A FRAMEWORK FOR ESTIMATING THE TOTAL COST OF BURIED MUNICIPAL INFRASTRUCTURE RENEWAL PROJECTS

A Case Study in Montreal

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Abstract

As Canadian municipalities venture into rehabilitation and replacement of extensively deteriorated underground water distribution and sewerage assets, municipal decision-makers, engineering and construction research bodies and the public all feel that this type of construction work can have adverse effects on the society. This thesis reviews these negative impacts which include, but are not limited to damage of nearby buried and above-ground infrastructure, disruption of traffic, loss of accessibility to businesses, health hazards to workers and the public, and finally environmental pollution and damage. There is presently no accepted practice-oriented method for the evaluation of these social, economic and environmental impacts. This research project proposes a framework to enable municipalities, utility agencies and contracting firms to quantitatively estimate the total cost to society of buried municipal infrastructure renewal projects using open trench, or trenchless construction methods. The total cost of a project is the sum of all the direct and indirect costs borne by the client organization, and external costs borne by society. The external costs can be separated into three components: social, economic and environmental costs. Use of the proposed methodology in a case study of a water main rehabilitation project using trenchless technologies in the city of Montreal, Canada, revealed that the indirect and external costs of the project were approximately 25 percent of its direct costs. The most significant cost components were those attributable to increased vehicular travel time and lost business income.

Résumé

Les municipalités canadiennes s'apprêtent à implanter de grands programmes de réhabilitions et de remplacements des systèmes d'aqueducs et égouts gravement détériorés. Les ingénieurs, entrepreneurs, centres de recherches en génie civil, ainsi que le public affirment que ces travaux ont des impacts négatifs sur la société. Ce mémoire fait état de ces impacts qui incluent, entre autres, l'endommagement des infrastructures avoisinantes, le dérangement de la circulation, la perte d'accessibilité aux entreprises, les risques en santé chez le public et les ouvriers, mais aussi la pollution et l'endommagement environnemental. Présentement, en pratique, il n'y a aucune méthode pour évaluer ces impacts sociaux, économiques et environnementaux. Ce projet de recherche propose aux municipalités, aux fournisseurs de systèmes public et aux entrepreneurs un procédé pour quantifier le coût total à la société, attribuable à des projets de renouvellement des infrastructures-souterraines par les méthodes de tranchée ouverte ou sans-tranchée. Le coût total d'un projet est la somme des coûts directement et indirectement assumés par le client, ainsi que les coûts externes assumés par les membres de la société. Les coûts externes peuvent être séparés en trois catégories : les coûts sociaux, économiques et environnementaux. Dans le cadre de ce projet, une évaluation du coût total d'un projet de réhabilitation d'aqueduc par technique sans-tranchée à Montréal a conclu que les coûts indirects et externes montaient à 25 pour cent des coûts directs considérés dans le contrat. Les délais aux usagers routiers et la réduction des chiffres d'affaires des entreprises étaient attribuables aux deux plus grands coûts sociaux, économiques et environnementaux.

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1 Introduction

Managers of North America's buried water and wastewater infrastructure are now facing the challenge of adapting to modern needs. The American Water Works Association (2001) has labelled the current state of infrastructure the dawn of the replacement era. Much investment will be needed to replace and rehabilitate the nation's municipal systems (water and wastewater) which were installed, in some cases, over one hundred years ago and are no longer adequate to service society. This aging infrastructure is also burdened with higher demands as communities and business districts grow.

While the direct costs of buried municipal infrastructure renewal projects (BMIRP) are well understood by municipal practitioners, the indirect and external costs of these construction projects are currently not quantitatively considered in project evaluation, mainly because they are not well understood. Although there is no generally accepted quantitative method for the evaluation of these social, economic and environmental impacts associated with buried pipe renewal, the strong perception of municipal decision-makers, engineering and construction research bodies is that these impacts should be minimised due to their adverse effects. These negative impacts include, but are not limited to damage to nearby buried and above-ground infrastructure, disruption of traffic, loss of accessibility to businesses, health hazards to the public and finally environmental pollution and damage.

Currently, these impacts are only considered either qualitatively by municipal decision-makers based on prior experience, or quantitatively through basic preliminary studies which are limited to evaluation of a few of the "actual" impacts that are attributable to the project. As society strives to achieve social, economic and environmental sustainability, it is essential that the indirect and external costs be considered in an effort to help minimize the total social burden of buried municipal infrastructure renewal projects.

1.1 Scope of Study

The goal of this study is to enable municipalities, utility agencies and contracting firms to quantitatively assess the indirect and external costs of buried municipal water and wastewater infrastructure renewal projects with minimal additional time and resource requirements.

The objectives of this research project are:

1. To review the existing literature on valuation of social, economic and environmental impacts associated with buried municipal infrastructure renewal projects.
2. To provide the reader with a detailed understanding of total cost and all of its components.
3. To propose valuating techniques associated with these cost components through refinement of existing valuation methods and development of new methods, where necessary.
4. To develop a total cost evaluation framework incorporating social, environmental and economic costs into current project evaluation practices.
5. To apply this methodology to a case study in the city of Montreal.

2 Background Information

2.1 The Need to Rethink Current Construction Principles

Traditionally, open trench excavation has been adopted as the unique solution to renew buried infrastructure systems. When installation of North America's water and wastewater network took place over a century ago, the use of this construction technique was generally more acceptable because buried pipes were located beneath unpaved ground, construction materials were plentiful, labour was readily available, and the environmental impacts of construction were less known. The open trench excavation method used at that time is still used by current practitioners. In time, modifications have been made such as mechanization of the excavation process and improvement of pipe material quality, but the underlying principles remain the same.

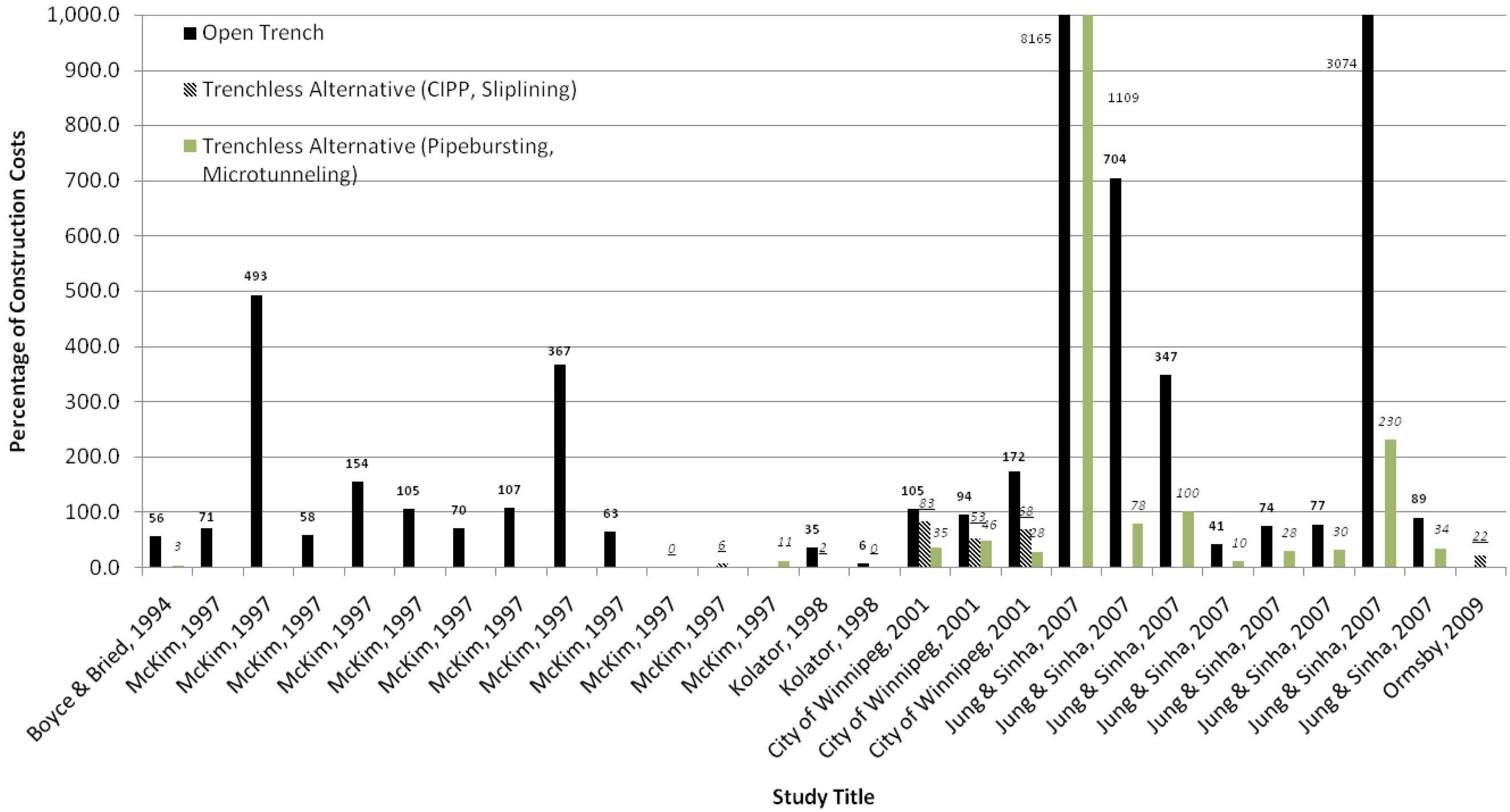
Presently, this practice is no longer acceptable as the only buried pipe installation and renewal alternative as it causes significant traffic disruption, deleterious environmental effects, health and safety hazards, premature deterioration of paved surfaces, and major risks of damage to adjacent infrastructure. Traffic densities, infrastructure renewal needs and the awareness of trenchless technologies are all increasing in North America (Tighe, Knight, Papoutsis, Rodriguez, and Walker, 2002). It is clear that various construction alternatives must be evaluated based on their ability to satisfy the required performance level while minimizing the total cost to the society which should include not only the contract costs incurred immediately by the promoting municipality, but also the indirect costs borne by the client organization and external social, economic and environmental costs borne by the public.

