MIIP Report: A Case Study of Use and External Components of Social Costs that are Related to Municipal Infrastructure Rehabilitation

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Municipal Infrastructure Investment Planning

MIIP Report: A Case Study of User and External Components of Social Costs that are related to Municipal Infrastructure Rehabilitation

for

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Municipal Infrastructure Investment Planning (MIIP)

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MIIP Report: A Case Study of User and External Components of Social Costs that are related to Municipal Infrastructure Rehabilitation

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Abstract

The Municipal Infrastructure Investment Planning (MIIP) project is a four-year collaborative project between the Institute for Research in Construction, six Canadian cities, three regional municipalities and the Department of National Defence (www.nrc.ca/irc/uir/miip). One of the project deliverables is research in the area of social costs.

The main objective of this client report is to establish a general procedure to quantify user components of social costs related to municipal infrastructure rehabilitation and construction projects. User costs include travel delay costs, vehicle operating and maintenance costs, and cost of accidents. Existing user costs quantification models are identified and modified where necessary to represent Canadian urban environment.

The proposed methodology is applied to actual infrastructure rehabilitation and construction projects carried out in the City of Regina, Saskatchewan, Canada in summer 2006. It is identified that travel delay costs represent a major part of project's user costs. Effective mitigation strategies are proposed as a result of this research. These include scheduling work for off-peak hours such as evenings and weekends; clear and accurate marking of work zone and detours; coordinating with other work in close proximity; detours through industrial instead of residential areas.

Keywords

Infrastructure, rehabilitation, work zone (road construction), social costs, user costs, traffic delay, vehicle operating costs, accidents.

1. Introduction

The Municipal Infrastructure Investment Planning (MIIP) project is a four-year collaborative project between the Institute for Research in Construction, six Canadian cities, three regional municipalities and the Department of National Defence (www.nrc.ca/irc/uir/miip). One of the project deliverables is research in the area of social costs. This research complements a client report for the MIIP project (Rahman *et al*, 2005).

Social costs, as described in the context of this client report, are the indirect costs of inconvenience and disruption to a municipality, businesses, citizens, and to the general public during construction, maintenance, repair and rehabilitation of municipal infrastructure. These costs are usually difficult to estimate. Social costs may include traffic disruption cost, losses due to business closure or tax reductions, long term environmental costs related to health and safety issues, noise, etc.

According to the results of previous research cited in this report, social costs can be up to four times the direct, measurable construction costs. However, it is still very difficult to quantify social costs due to a general lack of awareness about these costs, as well as the lack of standard procedure to identify and classify social costs. Thus, the main goal of this research is to establish a general method/procedure for social cost quantification and consideration in the total project costs.

The main focus of this report is on user delay costs, however, other social costs such as environmental costs, costs of accidents and noise are also considered. The methods available to estimate social costs are reviewed, and a detailed methodology to quantify user and external costs components is proposed.

Case studies of three municipal infrastructure rehabilitation projects carried out by the City of Regina in summer 2006 are used to collect data on social costs. Based on the collected data, a decision making tool has been developed. The tool consists of four modules: user delay costs, costs of accidents, environmental costs, and noise damage costs. This tool allows practitioners to enter parameters specific to the project such as daily traffic volumes, traffic restrictions during the project, number of days necessary for project completion, etc., and uses these data to calculate project related social costs.

The ultimate goal of this research is to give municipal practitioners and the general public a more comprehensive view on the total costs incurred by infrastructure rehabilitation and renewal. In addition to the direct costs borne by the municipality it is also important to be aware of social costs and how these help the general public and policy-makers make more informed decisions on the use of public funds for projects involving the construction and management of infrastructure.

2. Background

This research builds upon the study done by Rahman *et al* (2005). That study established a background for the development of a generic social cost identification and quantification protocol that can be used by municipal organizations. The authors proposed a three-level protocol to itemize social costs as: (1) costs borne indirectly by the municipality, (2) costs borne by citizens and businesses, and (3) costs borne by society at large. The study has also shown that the social costs can account for up to four times the construction costs on certain municipal infrastructure rehabilitation projects.

Rahman *et al* (2005) study presents a literature review of existing research in the field of social costs itemization and quantification. However, it only provides a very simplified framework to calculate social costs and does not provide data for specific infrastructure rehabilitation projects: -- the main objective of the work reported herein.

A literature review was completed to locate social costs quantification models developed in the world, and assess their applicability to Canadian urban traffic system, especially to the City of Regina. The literature review revealed that research on quantification of social costs associated with urban municipal infrastructure construction and rehabilitation projects reported so far is limited. The models most appropriate to the City of Regina environment were selected and applied in this study.

The U.S. Department of Transportation, Federal Highway Administration (FHWA), developed a manual to calculate Life Cycle Cost of transportation investment decisions (FHWA, 2002). In particular, Walls III and Smith (1998) developed detailed procedures to determine work zone user costs, which are a combination of delay costs, vehicle operating costs, and crash costs.

McKim (1997) also proposed methodologies for estimating social costs and suggested including these costs in the bidding process. The emphasis was made on comparison of social costs for conventional and trenchless technologies. The author suggested that the average social cost is 78% of direct project cost for conventional construction methods and only 3% for trenchless methods.

A number of recent projects completed by Transport Canada focus on costs associated with traffic delays, accidents, environmental impacts and noise due to congestion in large Canadian cities. *The Cost of Urban Congestion in Canada* examined the cost of urban traffic congestion for Canada's nine largest urban areas: Quebec City, Montreal, Ottawa-Gatineau, Toronto, Hamilton, Winnipeg, Calgary, Edmonton and Vancouver (Delcan, 2005; Transport Canada, 2006). The study found that recurrent congestion, which is the congestion caused by excessive traffic volumes at peak periods, in urban areas costs Canadian between $2.5 billion and $4.0 billion per year (in 2006 dollar values). More than 90% of this cost is associated with the time lost in traffic to drivers and passengers; 7% occurs because of fuel consumed; and 3% is from increased greenhouse gas emissions. The other main source of traffic congestion and point of interest of our research, i.e., the non-recurrent congestion (congestion due to traffic accidents, work zones, weather and special events, was not addressed in the study.

A similar study from the UK suggested that utilities' street works are responsible for about 5% of the total amount of congestion in the country (Goodwin, 2005). The annual cost of traffic delays due to utility construction is estimated to be 2006 C$ 2.3 billion[1].

Zhang *et al* (2004) prepared an extensive study "Towards Estimating the Social and Environmental Costs of Transportation in Canada" for Transport Canada. The authors examined five categories of social costs: (1) congestion and the value of travel time; (2) the valuation of life and accidents costs; (3) noise costs; (4) the costs of air pollution; and (5) the costs of greenhouse gases. Zhang and co-authors developed estimates of the unit costs and identified what portion of potential social costs is borne by transportation users.

Another project – *The Full Cost Investigation of Transportation in Canada* (Transport Canada, 2008), started in 2004 and was to run for three years. The project deals with the "full costs" of transport – i.e. the comprehensive financial and social costs associated with infrastructures, services, vehicles, and with the movement of people and goods. Social costs refer to the costs of accidents, noise damage, congestion delays and environmental damages. The final report entitled *Estimates of the Full Cost of Transportation in Canada* was published in August 2008 (Transport Canada, 2008).

Similar studies have been completed for a number of European countries under a major EU-funded project – UNITE – Unification of accounts and marginal costs for transport efficiency (Nash, 2003). The case studies from EU countries cover the following cost categories: infrastructure costs, supplier operating costs, transport user costs and benefits, accidents costs, and environmental costs. Estimated costs are presented for 17 European countries, per vehicle kilometre traveled.

[1] All values hereafter are in 2006 C$, unless otherwise stated. Bank of Canada exchange rates are used for conversion. http://www.bank-banque-canada.ca/en/rates/exchange.html.

Despite the evidence of the importance of social costs considerations in calculating the total project costs, there is a dearth of information from municipalities regarding life cycle cost analysis (LCCA) in their organizations, as well as actual data on social costs. A study conducted by Arditi and Messiha (1999) showed that only 24% of the municipal organizations in the United States consider social costs in LCCA. Of these, only 9% consider these costs partially, and the majority of the respondents (65%) do not include social costs in LCCA. The authors also identified that social costs are usually used in LCCA calculations by relatively large cities with populations over 150,000.

A survey of Canadian infrastructure managers and owners found that 24% of respondents identify LCCA as a potential decision support tool (Rahman and Vanier, 2004); only a few respondents indicated that LCCA is a current best practice relating to strategic asset management.

Therefore, it is important to establish procedures to accurately collect and quantify social costs so municipalities can consider them in the LCCA of infrastructure rehabilitation and construction.

3. Objective and Scope of the Research

The main objective of this research is to establish a general procedure for consideration and quantification of social costs in the total project costs. This includes:

- identification of the existing social costs quantification models,
- assessment of their applicability to the Canadian environment,
- modification of the models where needed, and
- application of the proposed calculation procedure to the urban infrastructure rehabilitation case studies.

The focus of the report is to propose a methodology to calculate user cost components, specifically travel delay costs, vehicle operating and maintenance costs and cost of accidents.

The intent of this report is to identify appropriate models to be used in the development of social costs calculation methodology. It is not the intention of this report to research the existing models in great detail.

The proposed methodology is applied to actual infrastructure rehabilitation and construction projects in the City of Regina in summer 2006. The emphasis is made on identification and quantification of three components of user costs in the case study: (1) travel delay costs; (2) vehicle operating and maintenance costs; and (3) cost of accidents. External costs such as costs of noise and environmental impact are also considered but not studied in detail.

4. Social Costs Classification

Social costs are indirect costs of inconvenience and disruption to a municipality and to the general public during construction, maintenance, repair and rehabilitation of municipal infrastructure. These costs are borne by users and society at large and are typically not directly accounted for in construction projects.

This chapter presents examples of social costs components and their grouping into categories. The proposed classification is based on Canadian study by Rahman *et al* (2005) and the methodology developed by the U.S. Department of Transportation, FHWA (Walls *et al*, 1998).

The components of social costs are grouped into three major categories: municipality costs, user costs and external costs, as shown in Tables 1, 2 and 3, respectively.

4.1 Cost to Municipalities

Municipality cost components include costs specific to the project. These costs can occur before or during the infrastructure construction/rehabilitation project and they are normally borne by the municipality. These costs can be defined as direct costs because they are directly attributable to the project and can be quantified with a high degree of accuracy.

Usually these costs are included in the contractual agreement with those implementing the works. If, for whatever reason, these costs do not form part of the construction contract; these social costs are typically borne by the municipality. One example of this type of costs can be a sudden, unforeseen failure of the existing pipe during a pipe replacement project.

The municipality costs quantification methods are explained in detail by Rahman *et al* (2005) and further description is not included in this study.

