THE LOCAL TOTAL DAILY POPULATION:

A sample calculation showing the method of approximating the total average daily population-equivalents nearby the test sidewalk location, Inter_W, for the gender-age group, females ages 55 to 64 (Φ_{28}), will demonstrate each of the model calculations.

Step 1: Equation 3.5 estimates the daily population-equivalents (λ_{rij}) attracted to a location to return home (h) or to visit friends and relatives (v):

$$\lambda_{r\,ij} = \left[\left(\frac{H_L}{H_T}\right)\left[\left(P_{\theta ij}\ \text{þ}_{v|\Phi_{ij}}\right) + V_{r\,ij}\right]\right] + \left[\left(P_{L\,ij}\ \text{þ}_{h|\Phi_{ij}}\right)\left(1 + \frac{n_{zL}}{N_z} + \frac{H_{gL}}{H_{gT}}\right)\right]$$

$$\lambda_{r\,28} = \left[\left(\frac{H_{\text{Inter\_W}}}{H_T}\right)\left[\left(P_{\theta\,28}\ \text{þ}_{v|\Phi_{28}}\right) + V_{r\,28}\right]\right] + \left[\left(P_{\text{Inter\_W}\,28}\ \text{þ}_{h|\Phi_{28}}\right)\left(1 + \frac{n_{\text{zInter\_W}}}{N_z} + \frac{H_{\text{gInt\_W}}}{H_{gT}}\right)\right]$$

$$= \left[\left(\frac{800}{80{,}675}\right)\left[\left(7{,}800 \times 0.04\right) + 224\right]\right] + \left[\left(49 \times 0.34\right)\left(1 + \frac{0}{5{,}380} + \frac{1}{122}\right)\right]$$

$$\approx 22 \text{ population-equivalents.}$$

Step 2: Equation 3.6 estimates the daily population-equivalents (λ_k) on a trip with a purpose attracted to commercial land parcels (k) nearby a location. The trip purpose chosen for the sample calculation is trips for personal or work business (b):

$$\lambda_{k\,ij} = \left(\frac{n_{kL}}{N_k}\right)\left[\left[P_{\theta\,ij}\ \text{þ}_{k|\Phi_{ij}}\right] + \left[V_{c\,ij}\ \text{þ}'_{k|\Phi_{ij}}\right]\right]$$

$$\lambda_{b\,28} = \left(\frac{n_{b\,\text{Inter\_W}}}{N_b}\right)\left[\left[P_{\theta\,28}\ \text{þ}_{b|\Phi_{28}}\right] + \left[V_{c\,28}\ \text{þ}'_{b|\Phi_{28}}\right]\right]$$

$$= \left(\frac{8}{1{,}388}\right)\left[\left[7{,}800 \times 0.21\right] + \left[724 \times 0.34\right]\right]$$

$$\approx 10 \text{ population-equivalents.}$$

Step 3: Equation 3.9 estimates the daily population-equivalents (λ_d) older than 19 years who are attracted to a location for a trip for education or to daycare as a student ($d_{+\varepsilon}$) or not as a student ($d_{-\varepsilon}$) :

$$\lambda_{d\ ij} = P_{\theta\, ij}\left[\left(\left(\frac{\Lambda_{UL}}{\Lambda_{UT}}\right)\text{þ}_{d_{+\varepsilon}|\Phi_{ij}}\right)+\left(\left(\frac{\Lambda_{dL}}{\Lambda_{dT}}\right)\text{þ}_{d_{-\varepsilon}|\Phi_{ij}}\right)\right]$$

$$\lambda_{d\ 28} = P_{\theta\, 28}\left[\left(\left(\frac{\Lambda_{U\ Inter\_W}}{\Lambda_{UT}}\right)\text{þ}_{d_{+\varepsilon}|\Phi_{28}}\right)+\left(\left(\frac{\Lambda_{d\ Inter\_W}}{\Lambda_{dT}}\right)\text{þ}_{d_{-\varepsilon}|\Phi_{28}}\right)\right]$$

$$= 7{,}800\left[\left(\left(\frac{59{,}237}{1{,}315{,}162}\right)0.002\right)+\left(\left(\frac{73{,}709}{2{,}845{,}888}\right)0.003\right)\right]$$

$$\approx 1 \text{ population} - \text{equivalent} .$$

Step 4: Equation 3.10 estimates the daily population-equivalents (λ_m) related to trips for medical purposes (m) at a location:

$$\lambda_{m\ ij} = \left(\frac{\Lambda_{mL}}{\Lambda_{mT}}\right)\left[\left[P_{\theta\, ij}\ \text{þ}_{m|\Phi_{ij}}\right]+\left[V_{c\, ij}\ \text{þ}'_{m|\Phi_{ij}}\right]\right]$$

$$\lambda_{m\ 28} = \left(\frac{\Lambda_{m\ Inter\_W}}{\Lambda_{mT}}\right)\left[\left[P_{\theta\, 28}\ \text{þ}_{m|\Phi_{28}}\right]+\left[V_{c\, 28}\ \text{þ}'_{m|\Phi_{28}}\right]\right]$$

$$= \left(\frac{360}{309{,}027}\right)\left[\left[7{,}800 \times 0.02\right]+\left[724 \times 0.03\right]\right]$$

$$\approx 0 \text{ population - equivalents} .$$

Step 5: Equation 3.13 makes final adjustments to the sum of all estimated population-equivalents contribution by trip purpose ($\lambda_{\eta\ ij}$). These final adjustments consider bus stop availability (δ_Ξ), sidewalk availability (δ_S) and add extra weight for those groups who are more likely to walk ($\text{þ}_{W|\Phi_{ij}}$), such that,

$$\tilde{\lambda}_{L\, ij} = \left[\sum_{\eta}\lambda_{\eta ij}\left[1+\left(\delta_\Xi\ \text{þ}_{\Gamma|\Phi_{ij}}\right)+\text{þ}_{W|\Phi_{ij}}\right]\right]\delta_S$$

$$\tilde{\lambda}_{Inter\_W\,28} = \left[\sum_{\eta}\lambda_{\eta 28}\left[1+\left(\delta_\Xi\ \text{þ}_{\Gamma|\Phi_{28}}\right)+\text{þ}_{W|\Phi_{28}}\right]\right]\delta_S$$

$$= \left[(22+11+62+42+7+1+3+0)\times\left[1+(0.9\times 0.01)+0.05\right]\right]\times 1$$

$$\approx 157 \text{ total average daily female population - equivalents ages 55 to 64}.$$

ADJUSTMENT DETAILS – FACTORS AFFECTING THE LOCAL DAILY POPULATION

Three factors were suspected of affecting the number of pedestrians at a sidewalk location. Adjustments were made to the total local daily person-equivalents to account for the number of local senior's residences and high-risk land parcels, bus stop availability, and sidewalk availability. Details of these adjustments follow.

ADJUSTMENT FOR LOCAL SENIORS RESIDENCES AND HIGH-RISK LAND PARCELS

It is prudent to identify designated seniors residences and high-risk land parcels when assessing the amount of risk at a sidewalk location. The Saskatoon Public Library provided information and the location of personal and special care homes, supported independence residences and self-contained units (2006). There were approximately 5,380 units specified for residents ages 55 to 65 and older.

Let n_g indicate the number of seniors' households (g) within 300 metres of a sidewalk location. Let N_g express the total number of seniors' households in the city. Then the ratio $\left(\frac{n_g}{N_g}\right)$ is the weight added to the male and female age groups 55 and older to consider seniors' households situated within 300 metres of a sidewalk location.

Let n_z signify the number of land parcels with a high-risk (z) designation. High-risk land parcels have attached property use codes identifying seniors' homes, group homes, nursing homes and assisted living. Let N_z stand for the number of high-risk land parcels in the entire city. Then the ratio $\left(\frac{n_z}{N_z}\right)$ is the weight added to the age groups for 25 years and older. The weight adds extra consideration for high-risk land parcels (z) found within 400 metres of a sidewalk location.

Weights are added to the residential trip estimation within the influence area of a sidewalk location as the last term in Equations 3.4 and 3.5, respectively, restated below:

$$\lambda_{rij} = \left[\left(\frac{H_L}{H_T}\right)\left[\left(P_{\theta ij}\ \text{þ}_{v|\Phi_{ij}}\right) + V_{rij}\right]\right] + \left[\left(P_{Lij}\ \text{þ}_{h|\Phi_{ij}}\right)\left(1 + \frac{n_{zL}}{N_z}\right)\right] \ \forall\, i,\ j = 5,6,7.$$

$$\lambda_{rij} = \left[\left(\frac{H_L}{H_T}\right)\left[\left(P_{\theta ij}\ \text{þ}_{v|\Phi_{ij}}\right) + V_{rij}\right]\right] + \left[\left(P_{Lij}\ \text{þ}_{h|\Phi_{ij}}\right)\left(1 + \frac{n_{zL}}{N_z} + \frac{H_{gL}}{H_{gT}}\right)\right] \ \forall\, i,\ j > 7.$$

ADJUSTMENT FOR THE IMPACT OF BUS STOP AVAILABILITY

Assume that the average number of bus stops in an area equivalent to the size of the influence area neither influences nor deters the decision to take a bus. However, if the number is higher than the average, the decision to use the bus is influenced and if the number is lower, the decision is deterred by the lack of available bus stops. Only those areas of the city that were established and occupied were considered for determining this average. Where the neighbourhood is established and occupied, land parcel areas, symbolized by ∂, include residential (r), to shop or buy (a), business (b), education and daycare (d), entertainment (e), restaurants (f), medical (m), and spiritual (w). The term occupied excludes industrial neighbourhoods from the bus stop average calculation.