Managers, designers and builders of municipal infrastructure must apply the principles of sustainable development to satisfy the present renewal needs without compromising the social, environmental and economic qualities of the future. Adopting sustainable practices by exploiting resources to the fullest, wisely directing investment and accomplishing institutional change will harmoniously enhance both the current and future potential to meet current and future human needs (Mirza, 2006).

Despite the fact that indirect and external costs are not considered explicitly in contract costs, they can be considerable and comparable or even higher than the contract value.

In the UK, attempts have been made to quantify the total cost of utility construction in terms of traffic delays and compare them with direct construction costs. The results range from 0% to 493% with a mean ratio of 30%. This translates to a $3.4 billion non-recoverable cost to society (Institute of Civil Infrastructure Systems and Urban Utility Center, 1999). Meanwhile, recent studies in Pennsylvania by Jung and Sinha (2007) have shown that estimates of costs related to traffic impacts alone can amount to more than 80 times the contract cost of a project on a busy roadway. Analysis of the relationship between the direct costs and the indirect and external costs found in the existing literature is presented graphically in Figure 1.

Figure 1. Indirect and external cost comparison between open trench and trenchless alternatives (presented as a percentage of direct costs)



2.2 The State of Canada's Buried Water and Wastewater Infrastructure

Most of Canada's infrastructure was installed between the 1950s and 1970s in response to the "babyboom", rapid urbanization and high immigration rates (Mirza and Sipos, 2008). Investment in this new infrastructure was high in those years, but maintenance was deferred intermittently over the past 30 years and deterioration of these assets is advancing at an accelerating rate (Mirza, 2007). The 2003 Technology Roadmap (CSCE, CCPE, CPWA and National Research Council Canada, 2003), a national consensus on the state of Canada's infrastructure systems, has claimed that the country has exhausted 79 percent of its public infrastructure's useful life. The cost of bringing this aged municipal infrastructure only up to par has been estimated at 123 billion dollars (Mirza, 2007).

Water and wastewater systems comprise approximately 30 percent of Canada's infrastructure stock (Mirza, 2007). This includes water treatment, supply and distribution systems and sanitary and storm water sewerage and their associated treatment facilities. In 2007, Statistics Canada estimated that sanitary and storm sewers had passed 53 percent of their useful life nationwide while water distribution systems had passed the 40 percent mark (Gagnon, Gaudreault, and Overton, 2008). The cost required to upgrade and maintain existing infrastructure is estimated as 31 billion dollars, while meeting new installation needs would require an additional 56.6 billion dollars (Mirza, 2007).

Canadian water distributions pipes are particularly subject to failure. In the winter season the combined effects of internal pressures, overburden loads imposed by surcharged truck traffic and the environmental loads caused by corrosion and frost-loading trigger catastrophic water distribution pipe breaks which routinely capture media attention across the nation. Water leaks resembling urban geysers, sinkholes in the roadway, evacuation of buildings, and flooding of roadways and basements are some of the impacts commonly reported in the news.

2.2.1 A Montreal Profile

In Montreal, the water distribution network includes over 5000km of buried pipe (Ville de Montréal, 2008). The City of Montreal estimates that one third of the network is in need of replacement, seeing as some network pipes were installed in 1900 and others are made of wood (Radio-Canada, 2009). More than 42 percent of the network pipes was built in the period between the 1950s and the 1970s which is characterized presently by its poor quality of construction materials (Croteau, 2009). Approximately 40 percent of the potable water that is distributed through Montreal pipes is lost through leaks in the system (Bueckert, 2004) – twice that of the national average (Environment Canada, 2004).

2.3 Buried Municipal Infrastructure Renewal Methods

2.3.1 Open Trench Construction

Open trench construction (also known as conventional trenching, open cut, cut and cover, and dig and replace) is a method in which access is gained by excavation from ground level to the required level underground for the installation, maintenance or inspection of a pipe, conduit or cable. Excavation in urban areas usually requires careful manoeuvring around existing buried utilities. Backhoes are typically used for bulk excavation and shovels are used manually by workers to expose and dig around fragile utilities situated within the construction area. Pipe removal and installation operations are undertaken; the excavation is then backfilled, and the surface restored to the original condition (NASTT, 2007). Typical steps involved in this operation are outlined by Parker (2007) and include the following:

- Cut through surface and provide side slopes (usually 2:1) and bench, wall shoring or worker shielding
- Excavate and remove the existing pipe with attention to special handling procedure and disposal regulations
- Provide proper pipe bedding and compaction
- Install warning tape and or identification wire where applicable
- Backfill the trench providing adequate cover
- Restore the surface conditions
- Perform the required testing prior to commissioning of the pipe

Figure 2 depicts a cross-section of typical construction elements associated with open trench excavation, while Figure 3 shows some of the Quebec safety distance regulations.

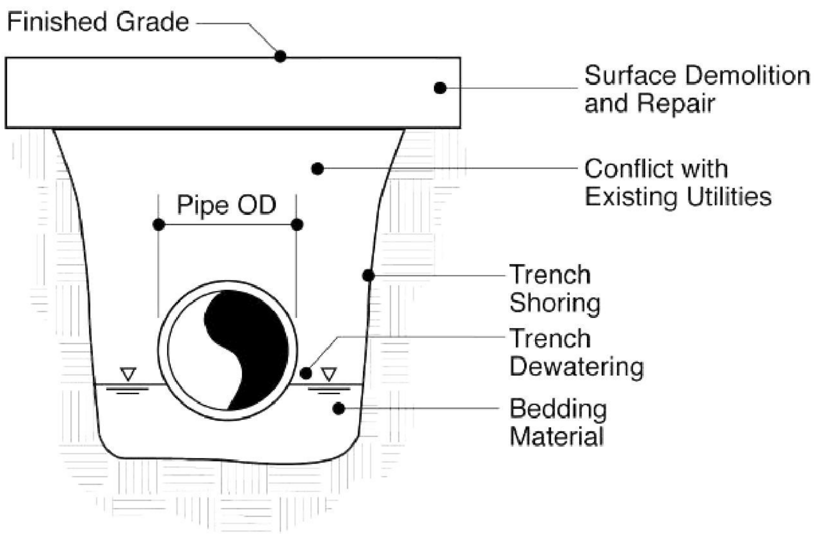


Figure 2. Typical open cut elements (Harbuck, 2000)

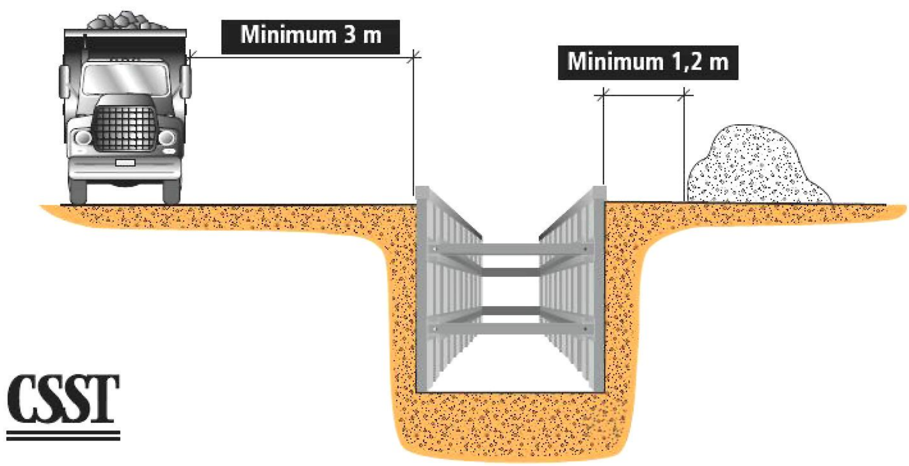


Figure 3. Illustration of safety regulations for open trench (CSST, 2006)

2.3.2 Rehabilitation through Trenchless Technology

Trenchless technology is a family of non-intrusive construction methods, materials and equipment, used for the installation, replacement or rehabilitation of underground infrastructure, while minimizing excavation and disruption at the ground surface (NASTT, 2007).

Trenchless installation techniques include horizontal directional drilling, microtunneling, pipe jacking, auger boring and pipe bursting while trenchless rehabilitation techniques include several forms of pipe lining. A table providing a comprehensive description of each of these techniques as well as cost estimates, their applications and useful references is located in Appendix A.

Trenchless technologies are used frequently in densely populated and built-up cities of Europe and Asia. The city of Tokyo has passed legislation limiting the time allowed to occupy a road lane for utility renewal to such an extent that trenchless technologies are the only feasible method of construction (Tighe et al., 1999). However, it was not until the pressing need in North America to rehabilitate deteriorating water, sewer and gas pipelines in the 1970's that fostered rapid development of trenchless technologies in Canada and the United Sates (Ariaratnam, Leueke, and Allouche, 1999). This growth continued into the 1980's as national efforts were made to provide utilities to all communities. Trenchless technologies have experienced considerable growth in the past decades. According to a survey conducted in 1999 (Ariaratnam et al., 1999), the use of trenchless technology for new construction in Canadian municipalities had increased 180% in the preceding five years. Similarly, the use of trenchless technologies for rehabilitation and repair of pipes had grown by 270% in the same time period.

2.3.3 Comparison of Trenchless and Open Trench Methods

Open trench replacement has been considered the conventional pipe renewal method in North America. The construction industry considers open trench construction to be "tried, tested and true" and its use still dominates that of trenchless technologies. However, open trench excavation has several disadvantages, which include health and safety concerns for workers, surface disturbance, disruption to traffic and reduction of pavement service life (Abraham, Baik, and Gokhale, 2002).