Table 1: Municipality cost components

Category	Examples
Unforeseen overhead costs	Planning, design, legal and administration fees
Unforeseen construction costs	Materials, labour, equipment and energy
Reinstatement costs	Sewers, pavement and roads, buildings
Redundant systems costs	Planning process for emergencies, extra storage of life saving materials, medicine
Property damages	Public and private property, litigation and legal fees
Emergency services	Drinking water, temporary toilets, pumps, detours, bridges and shelters
Municipal revenue loss	Parking meter and ticket income, tax rebates
Service life reduction	Reduced service life of pavement and other utilities

4.2 Social costs borne by users

The user costs are usually hidden costs, as they affect the users of the infrastructure indirectly. The extent of these costs depends on the size of the project, its duration, type of the street, traffic volume, etc. The impact of traffic disruption includes the loss of productive labour of the driver and passengers due to delays or changes in traffic patterns. Traffic disruption can also increase vehicle operating and maintenance costs.

Table 2: User cost components

Type	Examples
Travel delay costs (Reduced speed through work zone, detours; slowing and returning to approach speed; queue)	Costs for extra time to travel through the construction zone
Vehicle operating and maintenance costs (Reduced speed through work zone, detour; queue)	Fuel and oil consumption, tire wear, maintenance and repair costs, depreciation
Accidents	Injury, fatality, damages to vehicles, insurance

Travel delay costs are determined by multiplying the value of time and the number of hours spent by travelers in the construction zone queues and detours. This cost is normally the greatest component of user costs.

The cost of accidents can be considered a user cost, an external cost, or a combination of both. Accidents at construction zones incur direct user costs both from the physical property and bodily damage, as well as from increased costs relating to vehicle insurance. The external costs associated with vehicle accidents include the vehicle emissions and noise associated with traffic congestion caused by the accidents.

As noted earlier, the focus of this research is mainly on user costs. Thus, we will come back to the description and quantification of user costs later in the report.

4.3 External cost components

External costs have often been excluded from analysis in the past because they are typically difficult to quantify and to valuate, as well as there is a lack of historical data on these costs. Recently, the number of guidelines and research data published in this area has increased, which offers an opportunity to include external costs in these analyses. Classification of external cost components is given in Table 3.

One example of an external cost component can be excess emissions that are produced by vehicles in congested traffic caused by construction or maintenance activities. The surrounding air quality is reduced, but the activities that cause this reduction in air quality are often not held accountable for the effects. This is particularly valid for residential areas.

Table 3: External cost components

Type	Example
Noise	Temporary evacuation, reduced work hours
Environmental costs	Pollution and contamination; Dirt and dust - cleaning, inconveniences
Vibration	Vibration due to construction work
Health and safety	Long-term effects of working in hazardous environments (health hazards), compensation
Business loss	Loss of revenue to business, loss of tax dollars to government

Another example is the increase in ambient noise caused by municipal infrastructure construction or rehabilitation activities. Noise pollution is an increasingly important type of pollution that has negative impacts on health and public comfort, which in turn results in negative impacts on the value of properties in residential areas and reduced business activities in commercial areas.

Models for predicting and quantifying external costs exist in various forms (Rahman *et al*, 2005). Examples of these models are evaluated in this report and applied to the City of Regina case studies.

5. Municipality cost components background

As noted earlier, the main focus of this study was to measure and quantify user cost components – travel delay, vehicle operating and maintenance costs, as well as costs of accidents. Some external cost components such as noise and environmental costs were also included in the scope of the study. Thus, the calculations for the municipality cost are only briefly described. More details can be found in the report by Rahman *et al* (2005).

Certain municipality costs are considered social costs if these costs do not form part of the construction contract. Basic calculation procedure of municipality cost components is shown below. Many of these costs are typically called indirect costs for a project; however, in the context of this client report, many of the categories of these costs are typically not considered in the final construction cost of a project and have been included in the municipal cost component of social costs, as shown in Table 1.

Overhead costs:

- Design costs equals approximately 5-6% of the construction costs;
- Administration and contingency costs equals 20-25% of construction costs.
- Construction, reinstatement and emergency services costs (so-called "what if" costs):
- Materials, labour, equipment and energy for alternative services and emergency repairs including temporary services;
- Sewers, pavement and roads, buildings;
- Drinking water, temporary toilets, pumps, detours, bridges and shelters.

Property damage:

- Estimated based on previous experience (for example, basement flooding due to construction).

Redundant systems and temporary services:

- Planning for emergencies, extra storage of life saving materials, medicine, etc.

Municipal revenue loss:

- Parking meters and ticketing:

Parking meter income =
Net meter rate × Number of meters × Operational hours × % Change occupancy × Project duration (1)

Parking ticket income =
Net fine × Number of tickets × % Change of ticketing × Project duration (2)

Example: Representative rates for downtown parking in Regina are in a range of $6 - $7 per day with a median of $6.25. If motorist pay per hour using street meters, then the parking cost is $1.00 per hour.

- Service life reduction:

  Service life reduction costs =
  Present value of asset (original service life) – Present value of asset (reduced service life) (3)

6. User cost components quantification

6.1 Introduction

One of the most important social costs of municipal infrastructure rehabilitation and construction projects is that associated with users' travel delays, vehicle operating and maintenance costs and cost of accidents or so-called user costs. This report is focused mainly on this type of costs.

In order to measure and estimate user costs for this case study, the following work needs to be carried out: a review of the work zone characteristics, a study of historical daily traffic distribution trends in the city, and a check of characteristics of vehicles used in the city (i.e. vehicle classes, age, occupancy, vehicle use by day of the week and time of the day, etc.).

This chapter begins by reviewing information on vehicle fleet characteristics in Saskatchewan. It then discusses the elements that comprise a typical work zone and examines the literature associated with predicting user costs. Finally, models for calculating these impacts are selected based on the results of the review of the existing literature and the findings of this study.

6.2 Saskatchewan vehicle fleet characteristics

Data on Saskatchewan vehicle fleet characteristics such as distribution by vehicle body type (e.g. car, van, sport-utility, truck, bus, etc.), age of vehicle fleet, fuel consumption, and vehicle occupancy described below are based on Transport Canada's Canadian Vehicle Survey (CVS, 2000). The survey represents average data for the 10 provinces for year 2000.

Saskatchewan is one of two provinces that have the highest per capita ownership rates of light vehicles (typically personal vehicles, i.e. cars, SUVs and vans) at over 600 vehicles for every 1,000 persons. Please see Appendix 2, Table A2.1 provides more detailed information.

In 2000, 58.3% of the vehicle fleet comprised automobiles (Table A2.2). Light pickup trucks were nearly 16% of the fleet, followed by vans with nearly 13% and sport-utility vehicles with nearly 7% of the fleet. Altogether, light trucks, vans and sport-utility vehicles accounted for approximately 35% of the total vehicle fleet.

Occupancy per light vehicle averaged around 1.7 persons per vehicle. Buses averaged over 16.0 persons per vehicle; it should be noted, that this number is slightly less for Regina and depends on a bus route (Regina Transit, 2007).

Table A2.3 provides a breakdown of the vehicle fleet, as well as fuel efficiency by the age of the vehicle. Almost 40% of the light vehicle fleet was under six years old, 20% under three years, and on average these lighter vehicles had the best fuel efficiency (10.7 L/100 km) and had the highest usage.

Approximately one-third of the medium truck fleet was under six years of age. Average fuel efficiency for medium trucks less than six years of age was 22.5 L/100 km. Heavy trucks were considerably newer with nearly half the fleet less than six years old. These vehicles accounted for 75% of the vehicle-km and their fuel efficiency was 42.6 L/100 km.

About 38% of the bus fleet was under six years of age in Canada. However, the effective average age of a Regina Transit bus was approximately 11 years in 2000 (Regina Transit, 2003). In the Canadian Urban Transit Association's 2000 Fact Book, the Regina fleet was classified as the second oldest of those in a comparable category.

In order to conduct a proper survey of an urban construction zone, but in Regina in particular, it is very important to know vehicle use by day of the week and by time of the day. Tables A2.4 and A2.5 provide these estimates for 10 provinces (CVS, 2000). These are summarized in Figures 1 and 2, respectively. In Figure 1, the summation of vehicle use by day for each vehicle type equals 100%.

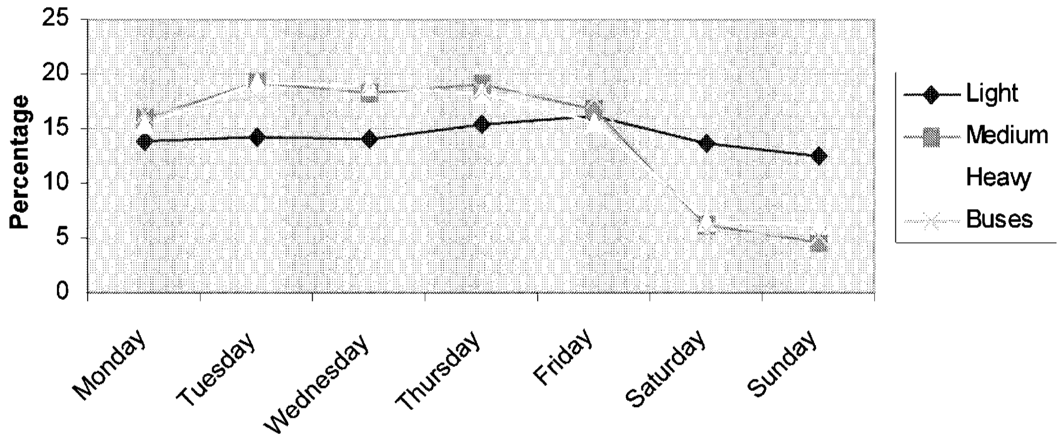

Figure 1: Percentage vehicle use by day of the week, 10 provinces, 2000 (Table A2.4)

In 2000, light vehicles use was distributed very evenly over the days of the week but did exhibit some peaking on Thursday and Friday and the least use on Sunday. The strong weekday pattern is observed for medium and heavy trucks. In 2000, the busiest day of the week for trucks was Tuesday and the least-busy days were Saturday and Sunday.

Overall, as shown in Figure 2, about three-quarters of all travel took place during daylight hours with the afternoon period from noon until 6PM the most heavily used with about 45% of the total activity. Truck activity was heavily concentrated during the day with about 85% of the total taking place at this time. The least heavily used period was, not surprisingly, the early morning period from midnight to 6AM, although heavy trucks were over-represented (owing to overnight deliveries) with almost 20% of total activity during this period.