Let $N_{\Xi T}$ characterize the number of bus stops in established occupied areas of the city. Let $\Lambda_{\partial T}$ correspond to the total land area in established occupied parts of the city. Then the standard size of the influence area, 502,655 m^2 divided by the quotient, established occupied total land area in the city divided by the number of bus stops in these areas of the city, provided the average number of bus stops in established occupied influence area sized regions of the city. In Saskatoon, the average number of bus stops per influence area ($\bar{n}_{\Xi}$) to assess bus stop availability at a location was

$$\bar{n}_{\Xi} = \frac{\Lambda_{\Re_{400\,\mathrm{m}}}}{\left(\frac{\sum_{\partial} \Lambda_{\partial T}}{N_{\Xi T}}\right)} \quad \forall\, \partial. \qquad \text{[A-15]}$$

$$\bar{n}_{\Xi} = \frac{502{,}655\,\mathrm{m}^2}{\left(\frac{46{,}756{,}929\,\mathrm{m}^2}{1{,}374\ \text{bus stops}}\right)}$$

$$\approx 15\ \text{bus stops per size of influence area}.$$

The average number of bus stops for a 400-metre radius area of established occupied land in the city was approximately 15. Therefore, population estimates for locations were weighted (Equation 3.13) with respect to the average bus stop availability to account for the population contribution to pedestrian traffic near bus stops.

Let $n_{L\Xi}$ denote the bus stop count within 400 metres of a sidewalk location. Then the bus stop availability weight, symbolized by δ_{Ξ}, is the ratio of the local bus stop count ($n_{L\Xi}$) divided by the average bus stop count for the city ($\bar{n}_{\Xi}$), or

$$\delta_{\Xi} = \left(\frac{n_{L\Xi}}{\bar{n}_{\Xi}}\right) \qquad \text{[A-16]}$$

ADJUSTMENT FOR THE IMPACT OF SIDEWALK AVAILABILITY

Assume that the average sidewalk to curb ratio in established non-industrial areas of the city neither encourages nor discourages the decision to walk. Let 1 represent the perfect sidewalk to curb ratio, meaning that adjacent to every curb sidewalk exists. Then the difference between the perfect ratio and the average ratio for the city is the tolerable deviation that does not deter people from walking. Then assume that the average minus this difference is also tolerated.

For established non-industrial areas of the city, let ℓ_{ST} be the total sidewalk length and let ℓ_{CT} be stand for the total curb length. Then $\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}$ is the average sidewalk to curb ratio for the city. In Saskatoon, the average sidewalk to curb ratio was

$$\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}} = \frac{1{,}114{,}993\,\mathrm{m}}{1{,}385{,}692\,\mathrm{m}} \approx 0.80\ .$$

For the 400-metre radius area surrounding a sidewalk location, let ℓ_{SL} identify the sidewalk length and let ℓ_{CL} indicate the curb length. If, the sidewalk to curb ratio plus an adjustment upward for the accepted deviation from the perfect ratio or $1-\left(\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)$ is less than the city average sidewalk to curb ratio, then the decision to walk is deterred by a factor equal to the adjusted local sidewalk to curb ratio, otherwise there is no deterrent. This logic is summarized in Equation 3.11 and restated below. Sidewalk availability (δ_{S}) affects the decision to walk so an adjustment is made whereby

$$\delta_{\mathrm{S}} = \begin{cases} 1 & \text{if } \left[\left(1-\left(\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\frac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] > \frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}} \\ \left[\left(1-\left(\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\frac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] & \text{otherwise}. \end{cases}$$

The only test sidewalk location that met the criteria for an adjustment was Ind. This location had approximately 8,065 m of sidewalk per km^2, which was less than half of any other location assessed in this study. Therefore, the total daily population was grossly adjusted for sidewalk availability.

For example, at the test location, Inter_W,

$$\frac{\ell_{\mathrm{S\,Inter\_W}}}{\ell_{\mathrm{C\,Inter\_W}}} = \frac{16{,}239\,\mathrm{m}}{17{,}916\,\mathrm{m}} = 0.91 \quad \text{and}$$

$$\left[\left(1-\left(\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\frac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] = (1-0.80)+0.91 = 1.11 > 0.80\,, \quad \text{therefore}$$

$$\delta_{\mathrm{S}} = 1.$$

However, at the test sidewalk location, Ind,

$$\frac{\ell_{\mathrm{S\,Ind}}}{\ell_{\mathrm{CInd}}} = \frac{4{,}054\,\mathrm{m}}{15{,}233\,\mathrm{m}} = 0.27 \quad \text{and}$$

$$\left[\left(1-\left(\frac{\ell_{\mathrm{ST}}}{\ell_{\mathrm{CT}}}\right)\right)+\left(\frac{\ell_{\mathrm{SL}}}{\ell_{\mathrm{CL}}}\right)\right] = (1-0.80)+0.27 = 0.47 < 0.80\,, \quad \text{therefore}$$

$$\delta_{\mathrm{S}} = 0.47.$$

All total daily population estimates for each gender-age group estimated in the influence area of the sidewalk location, Ind, were adjusted to 47% of their total due to the lack of sidewalks which discourage pedestrian traffic.

ADJUSTMENT FOR MODE CHOICE AFFECT ON SIDEWALK USAGE

Recognizing that mode choice is a regional attribute, the U.S. transportation modal split was adjusted to better reflect the modal split in Saskatoon. Age and gender adjustments were made to the U.S. data based on the 2001 Saskatoon population. The modal split comparison is shown in Table A-3. Explanation of the Saskatoon mode split estimation in this table is found in the next section.

Table A-3 Age and Gender Standardized (2001 Saskatoon) Modal Split

Transportation Mode:	U.S.	Saskatoon
Personal Motorized	0.90	0.86
Walking	0.073	0.056
Public Transit	0.019	0.060
Bike	0.011	0.024

Adjusting for differences in transportation mode choice from the U.S. finding to Saskatoon must be done before the application of probabilities for mode choice given the gender-age group. An explanation of the filtered dataset that was used for these calculations is found in Appendix A in the section titled Estimation Details – Trip Purpose Probability given Gender-Age Group.

First, the probability of gender-age group given a modal choice was calculated from the filtered U.S. dataset. Transportation modes were grouped into four general areas: (1)

personal motorized included trips by car, van, sport utility vehicle, pickup truck, other truck, recreational vehicle, motorcycle, taxicab, limousine, and hotel/airport shuttle; (2) walking includes trips by walking; (3) public transit included trips by local public transit bus, commuter bus, school bus, charter/tour bus and city-to-city bus; (4) Bicycle included trips by bicycle and other.

Next, the data was age and gender adjusted for application to the Saskatoon population. Let $\text{þ}_{\Phi_{ij\,\mathrm{U.S.}}|\mathrm{M}}$ designate the probability that, given a transportation mode, a U.S. resident is in the gender-age group Φ_{ij}. Let $\text{þ}_{\Phi_{ij\,\mathrm{U.S.}}}$ denote the probability that a U.S. resident is in the gender age Φ_{ij} and let $\text{þ}_{\Phi_{ij\,\theta}}$ embody the probability that a person in Saskatoon is in the gender-age group Φ_{ij}. Then the ratio, the probability of a gender-age group in Saskatoon versus that same gender-age group in the U.S., multiplied by the probability, given the transportation mode, of a U.S. resident being in the gender-age group Φ_{ij} estimated the probability that, given that same mode, a Saskatoon resident was in the gender-age group Φ_{ij}, and was calculated by

$$\text{þ}_{\Phi_{ij}\,\theta|\mathrm{M}} = \frac{\text{þ}_{\Phi_{ij}\,\mathrm{U.S.}|\mathrm{M}}\ \text{þ}_{\Phi_{ij}\theta}}{\text{þ}_{\Phi_{ij}\,\mathrm{U.S.}}}\,. \qquad \text{[A-17]}$$

For example, the probability that if a resident (θ) is walking in Saskatoon, they are a male in the age range 25-34 (Φ_{15}) is

$$\text{þ}_{\Phi_{15}\,\theta|\mathrm{W}} = \frac{\text{þ}_{\Phi_{15}\mathrm{U.S.}|\mathrm{W}}\ \text{þ}_{\Phi_{15}\,\theta}}{\text{þ}_{\Phi_{15}\,\mathrm{U.S.}}}$$

$$= \frac{0.068 \times 0.070}{0.085} \quad \approx 0.056\,.$$

Let Φ indicate the gender-age group and let M identify the mode of transportation. Because the modal split was different between the source and target populations, the probabilities must be transformed using Bayes' Theorem where

$$\mathrm{P}(\Phi|\mathrm{M}) = \frac{\mathrm{P}(\Phi \cap \mathrm{M})}{\mathrm{P}(\mathrm{M})} \quad \text{and}$$

$$\mathrm{P}(\mathrm{M}|\Phi) = \frac{\mathrm{P}(\Phi \cap \mathrm{M})}{\mathrm{P}(\Phi)}\,.$$

Substituting for $\mathrm{P}(\Phi \cap \mathrm{M})$,

$$\mathrm{P}(\mathrm{M} \mid \Phi) = \frac{\mathrm{P}(\Phi \mid \mathrm{M})\,\mathrm{P}(\mathrm{M})}{\mathrm{P}(\Phi)} \quad \text{which is equivalently expressed as}$$

$$\text{þ}_{M|\Phi_{ij}\theta} = \frac{\text{þ}_{\Phi_{ij}\theta|M}\ \text{þ}_{M_\theta}}{\text{þ}_{\Phi_{ij}\theta}} . \qquad [A\text{-}18]$$

For example, the probability that a male ages 25 to 34 is walking in Saskatoon is:

$$\text{þ}_{W|\Phi_{15}\theta} = \frac{\text{þ}_{\Phi_{15}\theta|W}\ \text{þ}_{W_\theta}}{\text{þ}_{\Phi_{15}\theta}}$$

$$= \frac{0.056 \times 0.056}{0.070} \quad \approx 0.05 .$$

The probabilities did not transform accurately with this calculation. The sum of each gender-age group should but did not sum to 1.0 but they did to 1. Therefore, mode probabilities given gender-age groups were adjusted so that the summation did equal 1.0. The group in the above example was estimated to have a probability of 0.076 for walking. The estimated modal split for Saskatoon given the gender-age group is shown in Table A-4.