It has now become widely accepted that trenchless technologies can significantly reduce the above negative impacts of open trench replacement techniques (Sterling, 1997). Furthermore, these methods reduce the environmental impacts of buried municipal infrastructure renewal projects (BMIRP) through considerably reduced needs for handling and treatment of excavated soil (Abraham et al., 2002). However, the novelty of trenchless technologies has resulted in certain failures and its application is not always justified over the use of the open trench method. Heaving or subsidence of pavement at the surface has occurred in pipebursting and horizontal-directional drilling which affect in-situ geotechnical conditions. Damage to nearby utilities may occur when pipebursting or installing new pipe in congested ground; in this manner, utility strikes have even caused fatalities (Abraham et al., 2002).

It has been shown that trenchless technologies have the potential to reduce costs, mainly because excavation volumes can be greatly reduced through these "low-dig" or "no-dig" methods. Excavation in congested urban areas is especially costly since contractors must dig carefully to reach the desired depth of the utility line and manoeuvre around other buried utilities. The costs of restoration of surface infrastructure, such as sidewalks and pavement, are additional expenses that are associated with extensive excavation (Ariaratnam et al., 1999).

Based on 174 data records in Canada and the United States collected by Trenchless Technology Magazine and presented by Zhao and Rajani (2002), for projects including pipes of diameter of 940mm and less, the average contract cost of trenchless techniques (with the exception of microtunneling) is less than that of open trench practices. The trenchless techniques considered in this study include microtunneling, tunnelling, cured-in-place pipe (CIPP) lining, horizontal-directional drilling (HDD), sliplining, pipe bursting and pipe jacking. However, the average contract cost of construction and rehabilitation of buried pipe with diameters equal to and exceeding 960mm is larger for trenchless techniques than for open-cut practices. Microtunneling was found to be the most costly technique. The costs considered were the total contract costs. While the authors did not specify whether these included indirect and external costs, it is most likely that the data records included only direct costs.

The direct costs of open trench construction tend to increase with depth of cover to pipe, whereas trenchless installation and rehabilitation methods tend to be relatively insensitive to this parameter (McKim, 1997). This relationship is shown in Figure 4.

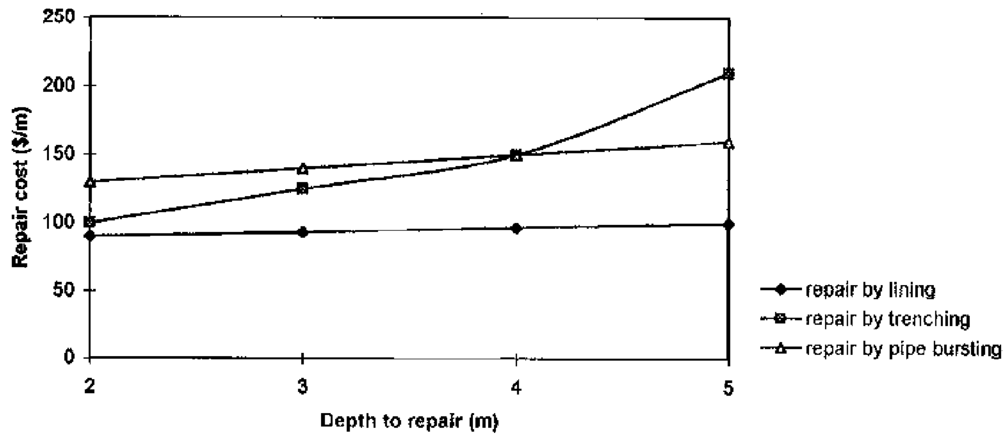


Figure 4. Depth to construction cost relationship for open trench and trenchless methods (McKim, 1997)

Emergency repairs of sewers or water mains cause direct costs to rise higher than the norm, depending on many case-specific factors, such as location and extent of failure, and depth and size of pipe. Zhao and Rajani (2002) reported emergency CIPP repair costs to be 3.6 times the average unit cost of normal rehabilitation. Indirect and external costs can also be greatly increased during pipe failure and repair events. Nankivil and Nichols (1997) reported that depending on the location of the pipe failure, the ratio of indirect and external costs to direct costs can range from a ratio of 1:1 to 4:1.

2.4 Definitions

Many definitions of the term "social cost" have been proposed by researchers throughout the years; however, consensus has yet to be reached. This section will identify and explain some of the key proposed definitions found in the literature. While these definitions will not be adopted for use in this thesis, it is a useful exercise to examine them in order to gain a better understanding of nomenclature discrepancies noticeable among available studies on the social, economic and environmental impacts of buried municipal infrastructure renewal projects.

2.4.1 Social Cost: A Notion in Need of Definition

Whereas the notions of social costs and benefits are relatively new to civil engineering, they are well studied topics in economics, with research dating back over a century and a half (Button, 1993). Economists developed social costs and benefits for use in public policy analysis and generally accept social costs to be defined as follows (Button, 1993):

“Social costs are the overall impact of an economic activity on the welfare of society. Social costs are the sum of private costs arising from the activity and any externalities.” (The Economist Newspaper Limited, 2009)

This definition implies that all costs relating to an activity are encompassed by the term “social costs”, whether borne by the member participating in, or initiating the activity, or borne by third parties. This definition implies that “social cost” is synonymous with total cost. Furthermore, the definition divides social costs into private costs which are internalised by the initiator and participants, and external costs which are not considered by the market, but are usually borne by a third-party not involved in the decision.

A study of the existing literature has revealed that, particularly in the area of buried municipal infrastructure renewal projects, many definitions of social costs have been proposed over the past 12 years (Allouche, Ariaratnam, and AbouRizk, 2000; Boyce and Bried, 1998; International Society for Trenchless Technology, 2009; McKim, 1997; Rahman, Vanier, and Newton, 2005; Read and Vickridge, 1997). For instance some researchers (Allouche et al., 2000; Jones, 1999) have considered social costs to be only those incurred by third parties not engaged in the contractual agreement, such as the environmental loss associated with air pollution, noise, vibration, the loss of amenity and the disruption to commercial and private traffic together with increased level of traffic accidents. Other costs accrued during the lifecycle of a project are termed either direct or indirect costs to the municipality. Thus, the **total cost** of a project would be the sum of direct, indirect and social costs.

Gilchrist and Allouche (2005) have built on this notion and have further separated the social costs into four categories as shown in Figure 5, based on the area of impact, such as traffic, economic activities, pollution and ecological/social/health-related impacts.

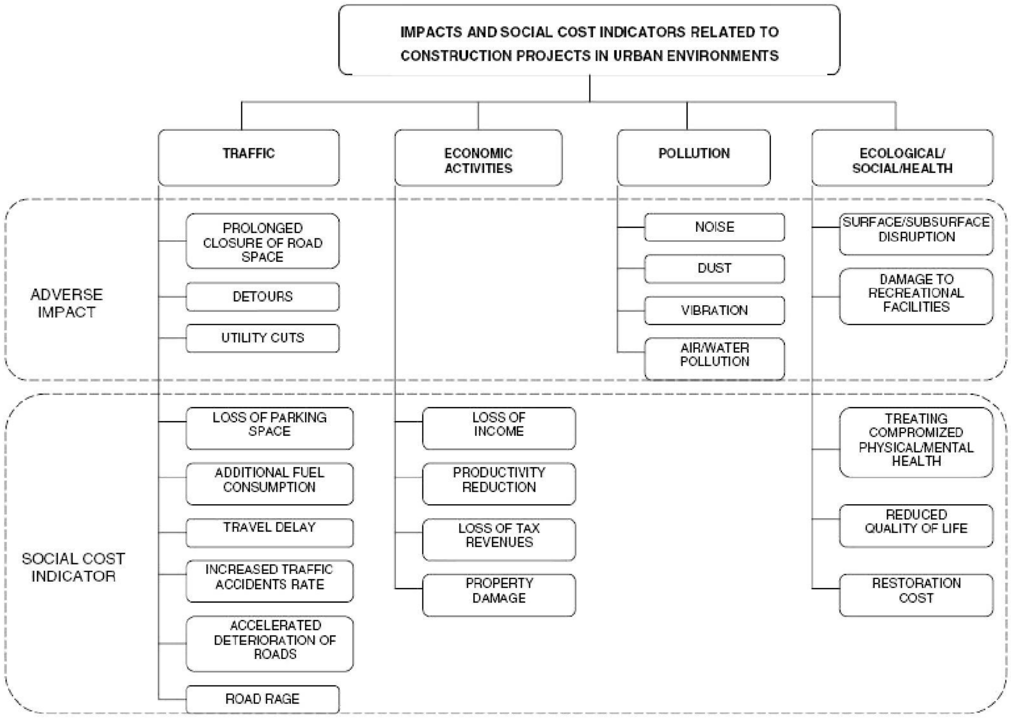


Figure 5. Social impacts and cost indicators according to Gilchrist and Allouche (2005)

Meanwhile, other researchers (Manuilova, Dormuth, and Vanier, 2008; McKim and Kathula, 1999; Peters, 1984; Rahman et al., 2005) accept the economic definition and consider all project costs to be encompassed in the social costs. Therefore “social cost” is synonymous with “total cost”. Research by the National Research Council Canada (Manuilova et al., 2008; Rahman et al., 2005) broke down the all encompassing social costs into three categories: direct, indirect and intangible costs which were named Category I, II and III, respectively. Social costs are categorized based on the entity impacted, and the time frame during which the cost was incurred. This breakdown is shown in Figure 6. This understanding of social costs is more consistent with the definition in the economic world described earlier which considers “social cost” to be the total cost to society. However, this leads to confusion of the terms “social cost” and “total cost”.