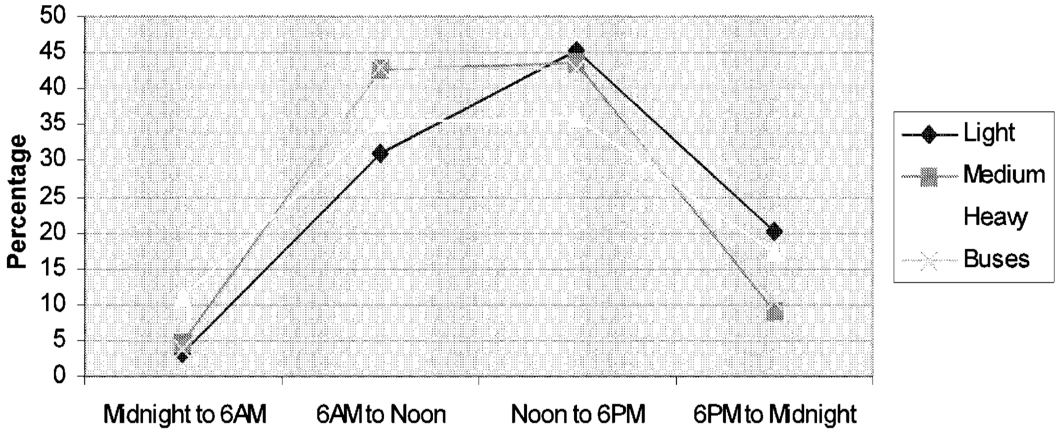

Figure 2: Percentage vehicle use by time of day, 10 provinces (Table A2.5)

Trip purpose for light and heavy vehicles is also interesting information to be mentioned in the report (Tables A2.6 and A2.7). Trips to or from work or school made by light vehicles accounted for 22% of vehicle-km but only 16% of passenger-km. Shopping trips represented over 25% of the activity while recreational or social purposes made up about 20% of vehicle-km and 23% of passenger-km. Use of light vehicles for work purposes accounted for 11.5% of vehicle-km and 8% of passenger-km.

Heavy trucks were used primarily for hauling goods or equipment with approximately 75% of the vehicle-km accounted for by this activity. Nearly 14% of heavy truck vehicle-km involved pulling an empty trailer. About 6% of heavy truck activity also involved a non-work purpose.

6.3 Important characteristics of work zone

When construction maintenance activities are undertaken on a section of urban road, a system of traffic controls and protective barriers are introduced to ensure worker and traffic safety. Traffic management in a work zone is influenced by the type of infrastructure, environment, traffic characteristics, project duration, type of work, and available sight distance. The configuration of a work zone balances contractor efficiency, traffic speed, and safety.

The work zone is usually characterized by its geometry, traffic volumes, lane capacities and vehicle speeds. The work zone is more than the area where the construction is taking place. It is an entire section of roadway on which traffic controls relating to construction work are placed. A work zone can consist of the following elements (Wilde *et al*, 1999):

- User information zone – where user is informed of the construction zone ahead and given direction for traveling safely through it.
- Approach zone, including detour exits – consists of a variable portion of the work zone where vehicle behaviour, particularly speed and direction, may change.
- Non-recovery zone – comprises the distance required to execute an avoidance manoeuvre, or the point beyond which the motorist cannot avoid the hazard unless erratic manoeuvres are undertaken.

- Construction zone – consist of (1) a buffer zone where there is no work activity or equipment and materials, and (2) the construction activity site where work is being undertaken.
- Termination zone –area after the construction where vehicles accelerate back to normal speeds.

When vehicle flows are light, impacts of the work zone on speed and safety may be slight. As demand increases, some impacts rise significantly and rapidly. Vehicle speeds are important because they relate directly to vehicle operating and maintenance costs, as well as user delay costs.

Increases in traffic through a construction zone also impacts number of accidents. The non-recovery zone is typically one where higher accident rates are recorded. However after the first week, drivers become accustomed to construction zone and adjust their behaviour.

6.4 Travel delay costs

Travel delay costs are those costs that result in additional time it takes to move through or around the construction zone.

Measuring travel delay costs involves the following components (Zhang *et al*, 2004):

- Measuring the amount of delays borne by transport users; and
- Estimating the value users place on these delays, i.e. value of time (VOT).

A review of measuring and estimation procedures of these components is presented below.

6.4.1 Time delays borne by transport users

The factors that are used to determine the time delay borne by transport users at the work zone include traffic volumes, daily traffic distribution, vehicle speed before, during and after the work zone, additional distance and time caused by detour, type of vehicle and number of passengers in the car. All the above-mentioned parameters should be measured during both normal road operations (i.e. free of construction) and during maintenance and/or rehabilitation (i.e. work zone) activities that restrict the capacity of the road.

Traffic volumes and daily traffic distribution information is usually collected by a municipality on a routine basis. Vehicle speed surveys, measurement of additional distance and time caused by detours, vehicle classification and passengers counting can be done for specific construction projects. Walls III and Smith (1998) research provides a detailed procedure to quantify work zone user costs components. A modified and simplified approach used in this study is presented below. The calculation steps involved are:

1. Determine traffic volumes with and without work zone (vehicles per day).
2. Determine directional hourly distribution with and without work zone (vehicles per hour).
3. Perform vehicle classification (number of personal cars, trucks, buses), passenger counting (number of people in the car), and then classify traffic into vehicle classes.
4. Collect data on work zone hours, length of work zone, number of lanes open/closed for work zone, approach speed and work zone speed, the posted velocity, and number of days work zone is in place.

5. Measure distance and time of detours.
6. Quantify number of vehicles affected by work zone

Total number of vehicles in work zone =
Number of vehicles in work zone per day × Number of working days × % Traffic mix (type of vehicle) (4)

Total number of vehicles that take detour =
Number of vehicles per day that take detour × Number of working days × % Traffic mix (type of vehicle) (5)

Total number of vehicles delayed due to queuing =
Number of vehicles per day in queues × Number of working days × % Traffic mix (type of vehicle) (6)

Number of vehicles in queues can be defined as difference between demand (in vehicles per hour, vph) and capacity of the road (vph).

7. Assign vehicle delay cost rates

Delay cost for vehicles =
Time delay (unit time) × Number of vehicles × Value of time (per unit time) × Project duration (7)

8. Compute user costs by vehicle class.

6.4.2 Value of time (VOT)

People can place a monetary value on their time because of construction delays and can also place a value on the amount of time-savings than could occur. Of all the user costs rates, the cost rate assigned to user delay (i.e. the value of time) is by far the most difficult to estimate. There is an extensive amount of research literature, mainly for road transport, that covers on estimation of the value of time (VOT). In this research, the focus is mainly on recent Canadian studies. The authors of Transport Canada's *The Cost of Urban Congestion in Canada* report used Transport Canada's (1993) approach to travel time valuation (Delcan, 2005 and Transport Canada, 2006). The approach develops time values according to business and non-business trip purposes. VOT for business travelers is valued at the traveler's gross wage rate (before tax) plus fringes and benefits. The percentages provided by Transport Canada for estimation of benefits and overhead costs are 19.5% for employee benefits, 14% for paid time off and vacations, 8% for the cost of office accommodation and 5% for personnel administration including training. The average VOT of business travel identified in these reports is $31.41 per hour[2] (in 2006 C$).

VOT for non-work travel purposes is set for 50% of the national average wage rate or $9.73 per hour (in 2006 C$). However, it is not always possible to find data on number of business and non-business trips made. Thus, weighted values are applied:

- for automobile travel, 15% is business, 85% is non-business
- for bus travel, 10% is business, 90% is non-business.

It should be noted that the Transport Canada 1993 study focused on interurban trips and the weights presented were developed from interurban trips databases. The weights represent an

[2] The value has not been updated to reflect increased real wages.

overestimate of the weight of business travel during peak periods in urban settings, especially for buses. Transport Canada suggests using the VOT for children under the age of 17 half of that of an adult, i.e. 25% of non-business travel. According to census data (2001), the proportions of children for nine provinces vary between 16% and 20%.

Zhang *et al* (2004) presented a comprehensive review of the research in the field of travel time-savings. The literature review for urban commuting by car presented by authors shows a wide range of estimates (from 12 to 170% of average wage) with most of the values between 35 and 60% of the wage rate. The authors proposed to make no distinction based on trip purpose for non-work related journeys, and value of time on both leisure and commuting trips of 50% of the average wage rate. However, travel time for business trips should be valued at the gross wage plus labour related overheads.

In our study, due to limited information on the composition of traffic, a constant value of time (50% of the average wage rate in Saskatchewan) is used for all projects performed on week days and for projects that have duration longer than a week. No distinction is made based on business and non-business travel, as well as children travel. Travel time for weekends' projects is valued at 25% of the average wage rate in Saskatchewan.

6.5 Vehicle operating and maintenance costs

The second group of user costs relates to vehicle operating and maintenance costs. These costs comprise fuel consumption, oil consumption, tire wear, vehicle maintenance, vehicle depreciation, and spare parts. The most recent Canadian study carried out to estimate vehicles' operating and maintenance costs is "Estimation of Costs of Cars and Light Trucks Use per Vehicle-Kilometre in Canada" prepared by Transport Canada within the Full Cost Investigation project (Ray Barton Associates, 2006). The study estimates the costs per vehicle kilometre for Canadian-owned cars and light trucks in the year 2000.

Vehicle operating and maintenance costs are considered as either fixed (do not vary with vehicle usage) or variable; some costs items can contain elements of both. Table 4 illustrates the operating and maintenance costs and whether they are fixed or variable.

Table 4: Fixed and variable costs (Ray Barton Associates, 2006)

Example	Category
Cost item	Fixed or variable
Depreciation	Mostly fixed, minor component variable
Financing	Fixed
Insurance	Mostly fixed, minor component variable
Registration and licensing	Fixed
Fuel	Variable
Maintenance and repair	Variable

In our study operating and maintenance costs are calculated separately. Operating costs account for fuel consumption and depend only on fuel price. In 2006, average fuel price in Regina was $1.015 per litre of gasoline and $0.815 per litre of diesel fuel. Federal and provincial taxes are included in the prices.

Fuel consumption increases in the work zone due to changes in vehicle operating speed, increased number of stop-and-go cycles (i.e. idling, accelerating and stopping). However, changes in fuel consumption due to these factors are not accounted for in this study.

Maintenance costs take into account other non-fuel operating and maintenance costs such as cost of oil, tires and maintenance parts, labour costs, driving lessons and auto association or similar costs. Data on these costs for the province of Saskatchewan is obtained from Transport Canada report and illustrated in the Appendix in Table A2.8 (Ray Barton Associates, 2006).

Owing to the diversity of vehicles that can be included in any one-vehicle class (i.e. two-seaters, compact, full-size, etc.), Transport Canada provided a list of the top selling vehicles in each class. Most classes include four vehicles; however, some classes include only one vehicle. The data is also broken down into several 3-year groups (0-2, 3-5, 6-8, 9-11, 12-14, and 15+ years old). On average, the cost of maintenance for the non-fuel operating and maintenance for paved roads in 2006 Canadian dollars is $ 0.033 per vehicle-km (Ray Barton Associates, 2006).

6.6 Cost of accidents

The third group of user costs is associated with accidents, which are generally higher at construction zones. And the largest cost component of accident costs is the loss of human life. Therefore, this chapter begins by describing methods to estimate the value of statistical life – society's willingness to forego other output in order to reduce the loss of life.

6.6.1 The value of statistical life

The loss of human life is the largest component of accident costs. Thus, it is necessary to estimate the value of a statistical life (VSL) accurately.