Table A-4 Estimated Modal Split for Gender and Age Groups

	Probability(Person in Group *ij* chooses a Transportation Mode)			
Group *ij*	Personal Motorized	Walk	Public Transport	Bicycle
M 0-11	0.7	0.08	0.2	0.06
M 12-14	0.4	0.07	0.4	0.1
M 15-19	0.7	0.06	0.2	0.04
M 20-24	0.9	0.05	0.02	0.01
M 25-34	0.9	0.05	0.02	0.03
M 35-44	0.9	0.04	0.01	0.04
M 45-54	0.9	0.05	0.01	0.03
M 55-64	0.9	0.04	0.01	0.02
M 65-74	0.9	0.05	0.002	0.02
M 75pl	0.9	0.05	0.03	0.02
F 0-11	0.7	0.07	0.2	0.04
F 12-14	0.5	0.1	0.3	0.06
F 15-19	0.7	0.05	0.2	0.02
F 20-24	0.9	0.07	0.0	0.003
F 25-34	0.9	0.06	0.04	0.003
F 35-44	0.9	0.04	0.01	0.01
F 45-54	0.9	0.05	0.01	0.02
F 55-64	0.9	0.05	0.01	0.007
F 65-74	0.9	0.05	0.02	0.006
F 75pl	0.9	0.07	0.04	0.005

Determining Saskatoon Modal Split

Referencing the Saskatoon Transit Strategic Plan Study Appendix E (IBI Group 2005b),

Saskatoon population (P_{θ})	202,900
Daily person-trips per capita (n_T)	2.5
Daily transit modal share (þ_{Γ})	0.059
Daily non-motorized trips per capita ($\text{þ}_{W \cup \Psi}$)	0.08

Let n_{Γ} represent the number of daily person-trips per capital using transit. The following is the equation used to determine the number of transit trips in Saskatoon which is equal to the product of the probability of a trip using the transit system (þ_{Γ}) multiplied by the total number of daily person-trips per capita (n_T) :

$$\begin{aligned} n_{\Gamma} &= \text{þ}_{\Gamma}\ n_T \\ &= 0.059 \times 2.5\,\text{daily trips / capita} \\ &\approx 0.15\,\text{daily transit trips / capita}. \end{aligned}$$

Let $n_{W \cup \Psi}$ represent the number of daily person-trips per capital using non-motorized modes of transportation. Non-motorized modes include walking (W) and biking (Ψ). Then the calculation for $n_{W \cup \Psi}$ is equal to the probability of using non-motorized modes multiplied by the number of total daily person-trips per capita:

$$\begin{aligned} n_{W \cup \Psi} &= \text{þ}_{W \cup \Psi}\ n_T \\ &= 0.08 \times 2.5\,\text{daily trips / capita} \\ &\approx 0.20\,\text{daily non} - \text{motorized trips / capita}. \end{aligned}$$

Let n_{γ} be the number of daily person-trips per capital transported by personal motorized vehicles. Then the estimation of n_{γ} is equal to the number of transit and non-motorized daily trips per capita subtracted from the number of total daily person-trips per capita:

$$\begin{aligned} n_{\gamma} &= n_T - n_{\Gamma} - n_{W \cup \Psi} \\ &= 2.5 - 0.15 - 0.20 \\ &\approx 2.15\,\text{daily personal motorized vehicle trips / capita}. \end{aligned}$$

From Statistics Canada 2001 Census Mode of Transportation to Work (2001e):

Transportation modal split to work for 106,025 workers in Saskatoon ages 15 or more years old with a usual place of work or no fixed workplace address was as follows:

Private Motorized Vehicle or other ($\text{þ}_{\gamma\ \text{worker}}$)	0.88
Transit ($\text{þ}_{\Gamma\ \text{worker}}$)	0.041

Walk ($þ_{W\ worker}$)	0.058
Bike ($þ_{\Psi\ worker}$)	0.025

Because this only covers a specific group of residents described above and excluding those residents less than the age of 15, the mode distribution cannot be directly applied to the total Saskatoon population. It was documented that youth and the elderly are more likely to use non-motorized modes of travel (Matlick 1998). Therefore, this data was used only to determine the ratio of walking versus biking trips to add to the information provided by IBI Group.

Let the symbol for the worker population in Saskatoon be $P_{\theta\,\mathrm{worker} \cap W}$ and $P_{\theta\,\mathrm{worker} \cap \Psi}$ for those that, respectively, walk and bike to work. Then the number of daily person-trips per capita made by walking (n_W) is equal to the number of trips made using non-motorized modes of transportation multiplied by a ratio. The ratio is the Saskatoon working population who walk to work divided by the sum of the working populations who walk or bike to work:

$$n_W = n_{W \cup \Psi}\left[\frac{P_{\theta\,\mathrm{worker} \cap W}}{\left(P_{\theta\,\mathrm{worker} \cap W} + P_{\theta\,\mathrm{worker} \cap \Psi}\right)}\right]$$

$$n_W = 0.20 \times \left[\frac{6{,}105}{(6{,}105 + 2{,}655)}\right]$$

$$\approx 0.14 \text{ daily walking trips / capita.}$$

Then the number of daily trips taken per capita using a bike, characterized by n_Ψ is equal to the number of walking trips subtracted from the number of non-motorized trips or

$$n_\Psi = n_{W \cup \Psi} - n_W$$

$$= 0.20 - 0.14$$

$$\approx 0.06 \text{ daily bike trips / capita .}$$

Results:

Daily personal motorized vehicle and other modes trips per capita	~ 2.15
Daily transit trips per capita (given)	~ 0.15
Daily walking trips per capita	~ 0.14
Daily bike trips per capita	~ 0.06

Estimates for the probability that a person in Saskatoon chooses to take a trip using a personal motorized vehicle is $þ_\gamma = 0.86$, using a bus is $þ_\Gamma = 0.060$, by walking is $þ_W = 0.056$ and using a bike is $þ_\Psi = 0.024$. These results are also summarized in Table A-3.

METHOD OF ESTIMATING THE PROBABILITY OF TRIP INJURY EVENTS

The Canadian Community Health Survey (CCHS) data collected in 2000/2001, 2003 and 2005 were used to estimate the probability, given a gender-age group, of a trip event causing an injury type (I) that affects a body part (B). The surveys included only persons 12 years and older. Some of the variables changed in each survey so the sample queries provide the general extraction of data needed for these estimations with additional notes that identify specific survey changes:

SAMPLE QUERIES

QUERY FOR 2003 CANADIAN FALL STATISTICS

```
SELECT        t3.DHHCGAGE AS 'Age',
              t3.DHHC_SEX AS 'Sex',
              t3.INJCG05 AS 'InjTyp',
              t3.INJCG06 AS 'BdyPrt',
              Sum(t3.WTSC_M) AS 'IB_Tot'
FROM  `2003CCHS.csv` t3
WHERE   t3.INJC_01 In (1,7,8)           //INJC_01:Injured in past 12mon.(excl repetitives strain)
                                        where   1=YES, 7=DON'T KNOW (Missing),
                                         and    8=REFUSAL (Missing)
        AND t3.INJC_10 In (1,7,8)       //INJC_10 : Was this most serious injury a result of a fall
                                        where   1=YES, 7=DON'T KNOW (Missing),
                                        and     8=REFUSAL (Missing)
        AND t3.INJCG08 In (5)           //INJCG08:G: Most serious injury: place of occurrence
                                        where 5 = STREET, HIGHWAY, SIDEWALK
        AND t3.INJCG11 In (4)           //INJCG11 : G: Most serious injury: how fell
                                        where 4 =  SLIP, TRIP, STUMBLE ON ANY SURFACE
        AND t3.INJCG05 Not In (3,99) //INJCG05: G: Most serious injury: type
                                        where3=BURN, SCALD, CHEMICAL BURN
                                        and 99 = NOT STATED (Missing)
GROUP BY      t3.DHHCGAGE,
              t3.DHHC_SEX,
              t3.INJCG05,
              t3.INJCG06
ORDER BY      t3.DHHC_SEX,
              t3.DHHCGAGE,
              t3.INJCG05,
              t3.INJCG06
```

// ***DHHCGAGE*** *: G: Age in years*

where 1= 12 TO 14, 2 = 15 TO 19, 3 = 20 TO 24, 4 = 25 TO 29, 5 = 30 TO 34,
6 = 35 TO 39, 7 = 40 TO 44, 8 = 45 TO 49, 9=50 TO 54, 10 = 55 TO 59,
11 = 60 TO 64, 12 = 65 TO 69, 13 = 70 TO 74, 14 = 75 TO 79, and
15 = 80 YEARS OR MORE.

For 2000/01 (DHHAGAGE) and 2003, age ranges are grouped as follows: 1, 2, 3, 4+5, 6+7, 8+9, 10+11, 12+13, and 14+15.

// ***DHHEGAGE*** *: G: Age in years*

where 1=12 TO 14, 2=15 TO 17, 3=18-19, 4=20 TO 24, 5=25 TO 29,
6=30 TO 34, 7=35 TO 39, 8=40 TO 44, 9=45 TO 49, 10=50 TO 54,
11=55 TO 59, 12=60 TO 64, 13=65 TO 69, 14=70 TO 74,
15=75 TO 79, and 16=80 YEARS OR MORE.

For 2005, age ranges were grouped as follows: 1,2+3, 4, 5+6, 7+8, 9+10, 11+12, 13+14, and 15+16.