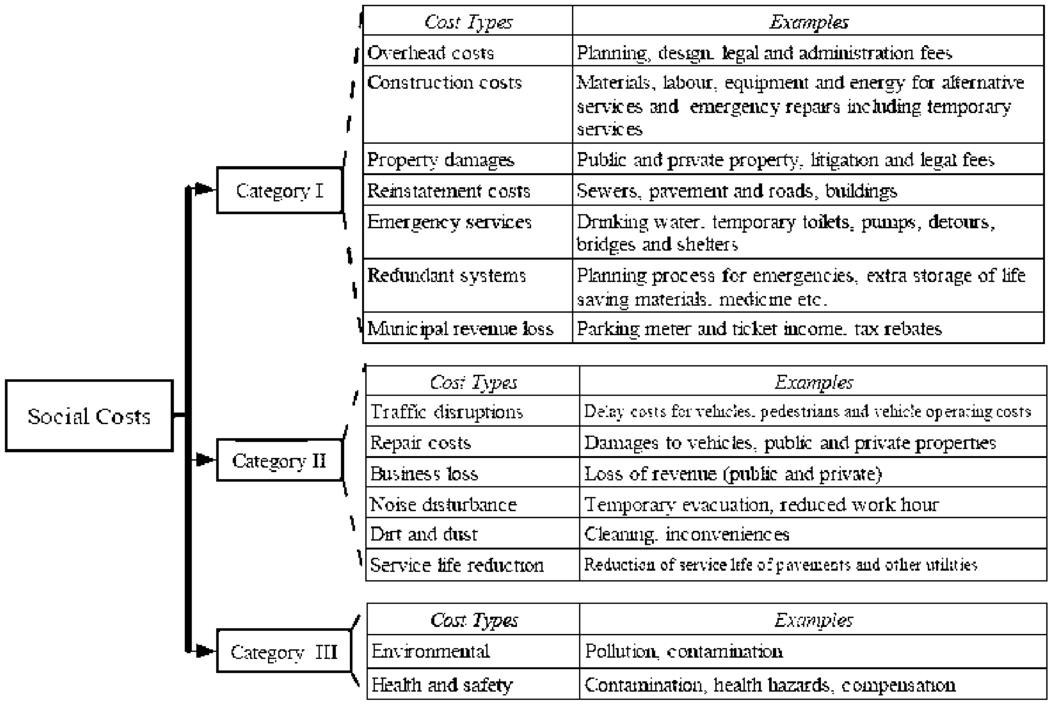


Figure 6. Social cost categories according to Rahman, Newton and Vanier (2005)

Also, the lack of a proper definition for the terms social cost, indirect cost and external cost has often resulted in their interchangeable use in the existing literature. Clear definition of all costs is crucial for further development in this field of study.

2.4.2 Total Cost Defined: The Sum of Direct, Indirect and External Costs

The total cost of a buried municipal infrastructure renewal project will be defined by a holistic principle considering the direct, indirect and external costs associated with the project and recognizing its impact on social, economic and environmental sustainability.

Total cost is the sum of all direct and indirect costs borne by the client organization, and external costs borne by society. Specifically, in the context of municipal infrastructure projects, total cost is the entire value of all the money, time, materials, utilities, lost opportunities and damages resulting from project initiation and implementation regardless of the bearer of the costs. The total cost is separated into three components: direct costs, indirect costs, and external costs as shown in Equation 1.

$$\textit{Total Cost} = \textit{Direct Costs} + \textit{Indirect Cost} + \textit{External Costs} \tag{1}$$

Direct costs are the project specific costs of conception, development and implementation that are borne by the client organization and which are normally considered in the contract.

> Examples: Overhead, construction costs (materials, equipment and labour), restoration, traffic control, taxes, insurance, emergency and temporary services, contingency.

Indirect costs are the costs that are borne by the client organization that normally accrue during or after construction as a result of extraneous factors and actions performed in the project.

> Examples: Pavement service life reduction, buried utility damage, unplanned property damage, loss of parking metre and ticketing revenue, loss of municipal tax revenue

External costs are the sum of all social, environmental and economic costs, market-priced and non-market-priced, that accrue to third parties at any time as a result of actions promoted by the client organization.

> Examples: Increased travel time, increased vehicle operating costs and collision rates; obstruction to emergency vehicles; lost business income and property value; accidental injury and death; air pollution and greenhouse gas emissions; water and ground contamination; loss of amenity and dust and dirt generation

A detailed list of total cost components associated with BMIRPs is presented in Table 1.

Table 1. Total cost components of a municipal infrastructure renewal project

	ID
Direct Costs (DC)	
Project conception, development and implementation costs (Overhead, construction, restoration, emergency and temporary services, traffic control, contingency, taxes and insurance)	-
Indirect Costs (IC)	
Pavement damage due to excavation	PDE
Pavement damage on alternate routes due to increased traffic	PDT
Adjacent buried utilities damage	BUD
Lost parking ticket revenue	PTR
Lost parking meter revenue	PMR
Compensation and tax rebates	CTR
External Costs (EC)	
Social Costs	
Increased vehicular travel time	VTT
Increased vehicle operating costs	VOC
Increased pedestrian travel time	PTT
Increased collision rate	ICR
Obstruction to emergency vehicles	OEV
Accidental injury and death	AID
Property damage	PPD
Water and wastewater service interruption	WSI
Psychological and physical ailments	PPA
Economic Costs	
Lost business income	LBI
Lost property value due to noise	LPV
Environmental Costs	
Air pollutant and greenhouse gas emissions	APE
Environmental damage and contamination	EDC
Dust and dirt pollution	DDP
Damage and lost amenity of recreational facilities	LOA
Total Cost (TC)	

2.5 Literature Review of the Total Cost Associated with Buried Municipal Infrastructure Renewal Projects

The transportation industry and the energy sectors have attempted to estimate the total cost of vehicle usage and of energy production, respectively; however, there exists no widely accepted method to quantify the many economic, social and environmental impacts of municipal renewal projects. A review of the existing literature shows that research in this area is limited to a few studies which focus only on several of the many impacts associated with buried municipal infrastructure renewal projects. Table 2 shows the focus areas of the most notable studies in this field in comparison with the topics covered in this thesis. From this table, the potential significance of this thesis to the advancement of knowledge in this subject area is made evident.

A recent escalating interest in the problem of social impacts of construction work, however, has fostered research in this area to understand better this topic and, ultimately, to mitigate these negative impacts. A summary including the working methods and findings of the most notable studies in this field are presented in the following sections.

Table 2. Total cost components of buried municipal infrastructure renewal project case studies

	Identification Code	Boyce and Bried (1994)	McKim (1997)	Kolator (1998)	Tighe et al. (1999)	Grondin (2004)	Gilchrist and Allouche (2005)	Rahman et al. (2005)	Veillette (2007)	Jung and Sinha (2007)	Ormsby (2009)
Direct Costs											
General	-	■	■	■		■	■	■		■	■
Indirect Costs											
Pavement damage due to excavation	PDE	■		■			□	■		□	■
Pavement damage on alternate routes due to increased traffic	PDT						□	■			■
Adjacent buried utilities damage	BUD									□	■
Lost parking ticket revenue	PTR	■	■				□	■			■
Lost parking meter revenue	PMR	■	■	■			□	■			■
Compensation and tax rebates	CTR	□					□			□	■
Social Costs											
Increased vehicular travel time	VTT	■	■	■	■	■	■	■	■	■	■
Increased vehicle operating costs	VOC	■		■		■	□	■	■		■
Increased pedestrian travel time	PTT	■	■					□		□	■
Increased collision rate	ICR						□			□	■
Obstruction to emergency vehicles	OEV										■
Accidental injury and death	AID	■					□	□		□	■
Property damage	PPD						□	□			■
Water and waster service interruption	WSI										■
Psychological and physical ailments	PPA	□	■	■			■	■			■
Economic Costs											
Lost business income	LBI	□		■			□	□		■	■
Lost property value due to noise	LPV						■			■	■
Environmental Costs											
Air pollutant and greenhouse gas emissions	AP/GHG						□	□	■	□	■
Environmental damage and contamination	EDC						□	□		□	■
Dust and dirt pollution	DDP	■		■			□	■			■
Damage and lost amenity of recreational facilities	LOA						□			□	■

where ■ = studied in a quantitative manner, and □ = studied in a qualitative manner

2.5.1 Boyce and Bried (1994) – Benefit-Cost Analysis of Microtunneling in an Urban Area

Boyce and Bried (1994) compared the direct and indirect costs associated with trenching versus trenchless installation of a storm drain in a heavy commercial area of Oakland, California. The project consisted of replacing and realigning a deteriorated brick lined culvert with an 84 to 90 inch (2100 to 2250mm) pipe at a depth of 12 to 20 feet (3.6 to 6.0m) below grade. The two construction alternatives examined were installations through open trench construction and microtunneling. The indirect costs that were quantified include those due to injury, vehicular and pedestrian disruption, business closures, noise, dust and dirt, road resurfacing, lost parking meter and ticketing revenue. Various methods were used to quantify these costs.

The authors used the cost of worker's compensation insurance to attribute injury costs to the two selected methods. At the time of the study, insurers did not distinguish between tunnelling and microtunelling; the insurance rate for open trench sanitary sewer construction was used in the evaluation of both alternatives. Injury costs were therefore based solely on the number of worker-hours lost. Microtunneling required less worker-hours, thereby resulting in a lower injury cost for the trenchless alternative. Injury costs for open trench construction were valued at approximately US(1994) $53,000 and those for microtunneling at US(1994) $38,000.

Traffic disruptions were quantified based on the value of time lost in detours and the vehicle operating costs incurred in increased travel distances. The value of time (VOT) was estimated using the full value of the local average hourly wage of the area's resident professionals, full time home makers and students. Other researchers (Ministère des Transports Québec, 2009a; Zhang et al., 2004) have used more conservative values of one quarter of the average local wage to reflect the fact that many trips are for leisure purposes and not for business. They have also used values greater than the full value of the local average hourly wage for truck traffic to reflect the loss of productivity associated with operating in congested areas. Vehicle operating expense was valued at US(1994) $0.29/mile in accordance with the Federal Government specifications at the time. Traffic disruption costs associated with open trench construction were more than US(1994) $400,000. Based on the assumption that trenchless construction would cause no disruption to traffic, the authors estimated traffic disruption costs as zero for trenchless construction. To quantify the impact of pedestrian disruption value of time was taken as US(1994) $8.40/hr and the total associated cost for trenching was nearly US(1994) $25,000 and again zero for microtunneling.