According to a comprehensive review of recent VSL studies conducted by Zhang *et al* (2004), most recent estimates of the VSL are based on one of three methods: wage-risk studies, consumer purchase studies, or contingent valuation method studies. The first two methods are based on revealed preferences, while the latter is based on stated preference. According to Zhang *et al* (2004) despite limitations of revealed preference methods, economists prefer them to survey methods.

Early methods to estimate the VSL were based on a person's earnings (Zhang *et al*, 2004). Earnings provide a measure of the value of a person's lost output, but it does not reflect an individual's willingness to pay to reduce the risk of death. Nor does it distinguish between the deaths of identifiable individuals and statistical death.

Willingness to pay (WTP) is a better concept to value the benefits of safety improvements. In this method the VSL is calculated as:

$$VSL = WTP/\text{reduction of risk} \quad (8)$$

It should also be noted that in this calculation the VSL depends on the level of risk – the higher the risk, the higher the VSL.

The most recent study done in European Union within the UNITE project, based on the willingness-to-pay approach, recommended an average European value of statistical life of €1.5 million (Euro) or 2006 C$ 2.4 million (Lindberg, 2003). However, the authors mentioned that the value depends on the purchasing power of the individual and is different between the EU Member States.

Zhang *et al* (2004) derived the VSL for use in policy analysis in Canada in two ways. Based on studies reviewed that are most pertinent to Canada, the authors computed an estimate and a range of the VSL. Then, they obtained a best estimate and a range for the U.S. and adjusted it to reflect lower average incomes in Canada.

The suggested VSL for policy purposes in Canada is 2006 C$ 4.6 million, which is a mid point of the obtained range: C$ 1.1 - 8.1 million (in 2006 C$). The best estimate obtained for the U.S. and adjusted for Canada is between 2006 C$ 4.6 million and 2006 C$ 5.0 million that is very close to, but slightly higher, than the 2006 C$ 4.6 million figure suggested above. The U.S. VSL range adjusted for Canadian incomes is between 2006 C$ 1.4 million and 2006 C$ 8.5 million. This range is very similar to the range estimated based on Canadian studies and confirms the previous results.

6.6.2 Cost of accidents estimation

A common method to compute the total cost of an accident is to sum the various components: the direct costs, indirect costs, and intangible costs. Direct costs pertain to property damage and other accident costs, medical costs and administrative costs (household help and insurance administration). Indirect costs include productivity losses, other associated work related costs, and costs imposed on family members. Intangible costs include loss of quality of life, pain and suffering.

Productivity losses are usually measured by the human capital approach (e.g., lost of wages). Intangible costs are measured from wage risk studies, consumer market studies, time trade off measures, etc.

The EU project UNITE proposed their equation for marginal costs external (MC^e) for accidents (Lindberg, 2003, Nash, 2003):

$$MC_j^e = r(a+b+c)\left[(1-\theta_j)+E\right]+\theta_j rc, \quad (9)$$

where **r** represents accident risk, **a** the value of statistical life, **b** cost imposed on relatives and friends, **c** the costs imposed on society, **θ** the proportion of accident cost that falls on the traveler of type **j** and **E** the risk elasticity (i.e. the relationship between accidents and traffic volume).

By marginal external costs the authors consider costs not borne by the user. The marginal costs external (MC^e) would be high if:

- the accident risk **r** is high;
- the cost per accident is high **(a+b+c)**;
- most of the costs fall on other traveller or user groups (**θ≈0**);
- the risk increases when the traffic increases (**E>0**);
- or a large part of the accident cost is paid by the society at large (**c**).

As a comparative example in the Canadian context, the recommended estimates of the cost of accidents proposed by Zhang *et al* (2004) are (in C$ 2006):

- Urban/Interurban vehicle: $154.38/1000 km
- Urban/Interurban bus: $482.32/1000 km

- Freight vehicle/Truck: $164.99/1000 km.

These estimates are derived from an extensive literature review by the authors. As they are the most recent and adjusted for Canadian wages, therefore, these estimates are used in our study to calculate accident costs.

The data for estimation of accident costs was also collected for the province of Saskatchewan. For cost benefit analysis, Saskatchewan Government Insurance (SGI) typically uses the following criteria for the estimation of traffic collisions costs, in C$ 2006 (McNaughton, 2006):

- Property Damage (only crash): $3,500
- Injury: $16,000 per injury
- Death: $96,000 per death.

However, costs are likely to vary between one accident and another. It is also possible that accident costs vary from one region to another with low-accident rate regions suffering higher per accident costs due to lack of economies of scale. Within a particular region, the marginal accident cost is unlikely to change much with changing frequency of accidents, assuming reasonably optimal provision of hospital and emergency services and assuming that accident rates do not change quickly.

6.6.3 Accidents at work zone

Overall rates of accidents in city roads are usually well established, however, accident rates for work zone are not. There is also little empirical evidence to support consistent relationships between accident rates / severity and work zone configurations. Not withstanding this dearth of evidence, some research does show that accident rates increase when a work zone is established (Wilde *et al*, 1999). The results vary widely, from a 7% to a 119% increase. Part of the variability in the results of these studies is due to the rarity of accidents, and especially to that of accidents at work zones.

Several factors were identified as contributing to the increase of work zone accidents. These are: inadequate or confusing traffic control, edge drop or soft shoulder, traffic slowdowns, lane changing and merging, etc. It was also identified that most of the accidents occur in the work zone itself. The next most dangerous sections of work zones are the advance zone and the non-recovery area.

It should be noted that the research in this area is mainly for highways, very limited data are available and the data found is out of date (Wilde *et al*, 1999). There is a clear need to conduct fundamental research in the area of accidents at work zones in urban areas – research supported by the latest data reflecting urban traffic conditions and improvements in work zone safety.

An attempt was made to collect data on accidents due to work zone in the City of Regina. Table 5 illustrates a summary of traffic crashes in work zones in the City of Regina for five years. The SGI (2006) data are not complete as minor collisions are not reported through a police agency.

Table 5: Traffic Collisions in Construction Zones in the City of Regina (McNaughton, 2006)

Year	Total Incidents	Persons Injured	Persons Killed
2000	25	9	0
2001	22	6	0
2002	43	12	0
2003	33	4	2
2004	46	7	0
2005	15*	3	0

* Police reported crashes only. Incidents reported through SGI Claims are not included.

The 2004 Traffic Collision Statistics for the City of Regina are presented in Table 6.

Table 6: 2004 Traffic Collision Statistics for the City of Regina (SGI, 2006)

Population	Collisions				Persons		
	Property damage	Personal injury	Fatal	Total	Acc/100 pop.	Injured	Killed
186,766	6,421	1,404	5	7,830	4.19	1,824	5

As it is shown in Tables 5 and 6, the total number of accidents in 2004 was 7,830, of which only 46 cases occurred in construction zones. Thus, accidents due to work zones represent only 0.59% of all accidents in the city in 2004. The fact that most of the road construction and rehabilitation activities are carried out in the period from April to October should also be taken into account.

In Table 7, the number of accidents and their respective configurations are reported. The configurations are explained in Figure 3.

Table 7: Distribution by accident configuration (AC) in work zone (McNaughton, 2006)

AC	2000		2001		2002		2003		2004		2005	
(Table 8)	#	%	#	%	#	%	#	%	#	%	#	%
1	5	20	4	18	7	16	4	12	8	17	3	20
2	2	8							2	4		
3					1	2						
4			1	5	1	2			2	4	1	7
5	9	36	7	32	25	58	16	48	17	37	9	60
6	2	8			5	12	4	12	6	13		
7									1	2		
8			2	9								
9			1	5			1	3	4	9	1	7
10			1	5			1	3	1	2		
11			1	5					1	2		
12					1	2	1	3				
13	2	8	3	14			2	6	2	4		
14					1	2	2	6				
15			2	9								
16	5	20			2	5	2	6	2	4	1	7
Total	25	100	22	100	43	100	33	100	46	100	15*	100

* Police reported crashes only. Incidents reported through SGI Claims are not included.

From the Table 7 it can be seen that the main configurations of accident at the construction zones are number 1, 5 and 6 – collision with fixed/movable object on roadway, rear end collision and sideswipe collision, respectively. Other collision configurations include loss of control (2, 4), collisions at the intersection (9, 10, 13) and other collisions not specified in Figure 3 (16).

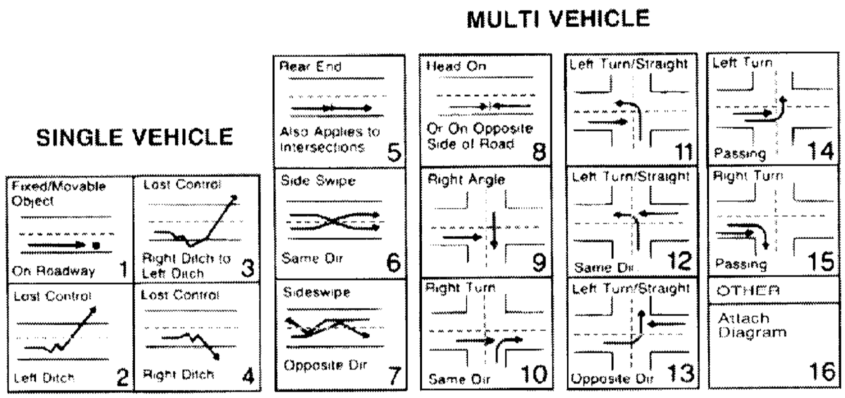

Figure 3: Accident configuration (AC) codes (SGI, 2006)

Collecting and analyzing information on accidents at work zones in urban areas would be an important area for future research. Some examples of research can include investigation of percentage change in accident rates when work zone is introduced; the location within work zone where accidents most likely to occur; accidents dependability on length of the work zone and the duration of the construction project.

7. External Cost Components Quantification

This chapter focuses mainly on two components of external costs: noise disturbance cost and environmental cost. Other external cost components (business loss, dirt and dust, and health and safety costs) have been identified as opportunities for future research and are not discussed here.

7.1 Noise disturbance cost

Vehicles create an unpleasant noise in our living environments. Factors that influence the amount of noise generated by a vehicle interacting with the infrastructure include background flow, the size of the vehicle, the speed and the pavement surface.

Several research works have shown that noise can have negative physiological and psychological impact on people (Sandberg *et al*, 2002, Zhang *et al*, 2004). Construction activities such as blasting, excavating, drilling, etc. during a municipal infrastructure rehabilitation project can bring an additional noise to the neighbourhood for several days and sometimes weeks or months.

In order to place a price on noise, two parameters must be established: the noise level and value which people place on it. The noise level is measured in decibels (dB). The value for noise can be established through secondary markets where noise is bundled with other market products such as housing.

Generally, sound measures are weighted to reflect what is perceived as "loudness". The most common weight, the A scale, gives the measure dB(A), where the number of decibels is weighted by sound at various frequencies to give equivalent loudness. Noise measured for a point in time are described as single event measures while those which are measured over time such as NEF (Noise Exposure Forecasts) reflect the amount of noise locations are exposed to over a day with night time noise carrying a higher weight than daytime noise.