// ***DHHC_SEX*** *: Sex*

where 1= MALE and 2 = FEMALE.

NOTE: The different font colour represents changes made in the different colour year.

// ***INJCG05*** *: G: Most serious injury: type*

where 1 = MULTIPLE INJURIES,
2 = BROKEN OR FRACTURED BONES,
4 = DISLOCATION,
5 = SPRAIN OR STRAIN,
6 = CUT, PUNCTURE, ANIMAL OR HUMAN BITE,
7 = SCRAPE, BRUISE, BLISTER,
8 = CONCUSSION or other brain injury OR INTERNAL INJURY,
9 = OTHER, includes poisoning

For each of 2000/2001, 2003 and 2005, the following injury types were grouped: 1+9, 2+4, 5, 6+7 and 8.

// ***INJCG06*** *: G: Most serious injury: body part affected*

where 1 = MULTIPLE SITES,
2 = EYES/HEAD/NECK
3 = SHOULDER, UPPER ARM,
4 = ELBOW, LOWER ARM,
5 = WRIST OR HAND,
6 = HIP OR THIGH,
7 = KNEE, LOWER LEG,
8 = ANKLE, FOOT,
9 = UPPER OR LOWER BACK/UPPER OR LOWER SPINE,
10= CHEST OR ABDOMEN OR PELVIS (excluding back and spine).

For 2003 and 2005, the following codes were grouped for body part affected: 1, 2+9, 3+4, 5, 6+7+8 and 10.

*// **INJAG06** : Most serious injury: body part affected (G)*
where 1 = MULTIPLE SITES,
2 = EYES / HEAD / NECK,
3 = SHOULDER / UPPER ARM,
4 = ELBOW / LOWER ARM,
5 = WRIST / HAND,
6 = HIP / THIGH/KNEE, LOWER LEG / ANKLE, FOOT,
7 = UPPER OR LOWER BACK / UPPER OR LOWER SPINE,
8 = CHEST OR ABDOMEN OR PELVIS.

For 2001, codes were grouped for body part affected: 1, 2+7, 3+4, 5, 6, and 8.

QUERY FOR 2003 CANADIAN TOTAL POPULATION REPRESENTED IN THE SURVEY

```
SELECT      t3.DHHCGAGE AS 'Age',
            t3.DHHC_SEX AS 'Sex',
            Sum(t3.WTSC_M) AS 'Pop_Tot'
FROM        `2003CCHS.csv` t3
GROUP BY    t3.DHHCGAGE,
            t3.DHHC_SEX
ORDER BY    t3.DHHC_SEX,
            t3.DHHCGAGE
```

ESTIMATION DETAILS – TRIP INJURY PROBABILITIES GIVEN GENDER-AGE GROUP

From the above two sample queries, the calculation for þ_{IBij}, the probability of a trip injury event type (I) affecting a certain body part (B) given the individual's gender and age group (ij), can be estimated.

Injury types (I) are expressed as the following groups: F is fractures or dislocates; S is sprains or strains; B is bruise, scrape, cut, or puncture; C is concussion or internal injury; and M is multiple or other injuries.

Body parts affected (B) are denoted as the following groups: b is head, neck, back or spine; s is shoulder, arm, or elbow; w is wrist or hand; a is hip, thigh, leg, knee, ankle or foot; t is chest, abdomen, or pelvis; and m is multiple sites.

Let IB_Tot_{IBij} be the SQL query variable IB_Tot that represents the number of trip injury occurrences with an injury type I that affects a body part B for a gender-age group ij. Let Pop_Tot_{IBij} correspond to the SQL query variable Pop_Tot that characterizes the population count for the gender-age group ij represented by the community health survey. Then the probability that, given the gender-age group ij, a person sustains a trip injury event IB on a street, sidewalk, or highway is calculated by the ratio of the number of trip injury occurrences for the identified injury type and body part combination (IB) divided by the population count for the gender-age group ij, symbolized by

$$\text{þ}_{IBij} = \frac{IB\_Tot_{IBij}}{Pop\_Tot_{IBij}} . \qquad [A\text{-}19]$$

Each of the three CCHSs covered approximately 98% of the Canadian population ages 12 and over living in private occupied dwellings. Those less than 12 years old and individuals living on Indian Reserves and on Crown Lands, institutional residents, full-time members of the Canadian Armed Forces, and residents of certain remote regions were not included in the surveys.

The probability of a trip injury event type given the gender-age group was estimated using 2001, 2003 and 2005 CCHS data with restrictions identified above. Because there were no data for the age group 0 to 11, probabilities were estimated from the 1987 National Medical Expenditure Survey (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994).

ALTERNATE DATA SOURCE FOR AGES LESS THAN 12 YEARS

QUERY FOR 1987 U.S. FALL STATISTICS FOR THE AGE GROUP 0 TO 11 YEARS

The next section provides the query used to construct a table called revDisDay that compiled pertinent information from the 1987 Medical Survey. From this compiled table, the following query provided the trip injury event summary data for each of males and females ages 0 to 11 years.

```
SELECT v.SMPSEXR,
        v.INJURY1 AS 'InjTyp',
        v.BODYHRT1 AS 'BdyPrt',    //BODYHRT1: Part of Body Hurt in Accident – 1.
                                   text data is used in this field so each record was
                                   coded manually.
        Sum(v.INCALPER) AS 'wtSum'
FROM revDisDay.csv v
WHERE (v.LASTAGE In (0,1,2,3,4,5,6,7,8,9,10,11))
        AND (v.dF_wt>0)
        AND (v.INJURY1 Not In ('0'))  //Injury1: Type of Injury to Body Part – 1.
                                   text data is used in this field so each record
                                   was coded manually.
        AND (v.WHEREHAP=3)         //WHEREHAP: Where accident happened.
                                           3 = Street or Hiway
GROUP BY    v.SMPSEXR,
            v.INJURY1,
            v.BODYHRT1
ORDER BY    v.SMPSEXR,
            v.INJURY1,
            v.BODYHRT1
```

Population estimates for these gender and age groups from Mare and Winship (1990) were used to approximate the probabilities of trip injury event types affecting a certain body part. These probabilities are included in Tables 4.2.3.1 and 4.2.3.3.

ESTIMATING INJURY RECOVERY RATES

EXPLORING THE 1987 U.S. DISABILITY DAYS & MEDICAL CONDITION STATISTICS

This research was unable to find a thorough source for disability days by injury type and body part affected as well as by age group. The 1987 U.S. National Medical Expenditure Survey (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994) was thought to be a compatible source. After much analysis, the source was abandoned. There were too many points missing in the data or the data represented too small of a sample so that the resulting disability day estimates did not follow the expected trends. Generally, the trends were expected to differ in magnitude depending on the injury type and age of the injured.

Records were restricted to ones where:

- the condition resulted from an accident or injury (1=Yes, -7=Refused, -8=Don’t Know, -9=Not Ascertain)
- a vehicle was not involved in the accident (2=No, -8=Don’t Know, -9=Not Ascertain)
- the accident happened near home(=2), street or highway(=3), adjacent to a business(=10), other(=91), not ascertain(=-9), don’t know(=-8)
- the part of the body hurt (primary) in the accident was not recorded as not ascertain(=-9)
- the part of the body hurt (secondary) in the accident was inapplicable(=-1) or don’t know(=-8)
- the type of injury to body part (primary) was not recorded as not ascertained(=-9) or don’t know(=-8) as well as many selected text responses that were obviously inconsistent with an unintentional injury similar to a fall related injury. (i.e. bullet wound, chemical burn, dog bite, etc.)
- the type of injury to body part (secondary) was either inapplicable (=-1) or don’t know(=-8)

The original tables had to be processed so that records could be linked before performing the analysis. To get the number of days of recovery from injury, the following sample queries were used to extract data from the resulting tables.

QUERY- EXTRACT DATA FROM 1987 U.S. NATIONAL MEDICAL EXPENDITURE SURVEY

```
SELECT      m.CONDIDX,   m.odux,   m.pn,   m.cn,   t.dn,   m.round,
            m.LASTAGE,   m.SMPSEXR,
            m.MMHAPPEN,   m.DDHAPPEN,   m.YYHAPPEN,
            m.ICD,   i.DIAGLABL,
            m.BODYHRT1,   m.INJURY1,
            m.BODYAFF1,   m.BODYAFF2,   m.BODYAFF3,   m.BODYAFF4,
            m.HURTNOW1,   m.HURTNOW2,   m.HURTNOW3,   m.HURTNOW4,
            m.WHEREHAP,   m.OCCURN87,
            m.HRDAYWEK,   m.NUMWAIT,   m.SERIOUS,   m.INJWORRY,
            m.RECOVERD,   m.MMRECOVR,   m.DDRECOVR,   m.YYRECOVR,
            m.RELATETO,   m.SAMEAS,
            d.DATEBDX,   d.DATEBMX,   d.DATEEDX,   d.DATEEMX,
            d.DDAZQUES,   d.NUMDDX,
            d.ICD1,   d.ICD2,   d.ICD3,   d.ICD4,
            d.CONDNUM,   d.OTHDATE,
            m.INCALPER,   m.STRATUMX,   m.SPSU,
            d.NCALPER,   d.STRAT29X,   d.SPSU29,   t.DLNKFLAG
FROM  RED.csv m,
      ICD5Lbl.csv i,
      (SELECT DDAZIDX, DATEBDX, DATEBMX, DATEEDX, DATEEMX, DAZQUES,
            NUMDDX, ICD1, ICD2, ICD3, ICD4, CONDNUM, OTHDATE, NCALPER,
            STRAT29X, SPSU29 FROM Disab2D.csv) d,
      (SELECT DN, DDAZIDX, CONDIDX, DLNKFLAG from L3DisD.csv) t
WHERE       m.CONDIDX = t.CONDIDX
            AND   d.DDAZIDX = t.DDAZIDX
            AND   i.ICD = m.ICD
ORDER BY    m.CONDIDX,
            t.DN,
            m.ROUND
```

The resulting table of extracted data was called revDisDay.csv. It was used for determining the probability of trip injury event types for the age group 0 to 11 years as well as disability day estimations for all gender and age groups.