Local merchants were surveyed to estimate the impact of the construction work on their janitorial needs. A half an hour increase in cleaning services to offset construction dust and dirt accumulation was attributed to all local businesses. This amounted to almost US(1994)$5,500 for open trench construction. Dust and dirt costs were zero under the trenchless scheme.

The cost of road resurfacing was valued using details from bid submissions. Open trench construction required replacement of the entire road width along the full length of the installed pipe which amounted to just over US(1994) $110,000. Microtunneling required approximately one tenth of the area required for open trench excavation. Therefore, the road resurfacing cost associated with microtunneling was valued at approximately US(1994) $11,000. Although this scaling technique simplified calculations, this method underestimates the true costs of patching several isolated sections requiring multiple setups as opposed to resurfacing one unique surface.

Boyce and Bried (1994) also calculated municipal parking metre and ticketing revenue loss. This was achieved simply by collecting average parking meter usage and ticketing data from the City and relating this to the number of lost operating hours due to construction. Lost parking meter revenue was valued at approximately US(1994) $11,000 and $400 for trenching and trenchless activities, respectively. Lost parking ticketing revenue amounted to over US(1994) $24,000 for trenching operations and zero for microtunneling.

The authors discussed business losses, loss of productivity and loss of tax revenue, but no monetary value was assigned to these due to a lack of the necessary data.

A study of the existing literature reveals that Boyce and Bried (1994) provided a sound basis for further studies on the total cost of municipal projects. Many of their equations have been used in subsequent case studies. However, methods of estimating the cost of resurfacing and the value of time have been surpassed by findings in more recent research which yield more representative results.

2.5.2 McKim (1997) – Bidding Strategies for Conventional and Trenchless Technologies Considering Social Costs

McKim (1997) of the Centre for Advancement of Trenchless Technologies at the University of Waterloo, Ontario, presented bidding strategies that would allow the inclusion of indirect and external costs in the tendering process for municipal projects. The author highlighted several key costs associated with reinstatement of public and private property, traffic rerouting, environmental impacts of large-scale earth moving, and business and tax losses.

McKim (1997) proposed an aggregate method of estimating the total cost by using data collected from fourteen projects: ten open trench and four trenchless. Using this small sample population, an average estimate of indirect and external costs based as a percentage of construction costs was calculated. On average, these costs represented 78% of the construction costs in open trench construction projects and 3% in projects using trenchless technology. The following preliminary equations were proposed in the aggregate method of estimating the total cost, considered "social costs" by McKim (1997).

$$SC_{OT} = 0.78DC_{OT} \tag{2}$$

$$SC_{TT} = 0.03DC_{TT} \tag{3}$$

where SC_{OT} is the indirect and external costs associated with open trench construction, DC_{OT} is the direct construction cost of open trench construction, SC_{TT} is the indirect and external cost associated with construction by trenchless technologies, and DC_{TT} is the direct construction cost of trenchless construction.

The author argued that municipal engineers usually have little input into the construction method selected for use on a project. Unless specifications are included in the contract document, the competitive bid process stipulates that the method selected by the lowest bidder will be adopted. The Canadian Contracts Document Committee CCDC-II standard stipulated that bids shall generally include direct construction costs, overheads, burden, contingency and profit with no allocation for indirect and external costs. The lowest bid method, therefore, does not actually identify the submission that is associated with the lowest total cost to society. To consider the total cost of construction projects, McKim (1997) suggested that municipalities evaluate the sum of the conventional contract costs using the selected technology and the total cost associated with it. The total cost should be estimated using either the detailed equations presented by Boyce and Bried (1994), or the aggregate method presented by McKim (1997).

McKim (1997) also discussed that the inclusion of indirect and external costs in the bidding process would necessitate changes in bidding strategy by contractors. It would be important for these contractors to understand the selection criteria in the award process.

In summary, McKim introduced many important issues regarding the inclusion of indirect and external costs in the municipal bid process. Furthermore, he proposed an aggregate method of estimating indirect and external costs based as a percentage of the direct costs. Although the resulting equations are preliminary in nature due to insufficient data, the proposed aggregate method for estimating indirect and external costs satisfies the need for estimating techniques which can be easily incorporated into the modern bidding process. However, until sufficient data is collected, this type of method cannot be applied to every project because of their unique nature.

2.5.3 Tighe, Lee, McKim and Haas (1999) – Traffic Delay Cost Savings Associated with Trenchless Technology

A research group from the University of Waterloo (Tighe et al., 1999) developed formulae to quantify the impacts of traffic disruptions associated with utility construction. Their research was based on well-established traffic analysis techniques of the Transportation Research Board (1994) and He, Cai and Haas (1996). Three typical traffic control plans for municipal infrastructure projects in an urban environment were studied. These are shown in Figure 7.

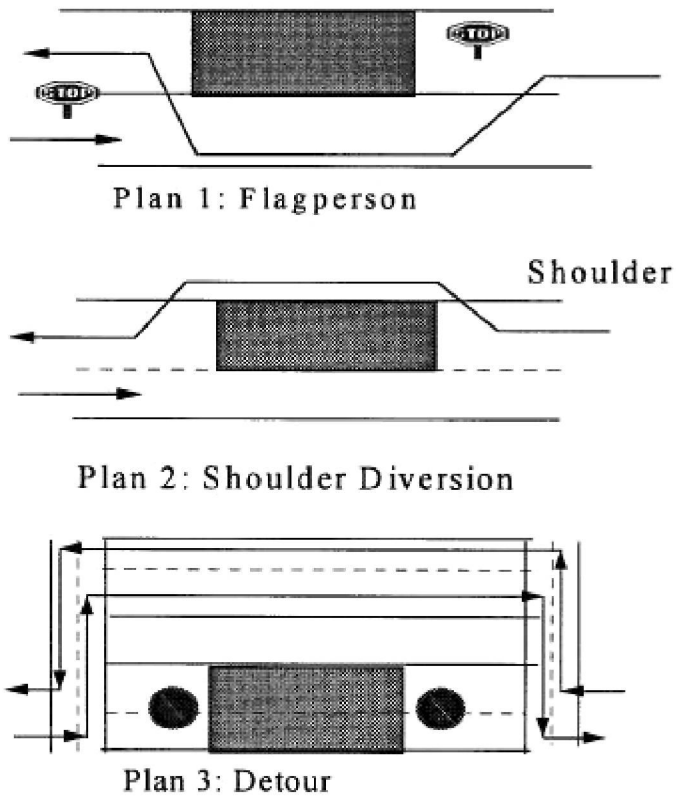


Figure 7. Traffic control plans (Tighe et al., 1999)

In their analysis the authors estimated delay due to slowing of traffic, queuing delay and detour delay. Slowing delay was estimated for traffic control plans 2 and 3 by first calculating the normal capacity of the road along with the reduced capacity during the project duration. The traffic demand is then calculated in terms of an hourly volume, followed by the vehicle speeds associated with both normal and reduced speed condition. The slowing delay is finally obtained by calculating the difference between the normal travel time and the additional travel time associated with delays due to the project activity as shown in the following equation:

$$D_j = \frac{L}{V_{rj}} - \frac{L}{V_{nj}} \tag{4}$$

where D_j = delay due to low speed with traffic control Plan j (h); L = length of work zone (km); V_{rj} = reduced speed with traffic control Plan j (km/h); V_{nj} = normal speed in zone affected by traffic plan j (km/h).

It is assumed that Plan 1 is associated with queuing delays only. These delays occur when demand exceeds capacity. The delay equation for a signalized intersection (Transportation Research Board, 1994) was modified and the average delay under Plan 1 is obtained as a function of reduced capacity, traffic volume and cycle timing of traffic signals.

Detour delays are estimated using Equation 5 by calculating the additional time to travel the detour route.

$$D_{detour} = \frac{L \times HV}{V_{ndetour}} \tag{5}$$

where D_{detour} = delay due to detour; L = length of detour; $V_{ndetour}$ = normal velocity, using detour; and HV = hourly volume (sum of both the volume of the detour route and the displaced volume from the work zone).

Tighe et al. (1999) then calculated the total time delay as a product of the delay calculated above, job duration, hourly volume and number of job times under traffic control. They then assumed an average user value of time of CA(1999) $25 and multiplied this by the average user delay time to obtain the user delay costs.

Through regression analysis, the authors developed well fitted equations for various municipal infrastructure project scenarios requiring only four variables: traffic control plan, lane widths, job duration and annual average daily traffic (AADT). A sample of these results can be found in Table 3.

Table 3. Traffic delay cost equations for traffic control plan 1 (Tighe et al., 1999)

Lane width (m) (1)	Job duration (h) (2)	Equation (3)	R^2 (4)
3.75	40	log(cost) = 0.00022AADT + 3.2545	0.982
	50	log(cost) = 0.00022AADT + 3.3515	0.982
	80	log(cost) = 0.00022AADT + 3.5556	0.982
	100	log(cost) = 0.00022AADT + 3.6525	0.982
	160	log(cost) = 0.00022AADT + 3.8566	0.982
	200	log(cost) = 0.00022AADT + 3.9536	0.982

Using readily available data, these tables can be easily used by engineers to quantitatively estimate the costs of traffic disruption and compare the impacts of the various alternatives. If the project details such as the number of lanes, lane width or AADT, for example, do not match the parameters selected in Tighe et al. studies (1999), the applicability of the results of this study is reduced, and engineers will be required to develop an equation set that relates to the intended project.