There is extensive literature on both noise measurement and noise valuation. The studies cover measurement and calculation of highway noise and noise due to congested traffic conditions in the cities. Values and formulas used in our calculations are based primarily on two studies: Levinson *et al* (1998) and Zhang *et al* (2004).

Noise cost calculations measuring willingness to pay for quiet are based almost entirely on the depreciation of real estate due to noise level. For road traffic noise (i.e. for auto, truck and urban bus), a noise depreciation index (the percentage reduction of house price per dB(A) above ambient noise) has been reported that range from 0.08% to 2.22%. A simple mean is a value of around 0.55%, although one would want to use a range of 0.4 to 0.65 in any calculations (Zhang *et al*, 2004).

Levinson *et al* (1998) proposed the noise cost calculation model for automobiles per vehicle km of travel (vkt):

$$AC_{hn} = f(D) * f(H) * f(C) (-0.018 + 0.0028 \ln (Q_h)) \quad (10)$$

where AC_{hn} is the average cost of highway noise (in \$/vkt), f(D) is the housing density (houses per square kilometre)/360 (default = 1); f(H) is the house value/\$250,000 (default = 1); and f(C) is the cost per dB(A) or noise depreciation index/0.0062 (default = 1), and Q_h is the traffic flow in vehicles per hour. The default is for a typical suburban density of 360 houses per square kilometre and average house value of \$250,000. Thus to use different values they would be expressed in terms of the values originally used. For example, if housing density is assumed to be 400 houses per square kilometre, it would be expressed as f(D)=(400/360)=1.11 or a 11% higher density.

For automobile travel the highway noise model gives a range of between \$0.0007/vkt and \$0.0070/vkt average cost, depending on flow, given the assumptions of annual interest rate = 7%, years = 30, home value = \$250,000, density = 360 number of houses/km^2, cost/dB(A) = 0.068 (C\$ 2002), a speed of 100 km/hr, and a maximum range of 500 m on each side of the highway. At the vehicle occupancy of 1.5 and flow of 6,000 vehicles per hour, this converts to \$0.0045/pkt (passenger km traveled).

To compare, INFRAS/IWW (1995) gives noise estimates from Europe of \$0.0058/pkt for automobiles, about the same for buses (\$0.0054/pkt) and \$0.0163/tkt (tonne km traveled) by truck.

As noted above, models that estimate an increase in noise are mainly developed for highways, not for urban residential areas. These models are based on estimation of values and number of homes per linear km within the road, noise depreciation index and net increase in noise exposure. The output value of the models is annual residential property depreciation value.

The recent study carried out by Dai *et al* (2005) to assess the road traffic noise in various residential areas in the City of Regina should also be mentioned. The traffic noise in residential areas of the city was studied by classifying the roads into three categories:

- Category I: Residential areas adjacent to arterial road of daily traffic flow of around 20,000 or above.

- Category II: Residential areas at the vicinity of streets, which connect city main roads with other minor streets in residential areas (daily traffic flow in the range of 10,000 to 15,000).
- Category III: Streets in typical residential areas characterized by daily traffic flow less than 5,000.

Dai *et al* (2005) concluded that according to road traffic noise limits in Canada and recommended noise levels from World Health Organization (WHO), the environmental noise in Categories I and II locations does not satisfy the standards. The noise levels in Category III locations can generally be accepted. The authors also pointed out that traffic noise is the main noise source in the city.

7.2 Environmental costs

Environmental costs that are associated with traffic flow consist mainly of air pollutants and greenhouse gas (GHG) emissions. Motor vehicles air pollutants are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOCs), poly-aromatic hydrocarbons (PAH), hydrocarbons (HC), particulate matter (PM_{10})[3], methane (CH_4) and carbon monoxide (CO).

Air pollution created by traffic in the city worsens during any municipal infrastructure construction or rehabilitation work. There are two components of additional pollution sources during construction:

- Pollution created by the construction activity itself;
- The incremental vehicle emissions from interference with the normal traffic flow.

Most of the methods to estimate costs of air emissions adopted the "dose-response", or "damage function", approach. The approach involves the following six steps (Zhang *et al*, 2005):

1. Identification of major air pollutants;
2. Establish dose-response functions linking emissions and damage effects, based mainly on epidemiology studies;
3. An air dispersion model is used to estimate the atmospheric concentration of the pollutant;
4. Emission factors of air pollutants are estimated;
5. The monetary value of the damage incurred is estimated drawing from economic studies, which place values on mortality and morbidity (e.g., short-term illness, chronic morbidity, productivity loss, and cancer);
6. The results from the epidemiological and engineering literature are merged with the results from the economic literature to arrive at the cost estimates.

Zhang *et al* (2005), whenever possible, made an attempt to use Canadian studies and employ Canadian figures to estimate cost of emissions. The proposed cost estimates are the following (in 2006 $C):

[3] PM_{10} is used to describe particulate matter of 10 micrometres or less.

- Urban private vehicle: 0.00910 $/per passenger-km
- Urban transit: 0.00358 $/per passenger-km
- Freight transport (truck): 0.00544 $/per tonne-km.

These estimates are towards the lower end of the ranges estimated in other studies. The authors also conducted a sensitivity analysis, which showed that the estimates of road transportation appear to be sensitive to the choice of VSL. For example, when the occupancy rate for urban private vehicle increases by 7.1% from 1.4 to 1.5 passengers per vehicle, the cost estimate is reduced by 6.6%: from $0.00910 to $0.00850 per passenger-km.

GHG emission values are quite difficult to assess in the absence of a market for CO_2 emission reduction. Eventually, the Kyoto agreement may facilitate the establishment of a real international market for those gases. Canada's target is to reduce its GHG emissions to 6% below 1990 levels by the period between 2008 and 2012. Most European countries have a target of 8%.

A large range of emission factors has been reported in the existing studies, most of which have focused on EU countries (Nash, 2003; Clarkson and Deyes, 2002). In order to cope with the range of GHG emission values, some authors proposed to adopt a median value (Transport Canada, 2006). For example, the middle damage estimate based on Nordhaus (1991) is $12.62 (in 2006 C$) per tonne of CO_2 equivalent. Matthews *et al* (2001) suggested a median value of $20.62 (in 2006 C$) per tonne of CO_2 equivalent and a range of $2.94 to $33.87. Zhang *et al* (2005) used a value of $21.63 (in 2006 C$) to obtain the best estimates for Canada.

In this report the GHG emissions values estimated by Zhang *et al* (2005) are used in the calculations. The values are shown below (in 2006 C$):

- Urban private vehicle: 0.001267 $/per passenger-km
- Urban transit: 0.000454 $/per passenger-km
- Freight transport (truck): 0.000589 $/per tonne-km.

All these costs are marginal costs, since they are estimated at the current levels of environmental conditions.

8. Case Studies

8.1 Introduction

Municipal infrastructure rehabilitation and construction projects in Regina are usually carried out from April until October because of climatic conditions.

In order to collect data for social costs calculations, case studies of actual infrastructure rehabilitation projects were carried out in Regina in the summer 2006. The selection of the projects was pragmatic and based on the area of the city (industrial, residential, commercial), type of the street, traffic volumes, time and duration of the project. The selected locations for the survey were communicated to the City of Regina and historical data trends for these locations were reviewed by the authors. The following three projects were selected:

- Winnipeg Street and Ross Avenue intersection;
- Albert Street project;
- Victoria Avenue and Park Street.

All necessary information for calculation of user cost and external cost components was collected for these case studies. Data collection methods employed are described below.

8.2 Data collection methods

Traffic volume counts were carried out manually using tally sheets to record data. A blank traffic volume count intersection tally sheet is provided in Appendix 1. The data were recorded with a tick mark on a pre-prepared field form. A stopwatch was used to measure the desired count intervals of five minutes. Counting was done for all case studies with and without the work zone.

Measurements were taken every hour from 7am to 6pm. An emphasis was made on collection of data during peak flow periods in the morning (7-9am), lunch time (11am-1pm) and in the afternoon (4-6pm). The observer was positioned so that to have a clear view of the traffic. In some locations, observers counted traffic from inside a stationary vehicle.

The observer recorded the number, movements, direction, and classifications of vehicles and number of passengers in the vehicles at selected locations. For vehicle classification number of cars, vans, SUVs, trucks, buses (school and public) and motorcycles, as well as vehicle's direction of travel at the intersection were recorded. On each tally sheet, the observer also recorded the location, time and date of observation, and weather conditions.

8.3 Winnipeg Street and Ross Avenue intersection

Winnipeg-Ross intersection was selected mainly because of the intensive industrial traffic flow at this location. More information about this case study can be found in Table 8.

Table 8: Winnipeg Street and Ross Avenue project information

Category	Details
Type of project	Railway crossing repair
Time	Monday, Tuesday
Duration	2 days
City zone	Industrial
Road adjustments	Ross Avenue is closed from Winnipeg Street to McDonald Street
Detours	Industrial & Residential
Type of traffic	Mainly industrial

Winnipeg Street connects the Ross Industrial Park with the central part of the city. Ross Avenue connects two main arterial roads – Broad Street and Park Street (see Figure 4). Recorded daily traffic volumes at Winnipeg Street and Ross Avenue are 16,000 and 17,000, respectively.

Rehabilitation works were carried out on Monday and Tuesday; the railway crossing on Ross Avenue between Winnipeg and McDonald Streets was repaired. Ross Avenue from Winnipeg to McDonald Streets was closed for two days. Detour through industrial area (1st Avenue) was established. However, a problem with the detour was noted at this location, as signs showing direction of detour were not installed at Winnipeg Street and Ross Avenue intersection. This caused confusion, and most of the heavy vehicles' drivers chose to take a residential detour through 4th Avenue. Approximately 6,400 vehicles/day (of which 550 were trucks) took an industrial detour and 5,300 vehicles/day (680 trucks/day) passed through residential area.

The length of the residential detour is 1.6 km, average travel time is 133 seconds, in contrast, the length of detour through the industrial area is 1.5 km and average travel time is 123 seconds. This means that the industrial detour saves on average 10 seconds of travelers' time, as well some fuel since the travel distance is shorter. Thus, lack of detour signs at Winnipeg Street and Ross Avenue intersection added to the increase in user and external costs.