QUERY - SUMMARIZE DATA FOR REPORTED DISABILITY DAYS CAUSED BY INJURIES

```
SELECT       v.INJURY1 AS 'InjTyp',
             v.BODYHRT1 AS 'BdyPrt',
             v.DDAZQUES AS 'dTyp',
             Sum(v.INCALPER) AS 'wtSum',
             Sum(v.numD_wt) AS 'D_wtSum',
             Sum(v.dF_wt) AS 'dF_wtSum'
FROM         revDisDay.csv v
WHERE        v.LASTAGE In (35,36,37,38,39,40,41,42,43,44)  //different for each age group
             AND v.dF_wt>0
GROUP BY     v.INJURY1,
             v.BODYHRT1,
             v.DDAZQUES
ORDER BY     v.INJURY1,
             v.BODYHRT1,
             v.DDAZQUES
```

// DDAZQUES:

where B3=work days missed, B9=school days missed, B15=bed days and B21=reduced activity days.

DETERMINING THE DIFFERENCE IN TOTAL RECOVERY RATES BY AGE GROUP

Canadian statistics on hospital stays for fractures by gender and age groups were used to explore the differences in recovery rates by age and sex (Statistics Canada 2006a). The average days of recovery were similar for male and female age groups so the analysis was reduced to age groupings only.

Because ages were grouped differently than those in this research, it was assumed that within the groups given, each age was equally represented. That way, the data could be split into different groups using equal weight for each age. A 2-year average was calculated for average length of hospital stay. The difference in total recovery duration by age was estimated by comparing the ratio of the average length of stay for the age group divided by the average length of stay for all age groups from 20 to 74 for the 2 years (8.7 days). This age range coincided with the disability data found for workers only. In addition, it was assumed that hospital discharge occurred at the same point of recovery for each age group.

Table A-5 Estimated Recovery Rate from Hospital Stay due to Fracture

Age Group	Average Days	Recovery Rate
0-11	4	0.44
12-14	3	0.40
15-19	5	0.61
20-24	6	0.71
25-34	6	0.72
35-44	7	0.75
45-54	7	0.81
55-64	10	1.1
65-74	14	1.7
75+	21	2.4

Still, it was discovered during model testing that more detail was needed for recovery rates. It was decided that for each age group not only the recovery rate by trip injury type but also body part affected was necessary.

From the field of workers compensation, three sources were found that initiated another technique for estimating recovery rates. First, the Work Loss Data Institute (2003) provided disability duration adjustment factors by age for two sample guidelines for other unspecified disorders of the back and for sprains and strains of other and unspecified parts of the back. Second, the Nationwide Publishing Company (2004) provided tables for length of disability for injuries affecting certain parts of the body. Finally, the website, MDA Internet (Reed MD 2005) provided disability duration trends and minimum, optimum and maximum length of disability by general classification of physical demands for a job for injury types to body parts. From these sources along with Table A-5 and analysis from the 1987 National Medical Expenditure Survey (U.S. Dept. of Health and Human Services Agency for Health Care Policy and Research 1994), estimates for days of recovery were approximated and tabulated in Tables 4.2.4.1, 4.2.4.2, 4.2.4.3 and 4.2.4.4.

DETERMINING DEATH RATES CAUSED BY FALL INJURIES

Information on death rates for 2001, 2002 and 2003 was provided by the Canadian Vital Statistics death database (Statistics Canada 2006b). The cause of death used for the estimation was a fall on the same level from a slip, trip or stumble. Death occurrences in combination with the same level of detail from the 2001, 2003 and 2005 data provided by the CCHS database (Statistics Canada 2001a; Statistics Canada 2003; Statistics Canada 2005a) was used to estimate the probability of a death by gender and age for persons sustaining a previous trip injury from falling from the same level.

The following example is the SQL query for extracting pertinent data from the 2001 CCHS database. It was assumed that each subsequent year would provide similar events so using similar years of death and injury data would approximate the needed estimates.

CAUSE OF DEATH - LEVEL OF DETAIL

```
SELECT      o.DHHA_SEX,
            o.DHHAGAGE,
            Sum(o.WTSAM) AS 'F_Tot'
FROM        `2001CCHS.csv` o
WHERE       o.INJA_10=1        // Most serious injury was a result of a fall
            AND o.INJAG11=3    // Most serious injury- fell by slip, trip, stumble on
                                                        any other surface
GROUP BY    o.DHHA_SEX,
            o.DHHAGAGE
ORDER BY    o.DHHA_SEX,
            o.DHHAGAGE
```

The resulting death rates were tabulated for the 3-year average. Even though this data was for all places of occurrence, it was assumed that the approximation was appropriate for predicting death rates for trip injury events on streets, highways and sidewalks.

Let $\bar{n}_{\Delta|\o\cap\Phi_{ij}}$ indicate the 3-year average reported deaths (Δ) because of a previous fall from the same level from a slip, trip or stumble ($\o$) for a gender-age group (Φ_{ij}). Let $\bar{n}_{\o|\Phi_{ij}}$ identify the 3-year average reported falls from the same level from a slip, trip, or stumble for a given gender-age group ij. Then the quotient, deaths because of a previous fall divided by the number of falls provides an estimate of $\text{þ}_{\Delta|\o\cap\Phi_{ij}}$, a symbol of the probability that, given a gender-age group and previous slip, trip, or fall injury event on a sidewalk, street, or highway, the person dies because of this previous injury:

$$\text{þ}_{\Delta|\o\cap\Phi_{ij}} = \frac{\bar{n}_{\Delta|\o\cap\Phi_{ij}}}{\bar{n}_{\o|\Phi_{ij}}} . \qquad \text{[A-20]}$$

For example, the probability that a female in the age group 55 to 64 years (Φ_{28}) who has previously sustained a trip injury event (ø) and then dies (Δ) because of the previous injury ($\text{þ}_{\Delta|ø\cap\Phi_{28}}$) is calculated by

$$
\begin{aligned}
\text{þ}_{\Delta|ø\cap\Phi_{28}} &= \frac{\bar{n}_{\Delta|ø\cap\Phi_{28}}}{\bar{n}_{ø|\Phi_{28}}} \\
&= \frac{[(3+1+3)\div 3]}{[(51{,}000+61{,}000+33{,}000)\div 3]} = \frac{2.3}{48{,}000} \\
&\approx 0.00005\ .
\end{aligned}
$$

DETERMINING SASKATCHEWAN LIFE YEARS LOST PER YEAR UPON DEATH

Table 4.2.4.5 provides a summary of the estimated average life years lost per year upon death. The tables provided by Statistics Canada specified single years of age for each gender. A weighted average life years lost was needed to represent the age groups used in this research.

Let T_u signify the total number of life years lived by the stationary population beyond age u and let R_u embody the average remaining lifetime at age u. Stationary population is a term used to provide standardized statistics for wide application. In a stationary population, the number of persons living in any age group does not change over time (Statistics Canada 2006c). Then the average life years lost due to death is equal the quotient of two summations. The numerator is the sum of the products for each u in the gender-age group ij of the total life years lived beyond an age multiplied by the average remaining lifetime at age u. The denominator is the sum of each u in the gender-age group ij of the total number of life years lived beyond age u. The estimated average life years lost due to death, LYL_{ij}, is calculated as follows for each gender-age group:

$$\mathrm{LYL}_{ij} = \frac{\sum_{u} \left(T_u R_u \right)}{\sum_{u} T_u} \quad \forall\, u \in j \text{ in } \Phi_{ij}$$

For example, to determine the average life years lost, LYL_{28}, for the gender-age group females ages 55 to 64,

$$\mathrm{LYL}_{28} = \frac{\sum_{u=55}^{64} \left(T_u R_u \right)}{\sum_{u=55}^{64} T_u}$$

$$= \frac{\begin{bmatrix} 2{,}807{,}441(29.61) + 2{,}712{,}851(28.75) + 2{,}618{,}723(27.89) \\ + 2{,}525{,}103(27.05) + 2{,}432{,}028(26.21) + 2{,}339{,}522(25.37) \\ + 2{,}247{,}604(24.53) + 2{,}065{,}637(22.87) + 1{,}975{,}672(22.05) \end{bmatrix}}{\begin{bmatrix} 2{,}807{,}441 + 2{,}712{,}851 + 2{,}618{,}723 \\ + 2{,}525{,}103 + 2{,}432{,}028 + 2{,}339{,}552 \\ + 2{,}247{,}604 + 2{,}065{,}637 + 1{,}975{,}672 \end{bmatrix}}$$

$$= \frac{622{,}602{,}816}{23{,}880{,}879} \qquad \approx 26 \text{ life years lost}.$$

DETERMINING QUALITY-ADJUSTED LIFE YEARS LOST PER YEAR

The output of the model, total QALYs lost per year at a location, expressed as Q_L, was calculated by Equation 3.17 (Refer to Section 3.3.2 for an explanation of the terms):

$$Q_L = \left[\sum_{IBij} \left(\text{þ}_{IBij} \, P_{Lij} \, Q_{IBj} \right) \right] + \left[\sum_{ij} \left[\left(\sum_{IB} \left(\text{þ}_{IBij} \, P_{Lij} \right) \right) \text{þ}_{\Delta | ø \cap \Phi_{ij}} \, LYL_{ij} \right] \right] \forall I, B, i, j.$$

A theoretical example will help to illustrate the procedure of assessing the risk at a location. The quality-adjusted life years lost contributed by a local daily population count of 10,000 females (i=2) in the age range 55 to 64 (j=8) for a hypothetical location, Π is estimated by

$$Q_{\Pi 28} = \left[\sum_{IB28} \left(\text{þ}_{IB28} \, P_{\Pi 28} \, Q_{IB8} \right) \right] + \left[\sum_{28} \left[\left(\sum_{IB} \left(\text{þ}_{IB28} \, P_{\Pi 28} \right) \right) \text{þ}_{\Delta | ø \cap \Phi_{28}} \, LYL_{28} \right] \right] \forall \; I, B, i = 2, j = 8.$$

The total probability of a trip injury event is 0.003 for this female population ages 55 to 64. Predicted injury events total 32 consisting of the following distribution of injury types and body parts affected:

Fracture or dislocate occurrences of the -

- head, neck, back or spine (Fb) ~0.2;
- shoulder, arm or elbow (Fs) ~2;
- wrist or hand (Fw) ~4;
- hip, thigh, leg, knee, ankle or foot (Fa) ~5; and
- chest or abdomen (Ft) ~1.