2.5.4 Grondin (2004) – Economic Analysis of a Rehabilitation Project through a Comparative Study with Open Trench Construction, Including Certain Costs Associated with Social Impacts

Grondin (2004) produced an independent life cycle costing study of an infrastructure renewal project in Laval, Quebec. Construction work included the replacement of an 870m length of pavement, wearing course and sidewalks, as well as the renewal of the underlying water main with diameters ranging from 150mm to 250mm. Water main renewal methods using cured in place pipe lining and the conventional dig and replace techniques were compared. Contractors were allowed to select the construction method to be used and the results of all five bid submissions were made available for use in the study.

Grondin (2004) analysed life cycle costs associated with both the trenchless rehabilitation and the open trench replacement options. He estimated indirect and external costs associated with traffic delays and vehicle operating costs. He acknowledged that his analysis did not consider the effects of increased traffic on detour routes, or the long-term effects of trenching on pavement performance. Studies have shown that both of these phenomena generate increased expenditure by municipalities in maintenance and replacement costs due to premature deterioration of the pavement (Iseley and Tanwani, 1990; Tighe et al., 2002). Grondin made the assumption that regardless of the construction technique, paving operations would be completed in a similar manner over the same period of time in year zero. In his comparative study, he did not consider the indirect cost associated with these pavement maintenance and rehabilitation efforts as their value would be equal in both alternatives.

Life cycle cost analysis using a 75 year study period and considering only bid costs indicated that both construction alternatives were economically equal with the cost estimates which were within a 3% range of each other. A sensitivity analysis of the project showed that changing the study period to 50 years, caused pipe lining to emerge as a slightly more economic option with approximately a 10% savings over the open trench alternative. Sine the service life of the water main installed using open trench construction techniques was estimated to be 75 years, the author recommended that this be the minimal study period for life-cycle cost comparisons.

By including indirect and external costs in the 75 year life cycle cost analysis, the trenchless alternative becomes more economic than open trench construction. While the economic valuation of this advantage is still only in the range of 10%, the difference is not insignificant.

The social costs of detours were quantified on the basis of lost time to roadway users and excessive vehicle operating costs. The lost time was calculated as a function of detour length, the full value of average annual wage according to Statistics Canada, average daily traffic, and estimates of average speed and average vehicle occupancy. The vehicle operating costs were calculated as a function of the average fuel cost, new vehicle fuel consumption data from Natural Resources Canada, and vehicle maintenance and ownership cost data from the Canadian Automobile Association. The resulting social cost associated with traffic detours due to open trench construction was presented as a dollar amount per unit length of pipe, and it was 150$/m. Of this value, 65% consisted of the cost of lost time and 35% consisted of the excess cost of vehicle operation.

Grondin (2004) contributed to the literature on the total cost of pipe renewal projects by breaking ground in attempting to include indirect and external costs in life cycle cost analysis. He showed that indirect and external costs can be included in life cycle costing as expenses at the time of construction. His report supports the fact that life cycle analysis is sensitive to the study period selected and that the study yields more representative results only when a study period that reflects the full expected service life of the longest lasting alternative is selected. However, Grondin's methods of quantifying the impacts of traffic delays and vehicle operating costs are based on many assumptions and the use of grossly generalized data. It is important to use more detailed valuation techniques to fully reflect the unique nature of every project.

2.5.5 Gilchrist and Allouche (2005) – Quantification of Social Costs Associated with Construction Projects: A State-of-the-Art Review

An extensive list of socio-economic and environmental impacts associated with construction projects has been prepared by Gilchrist of the University of Western Ontario and Erez Allouche of Louisiana Technical University's Trenchless Technology Center (2005). The authors also discuss many different methods of quantifying these impacts including direct and indirect valuation techniques. A generic framework to estimate total project costs is presented in the report.

According to the authors, society is becoming increasingly aware of the social, economic and environmental impacts of construction projects. Increasing traffic congestion, a growing presence of construction sites in urban areas, urban regeneration projects and the availability of alternative construction technologies bring these impacts to the public attention placing pressure on municipal decision makers to adopt sustainable solutions. Gilchrist and Allouche (2005) recommend including indirect and external costs in the bid evaluation process as a method of mitigating socio-economic and environmental impacts of construction.

Furthermore, the authors suggest that a paradigm shift is imminent. The old triad of time, quality and cost is being broadened to encompass the more sustainable goals shown in Figure 8 of life cycle assessment, human satisfaction and minimal environment impact, and total cost and resource consumption.

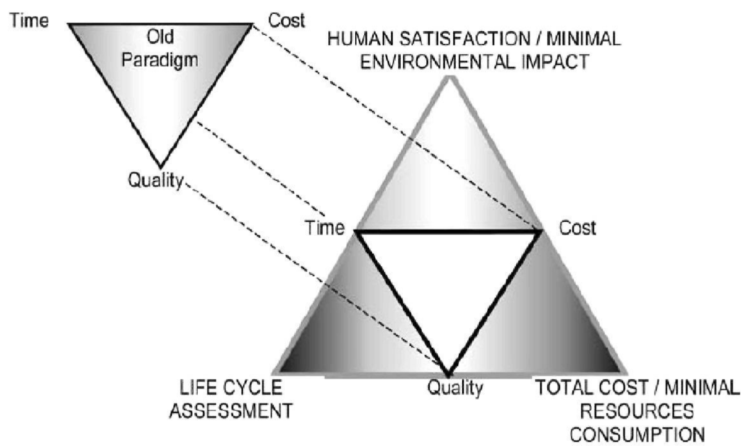


Figure 8. The new paradigm for sustainable construction (Gilchrist and Allouche, 2005)

The notion of social cost indicators is introduced in their report as monetarily quantifiable losses due to social, economic and environmental impacts of construction. Although this method of linking impacts to their associative measurable indicator provides a detailed overview of the relationship between society and construction activity, their use adds unnecessary complexity to the assessment of total cost as can be seen by the many intertwined relationships between impacts, social cost indicators and valuation methods shown in the relationship diagram (Figure 9). A single list of monetarily quantifiable social impacts would be more practical for use by current practitioners.

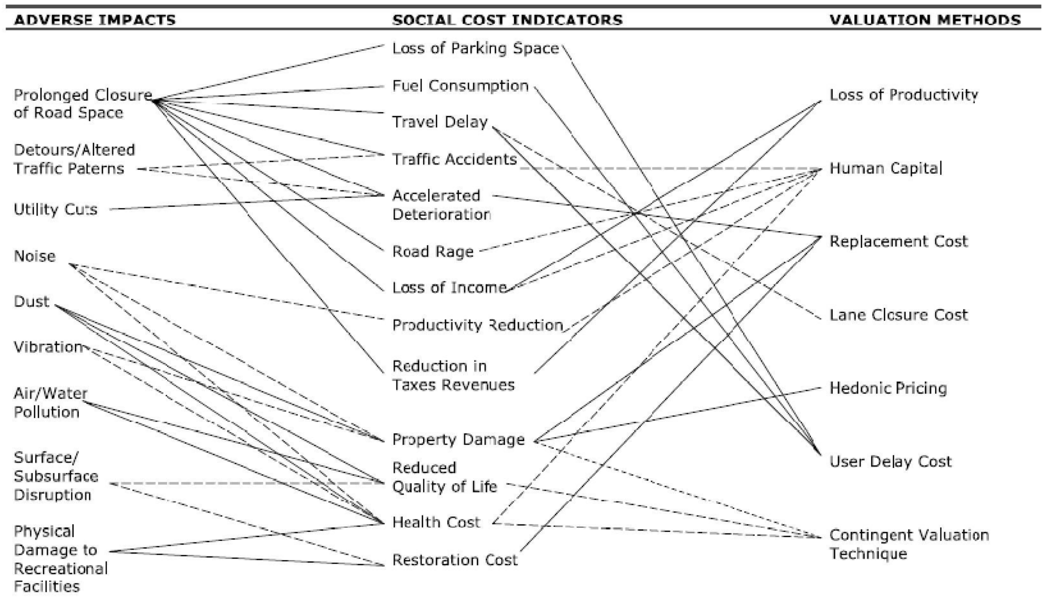


Figure 9. Relationship between impacts, social cost indicators and valuation methods (Gilchrist and Allouche, 2005)

Gilchrist and Allouche (2005) presented an extensive qualitative description of the existing indirect and external costs that exist, along with examples of quantitative studies that have been conducted for each of these costs.

Valuating techniques studied by Gilchrist and Allouche (2005) include loss of productivity, human capital, replacement costs, lane closure costs, hedonic pricing, user delay costs, and the contingent valuation techniques. Not all of these methods are appropriate for valuation of all indirect and external costs; however, the combined use of these techniques allows for a good estimation of the total cost associated with construction projects.

Finally, Gilchrist and Allouche (2005) compared many bid evaluation techniques that are currently being used in practice. It was concluded that the cost effectiveness analysis method and the multi-variable evaluation method were most suitable for the inclusion of indirect and external costs in the bid evaluation process. Both of these new evaluation methods are excellent tools for comparing the ability of the various alternatives to meet the user-defined objectives, using either quantitative or qualitative values.

In summary, Gilchrist and Allouche (2005) presented an in-depth study of the social, economic and environmental impacts of construction work along with the associated losses to society. Through their comparative studies, the authors laid a good foundation upon which further research can be developed. The key findings of this report were the emergence of two promising bid evaluation techniques as well as a generic framework for total cost analysis.

2.5.6 Rahman, Vanier and Newton (2005) – Social Cost Considerations for Municipal Infrastructure Management

This work undertaken at the National Research Council of Canada by Rahman, Vanier and Newton (2005) reported on the importance of considering, identifying, quantifying and verifying the total cost of municipal projects. Rahman, Vanier and Newton (2005), proposed three cost categories shown in Figure 6 which are defined on the basis of accuracy of cost estimation, timeliness of cost occurrences, and the bearer of the cost.

Category I costs are considered direct costs. They include items such as planning, design, construction, restoration, and provision for emergency and temporary services - items which are identified in typical contract documents.