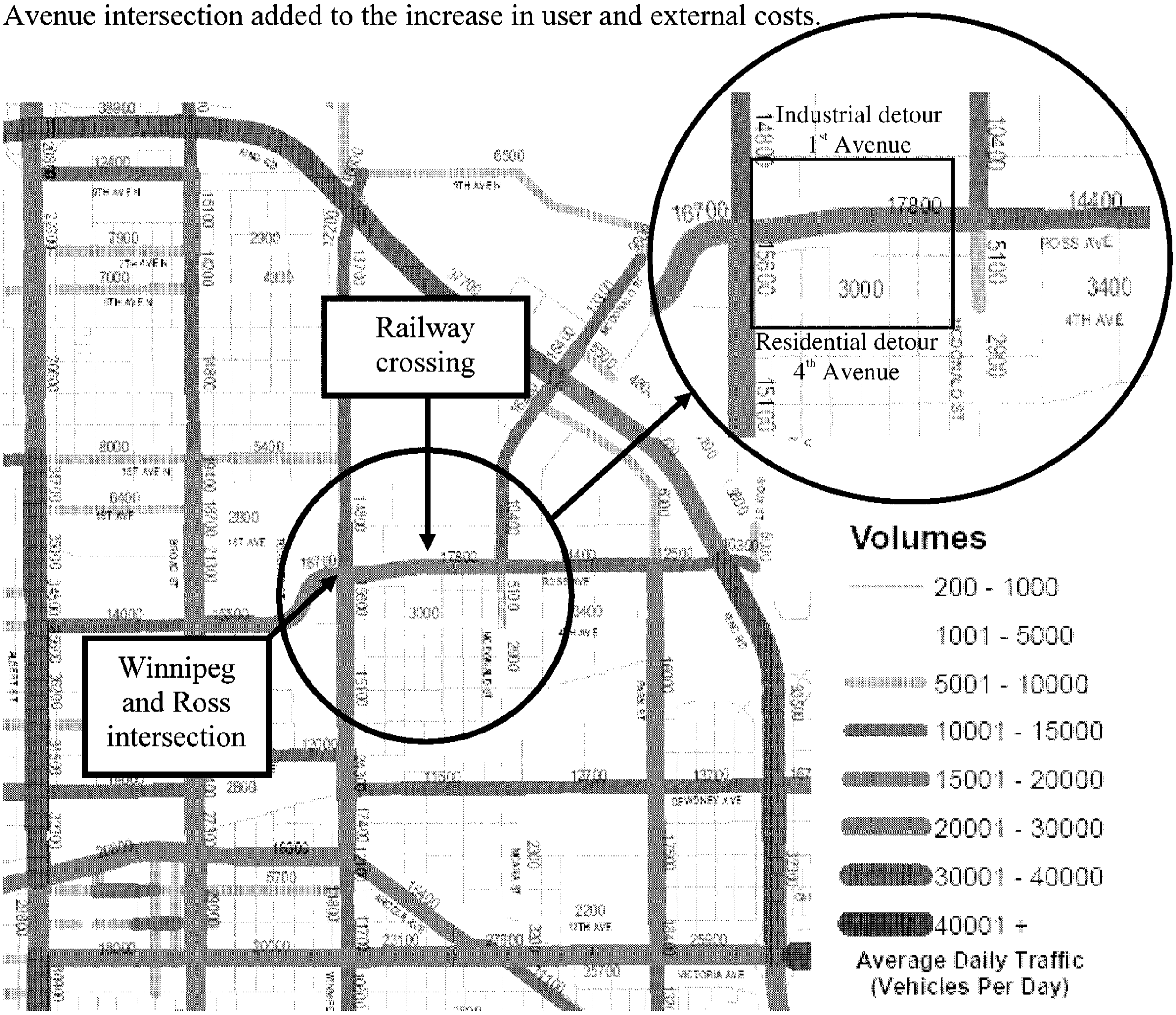

Figure 4: Winnipeg Street and Ross Avenue project – map of project location (2004 Traffic Flow Map Source: City of Regina)

8.4 Albert Street Case Study

The Albert Street project was conducted on a weekend, which was a main reason for its selection. Road resurfacing works were completed at Albert and 4th Avenue intersection on Saturday and Sunday, as shown in Figure 5. The railway crossing between 3rd and 2nd Avenue was repaired on Sunday.

Albert Street from 5th Avenue to 3rd Avenue was down to one lane in both directions on Saturday. The construction zone was disassembled on Saturday evening to allow for undisturbed traffic flow. On Sunday morning at 7 am, Albert Street was closed from 7th Avenue to 2nd

Avenue, and a detour through Broad Street was established. For more information on the project and location, please see Table 9 and Figure 5.

Table 9: Albert Street project information

Category	Details
Type of project	Road Resurfacing
Time	Saturday, Sunday
Duration	2 days
City zone	Arterial road
Road adjustments	Saturday: Albert Street from 5th Ave to 3rd Ave is down to one lane in both directions Sunday: Albert Street is closed from 7th Ave to 2nd Ave
Detours	Sunday: through Broad Street
Type of traffic	Mainly light vehicles

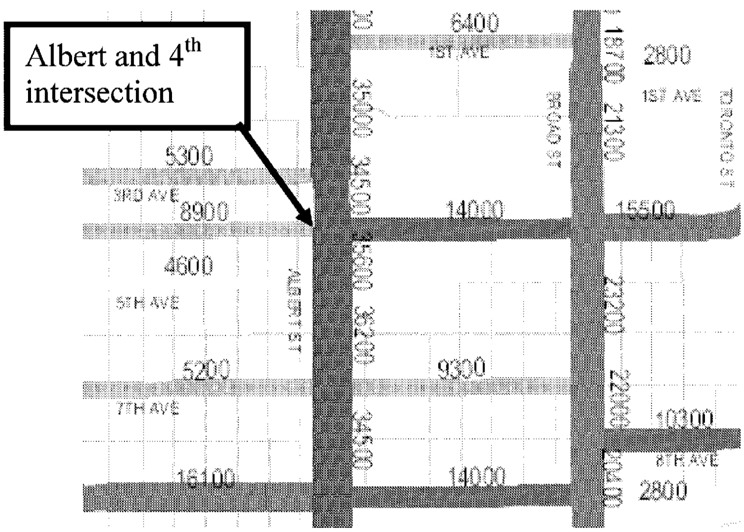

Figure 5: Albert Street project – map of project location

Albert Street is a main north-south arterial road in the city. Historical traffic volumes on Albert Street and 4th Avenue, at the intersection, are 35,000 and 14,000, respectively. However, according to traffic counts on Saturdays and Sundays, traffic volumes on Albert Street are lower during the weekend: in total, through the intersection passes 33,000 vehicles/day on Saturdays and only 23,000 vehicles/day on Sundays.

A detour through Broad Street was established on Sunday. The detour was properly marked and did not cause much confusion among drivers.

8.5 Victoria Avenue and Park Street Case Study

Victoria Avenue and Park Street Case Study was chosen due to its location (intersection of main arterial roads), as well as long project duration (two months). For information on the project and its location, please see Table 10 and Figure 6.

Table 10: Victoria-Park information

Category	Details
Type of project	Road repair (Contractor location)
Time	July-August
Duration	2 months
City zone	Main arterial road
Road adjustments	Park Street is down to one lane from Victoria to 12th Ave
Detours	Industrial
Type of traffic	Varies with time of the day

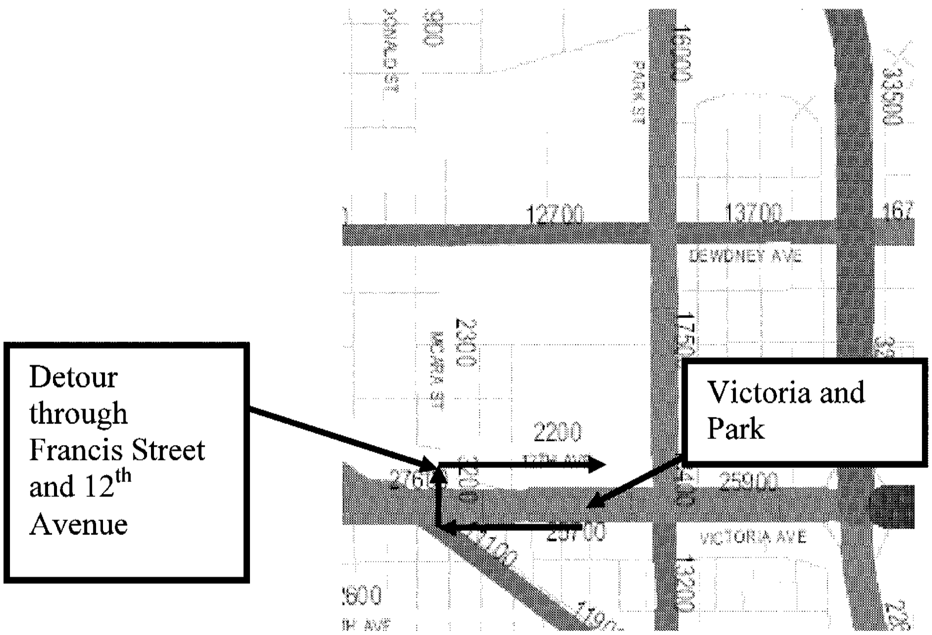

Figure 6: Victoria Avenue and Park Street project – map of project location

Park Street from Victoria Avenue to 12th Ave was down to one lane in both directions. The right turn (E-N) was closed and a detour through Francis Street and 12th Ave was established. Queues on Park Street from 12th Ave to Victoria were observed during peak flow hours.

As the project duration was approximately two months it enabled drivers to become familiar with the road restrictions at work zone and adjust their behaviour accordingly.

8.6 Analysis of results

All components necessary for user costs and external cost components calculations were first measured without the work zone. Then, the same measurements were performed during the construction project. The total cost to motorist is determined under normal traffic conditions and while the work zone is in effect. A social costs calculation tool, developed in the MS-Excel software, was used to document and analyze collected data.

Vehicle classification and occupancy results for three projects are summarized in Tables 11 and 12.

Table 11: Vehicle classification (in %)

Category	Winnipeg-Ross	Albert Street	Victoria-Park
Car	55.88	50.00	48.55
SUV	19.85	39.00	36.97
Van	13.24	9.62	10.07
Truck	8.82	0.98	4.21
Bus	0.74	0.20	0.20
Motorcycle	1.47	0.20	0

As noted earlier, the Winnipeg-Ross case study is in an industrial zone of the city. Thus, the percentage of industrial vans and trucks (13.2% and 8.8%, respectively) is the highest among all three case studies. The lowest percentage of trucks was observed for the case study carried out on a weekend; that is, the Albert Street case study (see Table 11).

The number of cars is in the same range for all case studies. Percentage of SUVs is slightly higher in case of Albert Street and Victoria-Park case studies (39.0% and 37.0%) then in case of Winnipeg-Ross project (20%).

Vehicle occupancy results are illustrated in Table 12. The lowest vehicle occupancy is noticed for the project in the industrial area at Winnipeg-Ross intersection. Nearly 79% of the vehicles had only one person per vehicle and 17% of the vehicles - two persons per vehicle. The highest occupancy rate is observed in case of the weekend work at Albert Street. The summary of social costs calculation results is presented in Tables 13 – 15.