Sprain or strain occurrences of the -

- head, neck, back or spine (Sb) ~1;
- shoulder, arm or elbow (Ss) ~0.3;
- wrist or hand (Sw) ~2; and
- hip, thigh, leg, knee, ankle or foot (Sa) ~11.

Bruise, scrape, cut or puncture occurrences of the -

- head, neck, back or spine (Bb) ~1;
- shoulder, arm or elbow (Bs) ~0.2;
- wrist or hand (Bw) ~0.2;
- hip, thigh, leg, knee, ankle or foot (Ba) ~2; and
- multiple sites (Bm) ~1.

Concussion or internal injury occurrences (Cb) ~0.3.

Multiple or other injury to multiple sites that occur (Mm) ~1.

Next, the quality-adjusted life years lost per year must be estimated for each injury type (I) and body part affected (B) for the 3 stages of recovery, bed days (τ_1), restricted activity days (τ_2), and reduced activity days (τ_3). The quality-adjusted life years lost per year for a combination an injury type affecting a body part for an age group j (Q_{IBj}) is estimated by Equation 3.14, and restated here:

$$Q_{IB\,j} = \left[\sum_{\tau} \left(\left(1 - HUI_{IB\,\tau}\right) \frac{D_{IB\,\tau j}}{D_{Y}} \right) \right].$$

The full explanation follows for determining Q_{IBj} for a fractured or dislocated wrist or hand that results from a sidewalk trip injury event sustained by a person in the age group 55 to 64 ($Q_{Fw\,8}$):

$$Q_{Fw\,8} = \left[\sum_{\tau} \left(\left(1 - HUI_{Fw\,\tau}\right) \frac{D_{Fw\,\tau 8}}{D_{Y}} \right) \right] \quad \forall \tau \,.$$

First, the health utility index (HUI) is approximated using the health status classification scores determined from Table B-1. The process is as follows:

- At the time just before the trip injury event, this person is assumed to be in perfect health or HUI=1.
- For the time starting when the trip injury event occurred to the time that the person no longer in bed most of the day, the health status classification is approximated to be, with attribute assessments in the same order as Table B-1, for τ_1, $\varphi = 1\ 1\ 1\ 3\ 6\ 4\ 1\ 5$.
- For the time duration when activities are restricted (τ_2), the health status classification is approximated to be $\varphi = 1\ 1\ 1\ 2\ 5\ 3\ 1\ 4$.
- For the time duration when activities are reduced (τ_3), the health status classification is approximately $\varphi = 1\ 1\ 1\ 1\ 3\ 2\ 1\ 3$.

Note that at the HUI determination only considers the injury type and affected body part. Age differences are reflected in the number of days it takes to recover at each stage.

The HUI is calculated for each stage of recovery using Equation 3.15, shown below, and referring to Table B-2 for retrieval of the associated multi-attribute utility score for each attribute classification. The following calculations estimate the HUI for the three stages of recovery for a fractured or dislocated wrist or hand:

$$HUI_{IB\,\tau} = 1.371\left(\beta_1\,\beta_2\,\beta_3\,\beta_4\,\beta_5\,\beta_6\,\beta_7\,\beta_8\right) - 0.371$$

$$HUI_{Fw\,\tau_1} = 1.371\left(1\times1\times1\times0.86\times0.56\times0.64\times1\times0.55\right) - 0.371 \quad = -0.139$$

$$HUI_{Fw\,\tau_2} = 1.371\left(1\times1\times1\times0.93\times0.65\times0.85\times1\times0.77\right) - 0.371 \quad = \ 0.171$$

$$HUI_{Fw\,\tau_3} = 1.371\left(1\times1\times1\times\ 1\ \times0.88\times0.95\times1\times0.90\right) - 0.371 \quad = \ 0.661$$

Now, using Equation 3.14 and referring to Table 4.2.4.1, the quality-adjusted life years lost per year as a direct result of a fractured or dislocated wrist or hand sustained by a 55 to 64 year old female is estimated by

$$Q_{Fw\,8} = \left(\left(1 - HUI_{Fw\,\tau_1}\right) \frac{D_{Fw\,\tau_1 8}}{D_Y} \right) + \left(\left(1 - HUI_{Fw\,\tau_2}\right) \frac{D_{Fw\,\tau_2 8}}{D_Y} \right) + \left(\left(1 - HUI_{Fw\,\tau_3}\right) \frac{D_{Fw\,\tau_3 8}}{D_Y} \right)$$

$$= \left((1 - -0.139) \frac{12\,\text{days}}{365\,\text{days / yr}} \right) + \left((1 - 0.171) \frac{104\,\text{days}}{365\,\text{days / yr}} \right) + \left((1 - 0.661) \frac{24\,\text{days}}{365\,\text{days / yr}} \right)$$

$$= 1.139(\,0.032\,) + 0.829(\,0.286\,) + 0.339(\,0.067\,)$$

$$\approx 0.296 / \text{yr}\ .$$

Back to Equation 3.17, the estimated direct health risk associated with a population of 10,000 females within the ages of 55 to 64 exposed to an unsafe sidewalk location is:

$$Q_{\Pi\,28} = \left[\sum_{IB\,28} \left(\text{þ}_{IB28}\ P_{\Pi\,28}\, Q_{IB\,8} \right) \right] + \left[\sum_{28} \left[\left(\sum_{IB} \left(\text{þ}_{IB\,28}\, P_{\Pi\,28} \right) \right) \text{þ}_{\Delta|\,ø\cap\Phi_{28}}\, LYL_{28} \right] \right]$$

$$Q_{\Pi\,28} = \begin{bmatrix} \ \ 0.2(0.411) + 1.8(0.199) + 4.4(0.296) + 4.5(0.236) \\ + 0.6(0.185) + 0.7(0.073) + 0.3(0.067) + 2.0(0.092) \\ + 11(0.103) + 0.8(0.027) + 0.2(0.030) + 0.2(0.028) \\ + 2.4(0.049) + 1.3(0.039) + 0.3(0.204) + 1.1(0.298) \end{bmatrix} + [32 \times 0.00005 \times 26]$$

$$= 4.90 + 0.04$$

$$\approx 4.94\ \text{QALYs lost / year}.$$

Appendix B

Table B-1 Multi-Attribute Health Status Classification System: HUI Mark3

VISION

1. Able to see well enough to read ordinary newsprint and recognize a friend on the other side of the street, without glasses or contact lenses.
2. Able to see well enough to read ordinary newsprint and recognize a friend on the other side of the street, but with glasses.
3. Able to read ordinary newsprint with or without glasses but unable to recognize a friend on the other side of the street, even with glasses.
4. Able to recognize a friend on the other side of the street with or without glasses but unable to read ordinary newsprint, even with glasses
5. Unable to read ordinary newsprint & unable to recognize a friend on the other side of the street, even with glasses.
6. Unable to see at all.

HEARING

1. Able to hear what is said in a group conversation with at least three other people, without a hearing aid.
2. Able to hear what is said in a conversation with one other person in a quiet room without a hearing aid, but requires a hearing aid to hear what is said in a group conversation with at least three other people.
3. Able to hear what is said in a conversation with one other person in a quiet room with a hearing aid, and able to hear what is said in a group conversation with at least three other people, with a hearing aid.
4. Able to hear what is said in a conversation with one other person in a quiet room, without a hearing aid, but unable to hear what is said in a group conversation with at least three other people even with a hearing aid.
5. Able to hear what is said in a conversation with one other person in a quiet room with a hearing aid, but unable to hear what is said in a group conversation with at least three other people even with a hearing aid.
6. Unable to hear at all.

SPEECH

1. Able be understood completely when speaking with strangers or friends.
2. Able to be understood partially when speaking with strangers but able to be understood completely when speaking with people who know me well.
3. Able to be understood partially when speaking with strangers or people who know me well.
4. Unable to be understood when speaking with strangers but able to be understood partially by people who know me well.
5. Unable to be understood when speaking to other people (or unable to speak at all).

AMBULATION

1. Able to walk around the neighbourhood without difficulty, and without walking equipment.
2. Able to walk around the neighbourhood with difficulty; but does not require walking equipment or the help of another person.
3. Able to walk around the neighbourhood with walking equipment, but without the help of another person.

4. Able to walk only short distances with walking equipment, and requires a wheelchair to get around the neighbourhood.
5. Unable to walk alone, even with walking equipment. Able to walk short distances with the help of another person, and requires a wheelchair to get around the neighbourhood.
6. Cannot walk at all.

DEXTERITY

1. Full use of two hands and ten fingers.
2. Limitations in the use of hands or fingers, but does not require special tools or help of another person.
3. Limitations in the use of hands or fingers, is independent with use of special tools (does not require the help of another person).
4. Limitations in use of hands or fingers, requires help of another person for some tasks (not independent even with use of special tools).
5. Limitations in use of hands or fingers, requires help of another person for most tasks (not independent even with use of special tools).
6. Limitations in use of hands or fingers, requires help of another person for all tasks (not independent even with use of special tools).