Category II costs are ones which are quantifiable and are associated with project elements which indirectly affect the users. These costs include those due to traffic disruption, reduction of the remaining service life, and noise, dust and dirt pollution. Category II impacts principally relate to longer term costs as compared with those in Category I.

Finally, *Category III* encompasses the intangible impacts which are very difficult to quantify. They relate mainly to the costs borne well after the completion of the project. These costs relate to either the environment, or health and safety.

Quantification of these costs can be achieved using a variety of valuation techniques. Most Category I costs are easily quantified using conventional project estimation techniques. Parking meter and ticketing revenue losses were quantified using the formulas proposed by Boyce and Bried (1994). It was proposed to estimate property damage using existing data from case studies or specialized organizations such as the Canadian Mortgage and Housing Corporation (CMHC). It should be noted that the existing data does not always agree, for example, case study values presented by Rahman et al. (2005) value the cost of flood damage at $500 to $2,500 per household and small business, while the CMHC proposed values ranging from $3,000 to $5,000 per basement flooding incident. It would be important to explore all available sources of this data and select the data which best reflects the project specifics.

Rahman et al. (2005) argue that value of time estimates, necessary for quantification of Category II costs, are the most controversial user costs. Literature suggests values ranging from one quarter to the full average of the local wage rate. The value of time is said to depend on factors such as personal income, nature of the time lost, vehicle type, location and local labour cost.

The authors explain the complexities of estimating the costs of business losses which are largely dependent on the scale of study. Individual businesses are liable to lose revenue during and after construction activities. It is suggested by the authors to estimate business losses by comparing property tax revenues for the surrounding area for the years preceding, during and after construction.

The equations proposed by Boyce and Bried (1994) for estimating the loss of productivity due to noise pollution and the cost of dust and dirt pollution control were used by the authors. The cost of service life reduction of neighbouring infrastructure was considered using the following equation:

$$SL\ reduction\ cost\ = \\ PV\ of\ asset\ (original\ service\ life) - PV\ of\ asset\ (reduced\ service\ life) \quad (6)$$

Category III costs were not quantified by the authors. It was stated that in order to estimate health and safety costs, it would be necessary to collect data on health and safety impacts directly attributable to a project element. Although studies have been conducted, results of the cost of greenhouse gas emissions were shown to range between US(2000) $6-$160 per tonne.

The authors also suggest different methods of mitigating indirect and external impacts due to municipal projects. These methods include reducing the duration of work, timing work for off-peak hours, coordinating with other work in close proximity, and using alternative rehabilitation technologies.

Finally, case studies were presented from work by Peters (1984) in the United Kingdom, McKim (1997) and the City of Winnipeg (2001) in Canada. Peters (1984) reviewed four sewer projects. He found that the indirect and external costs associated with traditional open cut construction ranged from 88% to 381% of construction costs. The City of Winnipeg (2001) studied three typical sewer rehabilitation projects using alternative construction techniques. Off-line, cured-in-place pipe (CIPP) lining and open trench methods were compared in each of the scenarios. In two cases, CIPP was estimated to have the lowest total cost, followed by off-line (noted to consist of low dig methods such as pipe bursting or horizontal directional drilling) and then open trench construction. In one case, off-line construction was less costly than CIPP. The average indirect and external costs associated with CIPP, off-line, and open trench construction, based as a percentage of construction costs were 36%, 68% and 124%, respectively.

2.5.7 Pucker, Allouche and Sterling (2006) – Social Costs Associated with Trenchless Projects: Case Histories in North America and Europe

Researchers at Louisiana Tech University's Trenchless Technology Center (Pucker, Allouche, and Sterling, 2006) reviewed three case studies of the total cost of BMIRPs and identified eight external and indirect costs. One of the case studies was of the work by Boyce and Bried (1994) and the other two were of work conducted in Austria by Kolator (1998). It was shown that the negative social, environmental and economic impacts are lower in suburban areas than in dense urban areas.

2.5.8 Jung and Sinha (2007) – Evaluation of Trenchless Technology Methods for Municipal Infrastructure

Jung and Sinha (2007) of Pennsylvania State University evaluated the total cost of eight sewer renewal projects in Pennsylvania. For each case study, costs associated with traditional open trench construction and pipe bursting, a trenchless alternative, were compared. Socio-economic and environmental impacts were quantified using existing techniques found in the literature and newly developed estimation methods. In all cases, except one, the trenchless alternative incurred the least total cost and the least indirect and external costs. The exception was a roadway project with very little traffic, situated outside of the urban centre (AADT=284).

The total cost was assessed using the equation:

$$TC = C_{DIRECT} + C_{SOCIAL} + C_{ENVIRONMENTAL} + C_{OTHER\ FACTORS} \quad (7)$$

where TC=total cost associated with the selected construction technique; C_{DIRECT}=earthwork cost, restoration cost, overhead cost, and others (including material, labor, and equipment cost); C_{SOCIAL}=traffic delay cost, business income loss, and others; $C_{ENVIRONMENTAL}$= noise pollution costs, air pollution costs, and others; $C_{OTHER\ FACTORS}$= productivity, safety, structural behaviour, and others.

Direct costs were estimated by the authors using standard construction industry costs. Social costs quantified in the study were traffic delay costs and business income loss. Traffic delay costs were estimated using regression analysis as proposed by Tighe et al. (1999) which accounts for the lane width, AADT and job duration.

It was found that traffic costs were the most significant of all socio-economic and environmental costs. In one instance, traffic delay costs associated with open trench construction in a heavily trafficked area (AADT=14,877) was estimated to be more than 80 times the direct costs, and 10 times the cost of using the pipe bursting alternative. These values are 2.5 to 10 times greater than any result in all previous studies. This can be explained by the significantly greater amount of traffic on the roadway being occupied during construction.

Business losses at the Pennsylvania project location were estimated by making some assumptions based on survey results obtained in Montana and Alberta. The study assumed that all local businesses grossing less than $100,000 annually would incur a 25% income loss during the duration of the project. Also, it was assumed that annual average income per small business was equivalent to the average household income of about $35,400. This method of estimating business losses is based on the assumption that business characteristics and customer behaviour is similar from one location to another. As further research is conducted in this area, this type of transfer of empirical data between locations will be avoided allowing for more representative studies.

Noise was the only environmental cost considered in the Jung and Sinha study (2007). The authors used a scaled version of the Noise Deprecation Index (NDI) developed by Feitelson, Hurd and Mudge (1996) whose research quantified the depreciation of housing values as a result of airport noise pollution. The NDI used in the study was developed to consider the effects of year-long noise, emitted 24 hours a day. Therefore, the noise depreciation index was modified by Jung and Sinha (2007) to reflect the temporary nature of pipe renewal projects. It was estimated that the willingness to pay to avoid each decibel of increased noise pollution was 0.17% of a respondent's rent, or house price. Jung and Sinha (2007) assumed that open trench construction caused a 20dBA increase in noise at street level, while pipe bursting caused only a 10dBA increase. In the specific case of noise pollution costs, it was assumed that project duration was unaltered regardless of the construction method selected. Therefore the only variable distinguishing open trench from trenchless construction was the noise level increase; the cost of noise pollution was, therefore, twice as much for open trench construction as for trenchless construction.

Other costs which were considered but not quantified include productivity, worker safety and structural issues. For each of these, it was identified that trenchless construction would typically be preferable. The study shows that the productivity of open trench construction (8m/day) is smaller than the productivity of trenchless construction (20m/day), and the success of open trench pipe laying can be compromised by poor bedding, haunching and compaction, whereas trenchless installation eliminates the need for these construction steps.

In summary, Jung and Sinha (2007) offered a good comparison of pipe renewal costs associated with trenchless and open trench construction methods. Their research was extensive in terms of the number of case studies undertaken. It was shown that traffic delay could be simply quantified using the method proposed by Tighe et al. (1999).

While noise pollution was quantified using a modified version of the well researched NDI, the valuating method used to estimate business losses relied on foreign data which may have led to inaccuracies. It can be improved by using more location-specific data to avoid loss of relevance due to transfer of application location.

2.5.9 Veillette (2007) – Social Costs: Revalorization of Water Distribution Networks

A study was undertaken by Veillette (2007) for Aqua Rehab, a trenchless pipe rehabilitation service provider, to compare the socio-economic costs of water main rehabilitation associated with open trench and trenchless construction techniques in Montreal. The total economic cost was calculated as the sum of private costs (construction costs and profit) and indirect and external costs (the cost of traffic congestion and accidents, damage to property and environmental impacts).

The study was based on the assumptions that open trench construction would last 30 working days while impeding all traffic flow and trenchless construction would last working 15 days and impede fifty percent of all traffic flow. Traffic disruption costs were estimated using a methodology proposed by Transport Canada (2006) and greenhouse gas emissions were valued at approximately CA(2007)$4 per tonne of greenhouse gas obtained from the Chicago Climate Exchange (2007). It should be noted that an equivalent market which provides a platform to trade carbon emitters' credits and offset credits in Montreal – the Montreal Climate Exchange (2009). It was determined that the costs of greenhouse gas emissions and traffic disruption associated with BMIRPs could be reduced by nearly 300 percent by adopting trenchless construction methods rather than open trench construction methods. It should be noted that these results were based on the underlying assumption that a trenchless construction project lasts half as long and occupies half as much space as an open trench project. While this study presents a good overview of the condition of the Greater Montreal Area's water distribution network, the indirect and external cost analysis was reliant upon the very basic assumptions that trenchless construction would involve half the amount time and traffic obstruction than would open trench construction. More research is needed in this area with different assumptions as the basis.