Table 12: Vehicle occupancy (in %)

Number of persons	Winnipeg-Ross	Albert Street	Victoria-Park
1	78.86	53.03	67.18
2	17.23	31.82	28.73
3	3.65	12.12	3.29
4	0.26	1.52	0.79
5	0	1.52	0

Table 13: Summary of data used to calculate user cost components

Category	Winnipeg-Ross	Albert Street	Victoria-Park
Wage rate, $/hr	8.61 (50% of average wage rate)	4.31 (25% of average wage rate – weekend traffic)	8.61 (50% of average wage rate)
Total delay, hr	825	970	9,700
Number of people delayed	29,000	32,500 /day 1 21,000 /day 2	400,000
Project duration, days	2	2	60

Table 14: Summary of user cost components for three case studies (in 2006 C$)

Category	Winnipeg-Ross	Albert Street	Victoria - Park
Travel delay costs, $	8,931	6,962	170,719
Vehicle operating cost, $	1,502	4,656	50,010
Vehicle maintenance cost, $	372	1,171	12,188
Cost of accidents, $	1,818	5,885	60,790
Total, $	12,623	18,674	293,707
Cost per day, $/day	6,312	9,337	4,895
Cost $/day Approx.	$6,300	$9,300	$4,900

8.6.1 Travel delay costs

Travel delay costs in Table 15 are calculated using Equation 7. The Winnipeg-Ross Case Study resulted in $8,931 of travel delay costs per two days. The daily social cost of the Winnipeg-Ross detour ($4,466) is higher compared to Victoria-Park ($2,845) mainly due to the lack of detour signs at Winnipeg- Ross intersection. Motorists were selecting a detour through a residential area with lower speed limits but a longer travel distance compared to the detour through an industrial area.

Albert Street project carried out over a weekend resulted in $6,962 per two days. During the first day of the Case Study, road restrictions were introduced: Albert Street was down to one lane in both directions for 12 hours. The travel delay costs ($759) on Saturday occurred mainly due to queuing. On Sunday, Albert Street was closed from 7th Avenue to 2nd Avenue, and a detour through Broad Street was established. A long detour distance (3 km) is a main contributor to high travel delay costs on Sunday ($6,203). However, two road rehabilitation projects were completed during that time.

8.6.2 Vehicle operating and maintenance costs

Vehicle operating and maintenance costs comprise fuel consumption, oil consumption, tire wear, vehicle maintenance, vehicle depreciation, and spare parts costs are illustrated in Table A2.8. The data used for estimation of these costs is based on Ray Barton Associates (2006) and Transport Canada report (CVS, 2000).

Vehicle operating and maintenance costs are three times higher for the Albert Street Case Study compared to the Winnipeg-Ross: $1,874 and $5,827, respectively. These costs come from increased fuel consumption due to queuing and extra distance traveled due to the detour. Road restrictions on Albert Street, as well as longer detour distance, are the main reasons for high vehicle operating and maintenance costs in this Case Study.

8.6.3 Cost of accidents

The estimates of the cost of accidents proposed by Zhang *et al* (2004) were used to calculate cost of accidents. These are:

- Urban/Interurban vehicle: $154.38/1000 km
- Urban/Interurban bus: $482.32/1000 km
- Freight vehicle/Truck: $164.99/1000 km.

These estimates are in 2006 Canadian dollars per 1,000 km traveled. Thus, the accident cost values are sensitive to detour distance. The calculation results obtained, demonstrated that the Albert Street Case Study has the highest cost of accidents per day: $2,943, compare to $909/per day for the Winnipeg-Ross and $1,013/per day for Victoria-Park. However, according to SGI data (SGI, 2006), the Victoria-Park intersection was identified as one of the intersections with the highest accidents rate in the city. Therefore, more information is necessary to develop accidents cost estimates applicable for the City of Regina. Collecting and analyzing information on accidents at work zones in the city is an important area to be included in future research.

Table 15: Summary of external cost components (in 2006 C$)

Case Study	Winnipeg-Ross	Albert Street	Victoria-Park
Noise disturbance cost, $	0.39 (1)	0 (1)	0 (1)
	67 (2)	367 (2)	3,489 (2)
Environmental cost, $	151	655	6,236

(1) Levinson *et al* (1998) – US
(2) INFRAS/IWW (1995) - Europe

Noise disturbance costs are calculated using two different approaches: the U.S. estimates developed by Levinson *et al* (1998) for highways and European estimates proposed by INFRAS/IWW (1995). The results are presented in Table 15. The US method is based on estimation of values and number of homes per linear km within the road, traffic flow, vehicle speed and occupancy, and resulted in very low ($0.39 in case of Winnipeg-Ross) or zero noise disturbance values (Albert Street and Victoria-Park). The European estimates should be applied to Canadian traffic with caution. These values were used in the study only for comparison. More research is necessary to estimate noise disturbance costs values relevant to the urban areas and particularly, to the City of Regina.

The total social costs for the Case Studies are summarized below.

- Winnipeg Street and Ross Avenue intersection: $12,700; $6,400/per day.
- Albert Street: $19,300; $9,700/per day.
- Victoria Avenue and Park Street: $299,900; $5,000/per day.

8.7 Experience from conducting the case studies

It is useful for practitioners at the municipalities and researchers to know the effort required to gather and analyze the data for social costs consideration in the total project costs.

Data collection is usually done during summer months; however, the timeline depends on infrastructure rehabilitation activities schedule in the city. In Regina, municipal infrastructure rehabilitation and construction projects are usually carried out from April until October, mainly due to climatic conditions.

Traffic volumes counts based on 24 hour mechanical count are usually done by the city on an annual basis, and the traffic flow map is prepared. Traffic volumes counts during construction period should be done for specific projects under study. Counts can be carried out mechanically or manually. In case of our study, all counts were done manually. Manual counting at the intersection requires one or two observers depending on the traffic volumes. Counting is done before or after and during the construction period. The measurements are taken every hour from 7 am to 6 pm with an emphasis on peak flow periods. A counting period is five minutes, and the counts are repeated two to three times for every hour. Each project usually takes one week to gather required data: traffic volumes, turning movements, traffic distribution, and passenger count.

The data could be analyzed using MS-Excel software. Calculation procedure development and data analysis takes from three to four months. If the calculation tool is already developed and was used by the practitioner before, the calculation time could be reduced to several weeks.

The working procedure presented below can help practitioners to plan and execute this type of study.

8.7.1 Working procedure

1. Obtain information on municipal infrastructure rehabilitation projects from the city municipality personnel (projects location, duration, start and end dates of the project, type of work to be performed).
2. Check projects' locations (area of the city, type of the street, controlled/uncontrolled intersections, and best position for the observer) and gather statistical traffic flow volumes.
3. Determine selection criteria for the project based on study goals (for example industrial or residential area of the city, type of the street, traffic volumes, etc.).
4. Select 2-4 projects to be studied based on chosen selection criteria (select construction project scheduled to be done simultaneously with caution, since it may require more observers and effort to gather the data).
5. Prepare data collection plan for observers (specify time and frequency of measurements to be taken by the observer).
6. Inform construction personnel about the presence of observers at the construction site.
7. Prepare safety equipment (vest, helmet) and traffic flow recording tools (tally sheets, stopwatch).
8. Perform traffic counts before/after and during the construction period.
9. Analyze collected data in MS-Excel spreadsheet.
10. Document findings in a report.

8.7.2 Experiences

It is not always possible to obtain an exact start date of the infrastructure renovation project from the municipality in advance. The start date of the project depends on number of factors such as weather conditions, availability of resources (equipment, workers), etc. It makes planning and project selection stage difficult, since the practitioner does not always want to select projects that will be executed at the same time, as this has conflicts in time.

Development and application of the methodology for social costs calculation is another tricky part. Methods for social costs calculations are not always applicable to Canadian environment and need to be adjusted. However, if the methodology and calculation procedure has been established once, it requires little effort to update it according to current market conditions (e.g., fuel prices, average wages in the province).

9. Conclusions and Recommendations

A general procedure for user and external cost components classification and quantification was established. The emphasis was made on user delay costs, however, costs of accidents, environmental and noise costs were also considered.

The methodology for user cost components quantification represents a solid procedure that can be used by any Canadian municipality without major adjustments. More work is needed to improve the external cost components (environmental and noise costs) calculation methodology. The methodology applied in this report is mainly based on US and European studies and should be further adjusted to Canadian urban traffic environment.

Case studies of three municipal infrastructure rehabilitation projects carried out by the City of Regina in summer 2006 were used to collect data on social costs. An Excel based social cost calculation tool was developed and used to document and analyze collected data.

Travel delay costs represent a major part of project's social costs. These costs account for up to 70% of all social costs in case of Winnipeg-Ross; 36% and 57% of total social costs of Albert Street and Victoria -Park Street projects, respectively. Effective mitigation strategies should be developed and adopted by municipalities to minimize travel delay costs.

A number of social costs mitigation strategies can now be proposed as a result of this research. These include timing work for off-peak hours such as evenings and weekends; clear and accurate marking of work zone and detours; coordinating with other work in close proximity (e.g., Albert Street project); detours through industrial instead of residential areas.

Other potential areas of future research can include improving understanding of work zone influence on accidents rate; measuring and quantifying noise exposure due to work zone activities in the city; surveying businesses and residents to study impact of work zone on their activities. Additional research can also include measuring noise levels in the city streets before, during and after construction.