EMOTION

1. Happy and interested in life.
2. Somewhat happy.
3. Somewhat unhappy.
4. Very unhappy.
5. So unhappy that life is not worthwhile.

COGNITION

1. Able to remember most things, think clearly and solve day to day problems.
2. Able to remember most things, but have a little difficulty when trying to think and solve day to day problems.
3. Somewhat forgetful, but able to think clearly and solve day to day problems.
4. Somewhat forgetful, and have a little difficulty when trying to think or solve day to day problems.
5. Very forgetful, & have great difficulty when trying to think or solve day to day problems.
6. Unable to remember anything at all, and unable to think or solve day to day problems.

PAIN

1. Free of pain and discomfort.
2. Mild to moderate pain that prevents no activities.
3. Moderate pain that prevents a few activities.
4. Moderate to severe pain that prevents some activities.
5. Severe pain that prevents most activities.

NOTE: The above level descriptions are worded here exactly as they were presented to interview subjects in the HUI3 (Health Utilities Index Mark 3) preference survey.

Taken directly from http://www.healthutilities.com/hui3.htm (June 1, 2007)

Table B-2 Multi-Attribute Utility Function on Dead-Healthy Scale

Vision		Hearing		Speech		Ambulation		Dexterity		Emotion		Cognition		Pain	
φ	β_φ	φ	β_φ	φ	β_φ	φ	β_φ	φ	β_φ	φ	β_φ	φ	β_φ	φ	β_φ
1	1.00	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00	1	1.00
2	0.98	2	0.95	2	0.94	2	0.93	2	0.95	2	0.95	2	0.92	2	0.96
3	0.89	3	0.89	3	0.89	3	0.86	3	0.88	3	0.85	3	0.95	3	0.90
4	0.84	4	0.80	4	0.81	4	0.73	4	0.76	4	0.64	4	0.83	4	0.77
5	0.75	5	0.74	5	0.68	5	0.65	5	0.65	5	0.46	5	0.60	5	0.55
6	0.61	6	0.61			6	0.58	6	0.56			6	0.42		

Taken directly from http://www.healthutilities.com/hui3.htm (June 1, 2007) (Feeny et al. 2002) (Health Utilities Inc. 2004).

Appendix C

Table C-1 Test Sidewalk Location Resident Population Estimate for Influence Area

Group	Saskatoon	CBD	SC_W	SC_E	Core_W	Core_E
M 0-11	15,900	30	226	94	112	47
M 12-14	4,215	9	39	21	26	11
M 15-19	7,245	12	56	32	39	40
M 20-24	8,705	30	72	42	44	152
M 25-34	13,690	64	127	64	87	121
M 35-44	15,235	63	107	68	102	51
M 45-54	12,665	51	67	59	65	59
M 55-64	7,170	41	59	62	42	41
M 65-74	5,405	65	32	103	30	36
M 75+	4,370	43	23	208	22	98
F 0-11	15,190	38	225	78	126	30
F 12-14	4,095	14	37	15	19	4
F 15-19	7,505	18	71	43	53	51
F 20-24	9,480	20	82	36	46	127
F 25-34	14,105	34	170	77	97	92
F 35-44	16,135	36	113	70	95	50
F 45-54	13,365	31	101	90	63	60
F 55-64	7,800	48	71	82	37	44
F 65-74	6,680	63	41	154	23	43
F 75+	7,840	124	38	495	35	272

Group	Inter_W	Inter_E	Out_W	Out_N	Out_EN	Out_E	Ind
M 0-11	164	102	155	90	180	211	31
M 12-14	5	24	46	30	64	62	7
M 15-19	48	36	78	53	109	123	11
M 20-24	105	58	100	40	198	167	11
M 25-34	187	138	181	50	190	161	23
M 35-44	163	113	134	84	153	192	33
M 45-54	116	82	141	106	143	226	22
M 55-64	51	41	85	74	75	134	13
M 65-74	49	30	72	34	35	129	16
M 75+	38	48	51	20	29	90	12
F 0-11	100	86	140	95	223	181	25
F 12-14	31	23	47	20	53	77	7
F 15-19	60	36	87	46	122	127	9
F 20-24	94	74	104	45	219	194	9
F 25-34	159	139	173	45	182	193	22
F 35-44	140	109	166	100	202	220	30
F 45-54	102	84	168	129	152	252	20
F 55-64	49	41	85	63	56	194	16
F 65-74	42	38	85	45	38	179	19
F 75+	69	63	82	23	15	154	9

Table C-2 Test Sidewalk Location Physical Land Statistics for Influence Area

Location -	Saskatoon	CBD	SC_W	SC_E	Core_W	Core_E
Count:						
Households	80,675	510	672	1,021	517	869
Seniors' Units	5,380	220	0	399	0	339
Bus Stops	1,374	22	20	11	11	13
High Risk	122	0	0	2	2	0
Business	1,388	61	4	10	33	3
Shop or Buy	700	91	7	1	32	2
Restaurant	90	15	1	0	2	2
Entertainment	148	13	1	5	3	1
Spiritual	153	3	2	2	6	0
Parcel Area (m^2)**:**						
Elementary Schools	1,122,921	0	0	0	5,162	0
High Schools	442,806	0	0	0	0	31,493
Trade Schools/Colleges	1,315,162	0	0	0	0	1,196,434
Medical	309,027	0	2,828	10,125	34,801	35,000
Length (lineal m)**:**						
Sidewalk	1,114,993	16,097	10,415	10,295	13,040	8,829
Curb	1,385,692	17,703	11,844	11,912	18,019	12,371

Location -	Inter_W	Inter_E	Out_W	Out_N	Out_EN	Out_E	Ind
Count:							
Households	800	647	907	419	920	1,404	139
Seniors' Units	0	0	0	0	0	23	0
Bus Stops	13	8	7	5	11	17	5
High Risk	1	0	2	0	1	1	1
Business	8	10	1	0	1	3	20
Shop or Buy	21	5	1	0	1	1	0
Restaurant	6	1	0	0	0	0	0
Entertainment	2	1	1	1	0	1	4
Spiritual	2	2	0	0	2	1	0
Parcel Area (m^2)**:**							
Elementary Schools	14,472	0	27,969	16,684	32,123	0	0
High Schools	0	0	0	0	60,684	0	0
Trade Schools/Colleges	59,237	0	0	0	0	0	0
Medical	360	0	0	0	0	0	0
Length (lineal m)**:**							
Sidewalk	16,239	10,312	8,473	8,924	10,711	16,831	4,054
Curb	17,916	16,001	12,115	9,489	12,405	19,003	15,233

Table C-3 Trip Category Groupings Used for Trip Purpose Probability Estimations

Trip Purpose Group	Trip Purpose Category from WHYTRP01
Home	Home
Visit	Visit friends/relatives
Business	Go to work Return to Work Attend business meeting/trip Other work related Buy gas Family personal business/obligations Use professional services: attorney/accountant Use personal services: grooming/haircut/nails Pet care: walk the dog/vet visits Attend meeting: PTA/home owners association/local Transport someone Pick up someone Take and wait Drop someone off Other reason
Shop Buy	Shopping/errands Buy goods: groceries/clothing/hardware store Buy services: video rentals/dry cleaner/post office/car service/bank
Restaurant	Meals Social event Get/eat meal Coffee/ice cream/snacks
Entertainment	Social/recreational Go to gym/exercise/play sports Rest or relaxation/vacation Go out/hang out: entertainment/theatre/sports event/go to bar Visit public place: historical site/museum/park/library
Education Daycare	School/religious activity Go to school as student Go to library: school related Day care
Spiritual	Go to religious activity Attend funeral/wedding
Medical	Medical/dental services

Table C-4 Property Uses Grouped by Trip Purpose – Education, Medical, Spiritual

Education or Daycare	Medical	Spiritual
Schools, University; private & public	Dental Clinic	Funeral Homes or Mortuaries
School, Elementary (Entire)	Medical Office	Churches, Religious Facilities
Day Care Centre	Medical Office Condominium	Mortuary
School, High	Hospital, General	Cathedral (Church Costing)
School, College	Hospital, Convalescent	Church
School, Technical Trades	Hospitals	Cemeteries
Pre-Schools		

Table C-5 Property Uses for Trip Purpose – Going Out to Eat

Restaurant
Restaurant & office
Wholesale & restaurant
Food, beverage, accommodation & other use(s)
Food, Beverage & Accommodation
Hotel, Beverage Room Type
Fast Foods
Bar, Tavern
Restaurant
Cafeteria
Snack Bar
Restaurant, Fast Food
Restaurant, Truck Stop
Food Booth, Prefabricated
Café
Family Restaurant
Family Restaurant with Licensed Lounge
Restaurant with Auto Fuel Service
Cocktail Lounge
Beverage Room Hotels