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Appendix 1. Tally sheet

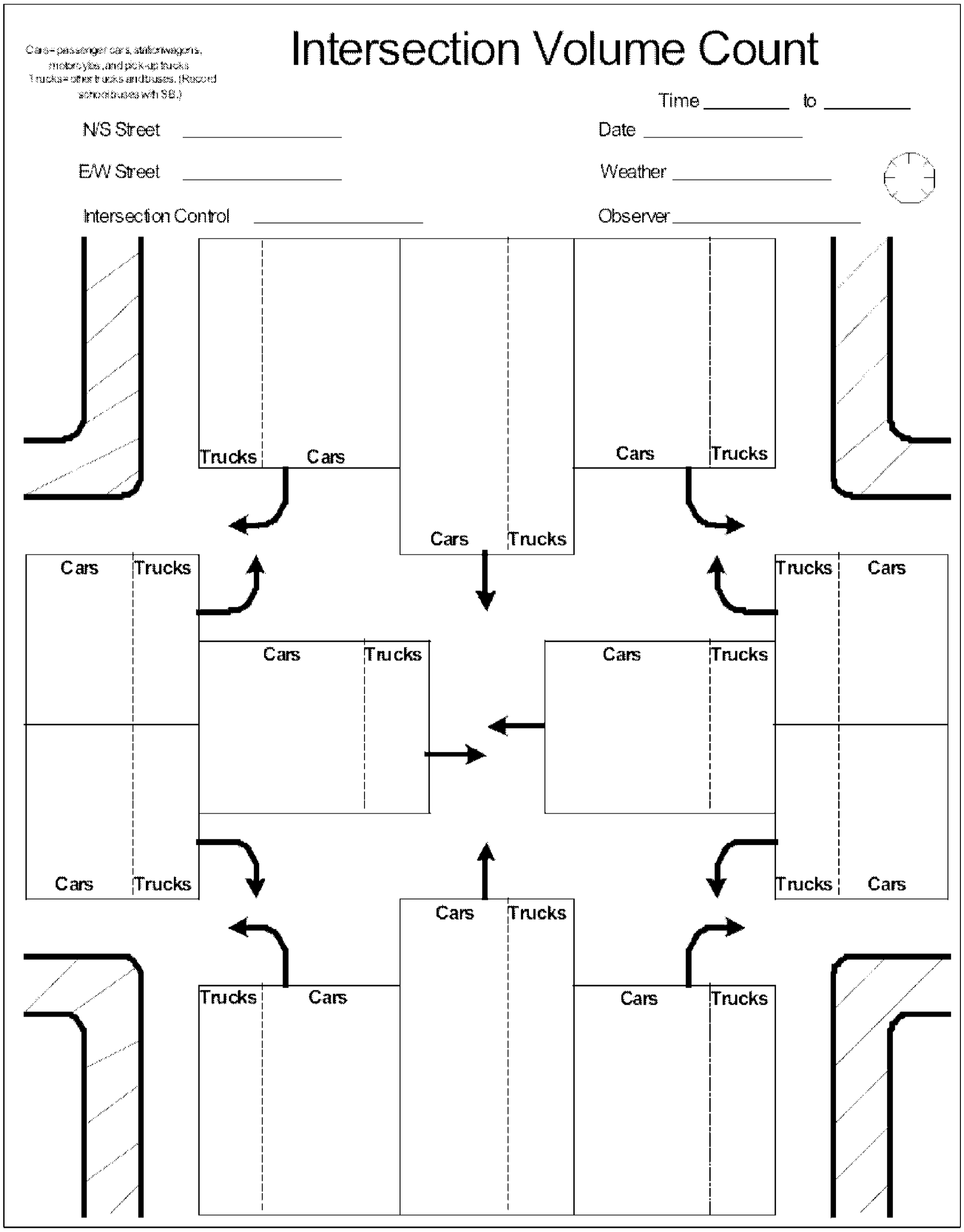

Figure A1.1: Traffic volume count intersection tally sheet

Appendix 2. Vehicle fleet characteristics

Table A2.1: Number of vehicles by weight class, 2000 (CVS, 2000)

Category	Light vehicles	Medium trucks	Heavy trucks	Buses	All vehicles
Number	615.8	44.9	21.5	3.8	686.0
Per capita	602	44	21	3.7	670

Number: Thousands of in-scope vehicles
Per capita: vehicles per 1,000 population.

Table A2.2: Distribution of vehicle activity by body type, 10 provinces, 2000 (CVS, 2000)

	Vehicles		Vehicle-km		Passenger-km		Fuel (Litres)		Ave. distance kms	Persons per vehicle	Fuel (Litres /100km)
	Millions	%	Billions	%	Billions	%	Billions	%	('000s)		
Car	10.05	58.3	161.0	52.0	268.8	53.2	16.3	38.1	16.0	1.67	10.14
Station wagon	0.41	2.4	7.8	2.5	13.8	2.7	0.9	2.1	18.9	1.78	11.49
Van	2.20	12.8	42.7	13.8	85.5	16.9	5.0	11.8	19.4	2.00	11.81
Sport-utility	1.14	6.6	22.1	7.1	36.7	7.3	3.1	7.3	19.4	1.65	14.20
Pickup truck	2.75	15.9	47.0	15.2	67.0	13.3	6.3	14.7	17.1	1.43	13.36
Straight truck	0.35	2.0	7.1	2.3	1.1	0.2	2.5	5.7	20.2	0.16	34.79
Tractor trailer	0.14	0.8	17.1	5.5	0.0	0.0	7.4	17.2	122.4	0.00	43.14
Bus	0.07	0.4	1.8	0.6	29.1	5.8	0.6	1.4	24.2	16.08	32.46
Other	0.13	0.7	3.1	1.0	2.9	0.6	0.7	1.6	24.4	0.92	22.12
Total	17.25	100	309.8	100	504.9	100	42.8	100	18.0	1.63	13.82

Table A2.3: Vehicle characteristics by age of vehicle, 10 provinces, 2000 (CVS, 2000)

Category Age	Vehicle count ('000s)	%	Vehicle-km Billions	Ave. Dist. Driven ('000s)	Fuel Efficiency (L/100km)
Light Vehicles					
Two years or less	3,514	20.9	69.71	19.8	10.7
Three to five	3,018	18.0	64.43	21.3	10.8
Six to nine	4,172	24.9	72.01	17.3	11.3
Ten to thirteen	3,735	22.3	51.26	13.7	12.3
Fourteen or more	2,346	14.0	24.01	10.2	12.0
Total	16,784	100.0	281.42	16.8	11.3
Medium trucks					
Two years or less	66	17.1	1.69	25.5	21.0
Three to five	56	14.6	1.51	26.9	24.2
Six to nine	58	15.1	1.16	19.8	25.8
Ten to thirteen	64	16.5	0.95	14.8	29.0
Fourteen or more	142	36.7	0.60	4.2	37.8
Total	387	100.0	5.91	15.2	25.8
Heavy trucks					
Two years or less	80	30.0	10.70	133.3	42.7
Three to five	51	19.2	5.49	106.7	42.5
Six to nine	38	14.1	1.94	51.3	46.8
Ten to thirteen	41	15.4	1.72	41.9	47.3
Fourteen or more	57	21.3	0.71	12.5	45.6
Total	268	100.0	20.57	76.8	43.5
Buses					
Two years or less	15	19.6	0.42	28.2	29.1
Three to five	14	17.9	0.51	37.1	28.1
Six to nine	18	23.5	0.45	25.1	28.8
Ten to thirteen	17	22.6	0.28	15.9	37.6
Fourteen or more	13	16.5	0.22	17.0	41.2
Total	77	100.0	1.88	24.5	31.4

Table A2.4: Vehicle use by day of the week, 10 provinces, 2000 (CVS, 2000)

	Light vehicle		Medium truck		Heavy truck		Buses		Total	
	Billion	%	Billion	%	Billion	%	Billion	%	Billion	%
Monday	39.3	13.9	0.9	15.9	3.2	15.4	0.3	16.4	43.7	14.1
Tuesday	40.1	14.3	1.1	19.3	4.0	19.3	0.3	17.8	45.5	14.7
Wednesday	39.6	14.1	1.1	18.3	3.9	18.8	0.4	18.9	44.9	14.5
Thursday	43.3	15.4	1.1	19.0	3.7	18.2	0.3	18.5	48.5	15.7
Friday	45.3	16.1	1.0	16.7	3.2	15.6	0.3	17.6	49.8	16.1
Saturday	38.7	13.7	0.4	6.2	1.3	6.5	0.1	5.5	40.5	13.1
Sunday	35.3	12.5	0.3	4.6	1.3	6.2	0.1	5.2	36.9	11.9
Canada	281.4	100.0	5.9	100.0	20.6	100.0	1.9	100.0	309.8	100.0

Table A2.5: Vehicle use by time of day, 10 provinces, 2000 (CVS, 2000)

	Light vehicle		Medium truck		Heavy truck		Buses		Total	
	(Bill.)	%	(Bill.)	%	(Bill.)	%	(Bill.)	%	(Bill.)	%
0-5:59	9.2	3.3	0.3	4.6	2.3	11.1	0.1	3.9	11.8	3.8
6:00-11:59	87.4	31.0	2.5	42.7	7.3	35.5	0.8	43.1	98.0	31.6
12:00-17:59	127.7	45.4	2.6	43.7	7.4	36.1	0.8	42.6	138.5	44.7
18:00-23:59	57.2	20.3	0.5	9.0	3.6	17.3	0.2	10.4	61.5	19.8
Total	281.4	100.0	5.9	100.0	20.6	100.0	1.9	100.0	309.8	100.0

Table A2.6: Light vehicle activity by trip purpose, 2000 (CVS, 2000)

	Vehicle-km		Passenger-km		Persons/
To or from	Billion	%	Billion	%	vehicle
Work/school	61.0	21.7	76.9	16.2	1.26
Shopping/errands	73.1	26.0	126.8	26.7	1.73
Recreational/social	54.9	19.5	111.0	23.4	2.02
Other destination	59.8	21.3	120.6	25.4	2.02
Pick-up/deliver goods	11.3	4.0	13.0	2.7	1.15
Service call	9.1	3.2	10.9	2.3	1.19
Other work purpose	12.1	4.3	15.8	3.3	1.30
Total	281.4	100.0	475.1	100.0	1.69

Note: the category "To go home" has been allocated to the other destinations in proportion to the other destinations' percentage of vehicle and passenger-km to better represent trip purpose.

Table A2.7: Truck vehicle-km by trip purpose, 10 provinces, 2000 (CSV, 2000)

	Medium trucks		Heavy trucks	
	Billion	%	Billion	%
To/from a service call	0.7	11.6	0.7	3.6
Carrying goods/equipment	3.0	50.0	15.5	75.2
Empty	0.3	5.8	2.8	13.6
Other work purpose	0.3	5.5	0.3	1.3
Non-work purpose	1.6	27.1	1.3	6.3
Total	5.9	100.0	20.6	100.0

Table A2.8: Average non-fuel operating and maintenance cost for paved roads, $/vehicle-km (Ray Barton Associates, 2006)

Vehicle class	Vintage	Cost (2006 C$)
Two-seater	0-2 years	0.025
	3-5 years	0.028
	6-8 years	0.032
	9-11 years	0.034
	12-14 years	0.034
	15+ years	0.035
Sub-compact	0-2 years	0.023
	3-5 years	0.028
	6-8 years	0.032
	9-11 years	0.033
	12-14 years	0.034
	15+ years	0.036
Compact	0-2 years	0.024
	3-5 years	0.029
	6-8 years	0.033
	9-11 years	0.033
	12-14 years	0.034
	15+ years	0.034
Midsize	0-2 years	0.024
	3-5 years	0.031
	6-8 years	0.033
	9-11 years	0.033
	12-14 years	0.035
	15+ years	0.035
Full-size	0-2 years	0.024
	3-5 years	0.031
	6-8 years	0.034
	9-11 years	0.035
	12-14 years	0.037
	15+ years	0.037

Vehicle class	Vintage	Cost (2006 C$)
Station wagon	0-2 years	0.023
	3-5 years	0.031
	6-8 years	0.036
	9-11 years	0.037
	12-14 years	0.037
	15+ years	0.038
Minivan	0-2 years	0.026
	3-5 years	0.032
	6-8 years	0.035
	9-11 years	0.037
	12-14 years	0.038
	15+ years	0.041
Passenger vans	0-2 years	0.025
	3-5 years	0.031
	6-8 years	0.034
	9-11 years	0.035
	12-14 years	0.036
	15+ years	0.038
Cargo vans	0-2 years	0.025
	3-5 years	0.032
	6-8 years	0.035
	9-11 years	0.035
	12-14 years	0.038
	15+ years	0.037
Special PV	0-2 years	0.025
	3-5 years	0.031
	6-8 years	0.034
	9-11 years	0.037
	12-14 years	0.036
	15+ years	0.041
Pickups	0-2 years	0.024
	3-5 years	0.031
	6-8 years	0.034
	9-11 years	0.036
	12-14 years	0.037
	15+ years	0.038