Table C-6 Property Uses for Trip Purpose – Shop or Buy

Shop or Buy
Retail & other use
Retail store & living quarters
Retail store & apartments
Retail store & office with apartments
Retail/Motel
Retail & restaurant
Retail/Warehouse
Bank & Restaurant
Retail/Car Wash
Automotive services & other use(s)
General Retail
Convenience Store, Mini Mart
Convenience Store
Market, Roadside
Store, Discount
Store, Warehouse Discount
Store, Warehouse Showroom
Retail: Freestanding (one unit)
Store, Retail
Store, Retail Freestanding >50,000
Store, Department, Mall Anchor
Store, Warehouse Discount >50,000
Market, Roadside CBD/Brdwy 10,000-49,999
Laundromat
Dry Cleaners/Laundry
Shopping Centre Nbhd >50,000
Shopping Centre, Neighbourhood
Shopping Centre, Community
Shopping Centre, Regional Discount
Shopping Centre, Regional
Store, Retail Freestanding, 2 or more storeys
Mixed Retail with Blended MAF
Store, Food Warehouse
Mixed Retail with Office
Store, Discount CBD/Brdwy 10,000-49,999
Store, Retail CBD/Brdwy 10,000-49,999
Retail Condominium Strip Mall
Retail: Strip Malls & warehouse
Shopping Centre, Nbhd CBD/Brdwy 10,000-49,999
Mixed Retail, Office CBD/Brdwy 10,000-49,999
General Retail & Office (excl Strip Malls)
General Retail & Fam Rest (excl Strip Malls)
Store, Warehouse/Showroom >50,000
Retail: Strip Malls with auto service
Retail: Strip Malls with gas bar
Retail: Strip Malls with car wash
Retail: Strip Malls with carwash & gas bar
Retail: Strip Malls with service station
Department Stores
Supermarket
Shopping Centers
Residences Converted to Commercial Use
Lumber Yard or Building Supplies: Retail & Wholesale
Bank & Financial
Bank, Downtown Central <10,000
Bank, Mini
Bank, Branches
Bank, Downtown Central >10,000
Bank or Financial Freestanding
Bank or Financial in Strip Malls
Automobile Services
Auto, Dealership <5,000
Auto, Mini-Lube Garage <5,000
Auto, Repair Garage <5,000
Auto, Showroom <5,000
Auto, Service Repair <5,000
Auto, Dealership 5,000-9,999
Auto, Mini-Lube Garage 5,000-9,999
Auto, Repair Garage 5,000-9,999
Auto, Showroom 5,000-9,999
Auto, Service Centre 5,000-9,999
Auto, Dealership >10,000
Auto, Repair Garage >10,000
Auto, Showroom >10,000
Auto, Service Centre >10,000
Automobile Specialty Repair Facilities
Automobile Sales Lot
Post Office, Branch
Post Office, Main

Table C-7 Property Uses for Trip Purpose – Work or Personal Business

Business

Agricultural Products
Seed Cleaning Plants
StockYard
Commercial Mixed Use
Office & other use
Office & apartment
Office & retail
Office & industrial
Office, transportation, communications, utilities
Office & institutional
Office & recreational & cultural
General commercial & other use(s)
Agricultural products & other use(s)
Warehouse/Office
Agricultural & commercial use
Agricultural & industrial use
Agricultural & other use(s)
Industrial Mixed Use
Industrial & residential use
Industrial & commercial use
Industrial & agricultural use
Industrial, transportation, communication, utilities
Industrial & other use(s)
Institutional & Mixed Use
Institutional & residential use
Institutional & commercial use
Institutional & agricultural use
Institutional & other use(s)
Residential, Converted to Commercial
Garage, Storage
Auto, Service Station <5,000
Rental Agency
Car Wash, Self Serve
Car Wash, Drive-Thru
Auto, Service Station 5,000-9,999
Auto, Mini-Lub Garage >10,000
Auto, Service Station >10,000
Automobile Service Station
Gas Bar
Car Wash
Automobile Paint Shop & Storage
Office Building
Laboratories
Computer Centre
Broadcast Facility
Shed-Office Structure
General Office
Office, Relocatable
Office, Prefab structure
Office, Highrise
Office Condominium
General Commercial
Industrial, Flex Bld, single sty
Loft, Multi-storey
Industrial, Light Mfg
Engineering (R&D) Bldgs
Mail Processing Facility
Warehouse, Mega >200,000 SF
Warehouse, Dist 15-30% office
Warehouse, Transit
Warehouse, Storage 3-12% office
Warehouse, Mini
Veterinary Hospital
Utility Bldg, Light Commercial
Material-Commodity Shelter
Quonset arch-rib, Lt Comm
Equipment Bldg, Lt Comm
Shed, Lt Comm Equipment
Storage & Warehousing
Storage Bldg, Material
Cold Storage (Mini Warehouses)
Warehouse, Storage 5,000-9,999
Warehouse, Storage 10,000-79,999
Warehouse, Storage >80,000
Condominium Warehouse
Commercial Greenhouses or Nurseries
Greenhouse, Modified Hoop
Greenhouse, Hoop, Arch-rib
Greenhouse, Straight Wall
Storage Shed, Prefab
Shed, Tool
Shed, Equipment
Greenhouse, Commercial
Steel Bldgs, Pre-engineered
Quonset Bldgs
Warehouse, Cold Storage
Storage Shed, Material
Storage Shed, Lumber
Salvage Yards: Scrap, Auto, Farm
Veterinary Services
Bulk Petroleum: Farm Service Centres
Farm Machinery Dealers
Condo, Commercial
Food & Beverage Processing
Creamery
Brewery (Creamery Costing)
Meat Packing Plant (Creamery Costing)
Meat Packing Plant
Fruit & vegetable

Business

Meat, poultry & fish
Dairy products
Bakery & biscuit manufacturing
Soft drink bottling
Brewery & distillers
Vegetable oil manufacturing
Flour mills
Malt plants
Forest & Allied Industries
Bogging lands
Saw mills or lumber mills
Plywood mills
Pulp & paper mills
Wood products manufacturing
Paper remanufacturing plants
Petroleum Industry
Oil & gas production plant & equipment
Oil refining plants
Petroleum upgrader
Mining & Allied Industries
Industrial, Heavy Mfg
Mining & milling; non-metallic
Potash
Sodium sulphate
Sodium chloride
Clay
Mining & milling; metallic
Gold
Uranium
Base minerals
Mining; coal
Resource Refining or Processing
Specific Purpose-Food & Beverage Processing
Concrete mixing plants
Specific Purpose-Cnd Light Source
Special Purpose, Chemical Plant
Specific Purpose-Petroleum Industry
Specific Purpose-Heavy Mfg
Light Manufacturing
Rubber & plastic products
Leather industry
Textiles & knitting mills
Clothing industry
Furniture & fixtures industry
Printing & publishing
Wood products; prefab & manufacturing
Masonry products
Other light manufacturing
Primary metal industries; iron & steel mills, pipe
Machinery manufacturing
Transportation equipment industry; railway car
Electrical & electronic products industry
Chemical & chemical products industry
Other heavy manufacturing
Transportation
Railway Station
Railway Yard
Hangar, Storage
Airport, Terminal & Runways
Hangar, Maintenance & Office
Hangars <10,000
Airports such as runways & terminals
Bus transportation
Truck transport
Communications
Cable such as telephone, cable TV & other
Tele-communications such as TV, microwave, cellular
Civic, Provincial & Federal Property
Government Building
Provincial Utilities
Civic Warehouse & Storage
Civic owned General Retail
Power Plant
Fed owned Land/Bldgs
Innovation Place
Fire Station, Staffed
Police, Fire & Ambulance Services
Armory
Jails, Police Stations
Jails, Correctional Facilities
Institutional - Override
Mixed, Comm & other Pres Use excl Res & Ag
Mixed, Ind & other Pres Use excl Res, Ag, Comm
Mixed,Transp Comm & Util & other Pres Use
Lic Prim Elevator
Lic Proc Elevator
Grain Elevators
Lic Term Elevator
Grain Storage Condominium
Grain Terminals
Licensed
Processing
Hangar, T-Hangar
Private Recreational Hangars
Heavy Manufacturing

Table C-8 Property Uses for Trip Purpose – Entertainment

Entertainment	
Entertainment & other use(s)	Swimming pools
Recreation & Cultural Mixed Use	Golf courses
Recreation, cultural & residential use	Golf Course Override
Recreation, cultural & commercial use	Arenas & rinks
Recreation, cultural & agricultural use	Stadiums such as grandstands & race tracks
Recreation, cultural & institutional use	Sports fields & other playing fields
Recreation, cultural & transportation, communication	Cultural
Recreation, cultural & other use(s)	Theatres, Live Stage
Hotel, Limited Service	Museum
Hotel, Full Service	Museums & galleries
Motel	Libraries
Accommodation	Historical & monuments
Full Service Hotels	Music & arts facilities
Motel & Auto Court	Live theatres
Commercial Campground	Municipal Halls, Private Clubs
Seasonal Resort	Clubhouse
Entertainment	Health Club
Bowling Centre	Golf, Country Clubs
Theatre, Cinema	Library, Public
Auditorium	Fellowship Hall
Tennis Club, Indoor	Fraternal Building
Racquetball-Handball Club	Community Centre
Fitness Centre	Other Recreation Facilities
Drive-In Theatres	Theme parks
Indoor Recreation Facilities such as Arcades, Roller	Special Recreational Facilities
Outdoor Recreational Facilities such as Miniature Golf	Recreational Override
Recreation Facilities	Civic Arena & Rink
Bowling Facility	Civic Swimming Pool
Rinks, Skating or Curling	Civic owned Rec Facility
Wading Pools & Small Waterparks	Health Facility, Clinic, Hs
Swimming Pools, Outdoor Commercial	Mixed, Rec & Cultural with Inst
Swimming Pools, Indoor (Natatorium)	Bed & Breakfast Inns
Field Houses	Residential Hotel
YWCA-Condo	Bed & Breakfast
Air Supported Structures	Seasonal Dwelling
YMCA/YWCA	Resort Summer Cottage
Grandstands or Bleachers	Travel Trailers in Resort Location
Gymnasium	Seasonal Out Buildings only
Condo, YWCA	Camp grounds; private & public
	Water slides; outdoor

Table C-9 Property Uses Potentially Occupied by High-Risk Residents

Clubhouse, Seniors Centre	Group Care Home, Single or Semidetached
Lowrise, Senior Citizen	Group Care Home, Residential Style
Lowrise, Assisted Living	Group Care Home, Institutional Style
Nursing Home	Group Home