2.5.10 Manuilova, Dormuth and Vanier (2008) – A Case Study of User and External Cost Components of Social Costs that are related to Municipal Infrastructure Rehabilitation

Three municipal rehabilitation projects in the City of Regina, Saskatchewan, were selected for a total cost study by National Research Council Canada (Manuilova et al., 2008). The three locations were pragmatically selected to reflect different settings. The Winnipeg Street and Ross Avenue intersection was a two-day railway crossing repair project in an industrial area. Albert Street was a two-day road resurfacing project on an arterial road. The Victoria Avenue and Park Street intersection was a two-month road repair project on a main arterial road. While the three case studies were not particular to buried pipe renewal, the methodologies used to quantify the total cost of municipal construction projects are very relevant to BMIRPs and will be explained in this section.

Manual traffic counts were carried out for each of the case studies with and without the work zone. Technicians recorded traffic volume, occupancy, vehicle type, and directional movement of flow. A total cost quantification procedure was proposed by the authors. This method made use of existing valuation techniques, which were modified by the authors to reflect the Canadian standards. Travel delay and accident costs were quantified in this procedure. The estimation methods for the costs of noise and environmental impact were discussed but not included in their quantitative study.

Travel delay costs were quantified using a method proposed by Boyce and Bried (1994), while the vehicle operating and maintenance costs were estimated using data provided by Transport Canada (Canadian Vehicle Survey (CVS), 2000; Transport Canada, 2006). The travel delay costs accounted for up to 70% of indirect and external costs considered in the study. These costs, dependent on the detour travel distance and speed, were observed to increase when improper detour signage was in place prompting motorist to drive along alternate less optimal detour routes. Also, it was noted that although closing down long sections of the roadway may well entrain greater detour lengths, thereby, increasing traffic delay and vehicle operating costs, this practice can allow significant construction progress, and if timed during off peak days (such as the weekend), can generate cost-savings.

The cost of accidents was calculated for each of the projects using a method proposed in a report for Transport Canada by Zhang et al. (2004). Manuilova et al. (2008) have selected this method as it is based on an extensive literature review, and it is specific to Canada. The method stipulates the following costs, which are separated by vehicle type and based on 2006 Canadian dollar per 1,000km travelled:

- Urban/interurban vehicle: $154.38/1000km
- Urban/interurban bus: $482.32/1000km
- Freight vehicle/truck: $164.99/1000km

The resulting accident costs ranged between $909 to $2,934/ per day. The authors found discrepancies between these results and the data from a traffic collision study for the City of Regina. While the methodology of Zhang et al (2004) indicated that the cost of accidents at the Victoria-Park intersection was the lowest of the three cases, it was reported that Saskatchewan Government Insurance data indicated that this intersection had the highest accident rate. It is clear that more research on accidents in work zones must be undertaken to improve the accuracy of estimates.

The total cost (sum of travel delay, vehicle operating and accident costs) and average daily cost for the three case studies are as follows:

- Winnipeg-Ross intersection: $12,774; $6,387/per day
- Albert Street: $19,329; $9,665/per day
- Victoria-Park intersection: $299,943; $4,999/per day

In summary, Manuilova et al. (2008) propose a procedure for quantifying the total cost of municipal rehabilitation projects which can be easily adopted by municipalities. Their quantification methods are based on extensive literature review and are modified to reflect the Canadian standards. This can be considered one of the most extensive studies in this specific field although not specific to buried infrastructure projects. The disadvantage of this method, however, is that it does not allow forecasting of the total cost to be incurred in a planned project. This method requires data to be gathered before, during and after construction, thereby making its use reserved for collecting data on completed projects. This method should be applied by future researchers to expand the body of knowledge in this field of study and to enable the eventual creation of an aggregate total cost estimation method. Until then, it is also necessary to provide municipalities with a framework which is easily integrated within their current practice to forecast indirect and external costs for inclusion in project evaluation.

2.5.11 Summary

In summary, North American discussion of the total cost of buried municipal infrastructure renewal projects (BMIRP) was initiated by Boyce and Bried (1994). A total cost comparison of a sewer renewal project revealed that the indirect and external costs associated with open trench construction were much more significant than those associated with the microtunneling construction technique. Boyce and Bried proposed many cost estimation equations which are still used by current researchers.

Mckim (1997) made significant contributions to the literature by describing the indirect and external costs associated with BMIRPs and developing estimation equations for these. He also explained the major benefits and challenges of including indirect and external costs into current bidding strategies.

Tighe et al. (1999) added to the body of knowledge in the area of traffic impacts associated with three typical BMIRP traffic control plans. They developed a set of equations to estimate travel delays as a function of AADT, lane width and job duration, with the assumption that a road user's hourly value of time is 25 dollars.

A life cycle cost analysis was undertaken by Grondin (2004) which considered infrastructure service life and vehicle delay and operating costs associated with a water main renewal project. He found that, by using a 75 year study period, the total life cycle costs of rehabilitation using a trenchless pipe lining rehabilitation method (characterized by high direct costs, but low indirect and external costs) was 10 percent lower than that of an open trench replacement (characterized by low direct costs, but high indirect and external costs).

Gilchrist and Allouche (2005) made significant contributions to the literature by describing in detail the many negative social, economic and environmental impacts of BMIRPs. They proposed the use of various direct and indirect valuation techniques to estimate the costs associated with these negative impacts. The authors conclude with a discussion on the benefits and challenges of considering the total cost in current project evaluation.

The National Research Council of Canada (Rahman et al., 2005) separated total cost into three categories based on accuracy of estimation, timeliness of cost occurrences, and the bearer of the cost. They reviewed the list of total cost components and proposed an equation to estimate the costs of lost pavement service life due to BMIRPs based on the present value of an asset before and after excavation.

The total cost of eight sewer renewal projects were studied by Jung and Sinha (2007), for both open trench construction and pipebursting installation. The most notable finding is that the traffic delay costs estimated using the equations by Tighe et al (1999) for a 55 day buried pipe renewal project in a high-traffic-volume roadway (AADT=14,877) were more than 5 million dollars, 80 times the direct costs, for open trench construction and almost 1 million dollars, 10 times the direct costs, for pipebursting installation. These are the highest traffic impact estimates to-date in the literature.

Veillette (2007) estimated that a 300 percent reduction in the costs of traffic delays and greenhouse gas emissions was achievable by using a trenchless rehabilitation method rather than conventional open trench pipe replacement. This result was obtained under the assumption that trenchless rehabilitation would last half the time and occupy half the space of an open trench construction.

Manuilova et al. (2008) presented a considerable review of the existing literature relevant to estimating the total cost of municipal infrastructure construction projects. Three case studies were examined, none of which consisted of pipe renewal projects, but rather roadway renewal projects. Nonetheless, the valuation methods proposed by the authors are very pertinent to this thesis.

3 Analysis of Total Cost

In this thesis, total cost analysis refers to the process of separating total cost into components which are direct, indirect and external costs. Analysis of total cost in civil engineering is a relatively new practice. Traditionally, project economic decisions and construction specifications were left in the hands of technical experts who used only narrow financial evaluation tools to assess direct costs such as planning, engineering, management and construction costs and did not consider social and environmental costs or benefits (Murphy and Delucchi, 1998). The significant increase in environmental awareness and concern for social welfare in the late 1960's gave rise to a new way of examining road, dam and other major infrastructure projects – one which was based on estimates of the social costs and benefits of projects in addition to the well known direct costs (Gifford, 1993).

Total cost analysis is to be used as a project evaluation tool to quantitatively consider all impacts associated with a selected project with the objective of comparing two or more project alternatives, or comparing a project with given standards. This is commonly achieved by researchers conducting economic and environmental cost-benefit analyses through what is referred to as *valuation*. Through valuation, project impacts are reduced to a common monetary term through various direct and indirect valuation techniques adapted for market and non-market goods. In this thesis, the term evaluation will be used to broadly describe the study of all a project's details and specifications along with their associated impacts (costs and benefits), whereas the term valuation will be used herein specifically to describe the process of placing a monetary value on these impacts.

Total cost analysis alone does not identify the most cost-efficient alternative (Murphy and Delucchi, 1998) but it is a helpful tool for municipal decision-makers as it can provide the user with cost data and cost estimates for use in project evaluation, policy establishment and asset management.

3.1 Total Cost Valuation

As described in the previous section, total cost valuation refers to the process by which a monetary value is placed on the studied impacts. Valuation of social and environmental costs and benefits has been a very well studied area over the past few decades (Button, 1993). Many valuation techniques have been developed throughout the years. Button (1993) summarizes these into the following broad categories which have been adapted in this thesis topic:

Precedents: This method consists of collecting information from past experiences. The empirical evidence generated can be used in estimation of similar impacts. Data collected, however, may be rather inconsistent, and information on the causes of these impacts may not be well documented.

Averting Behaviour: This method involves calculating the costs of avoiding an impact through preventive behaviour. This method may however over-estimate the value of these impacts if the positive benefits drawn from preventive measures derived from the study are neglected.

Revealed Preference: This procedure rests upon the relationship between items sold on the market place and an external impact to estimate the value of this impact through statistical analysis. A commonly used method is hedonic pricing which is used to estimate the value of external parameters such as crime rate, pollution levels and noise levels based on sophisticated statistical analysis of the price paid for homes. This method is limited in that firstly it can only consider pre-existent impacts and their levels of severity, and secondly it is very difficult to fully account for all parameters affecting a market price.

Travel Cost Method: This method is a particular form of the revealed preference approach. It is based on estimating the value of a facility such as parks and sites of natural importance through investigation of the costs willingly paid by visitors to travel to the facility. This method considers travel costs such as fuel and travel time. The travel cost method is limited in a manner similar to the hedonic pricing approach whereby it is difficult to fully consider all of the possible factors influencing one’s decision. Additionally this valuation technique itself requires estimation of the value of travel time which is another science in itself.

Stated Preference: By asking carefully formulated and targeted hypothetical questions, it is possible to gauge how much an individual values non-market goods, services or amenities. A common form of this approach is contingent valuation. An advantage of this method is that it can gain information on long-term costs and benefits. However, it is difficult to formulate questions so that a bias is avoided. Improper wording, or presentation of a survey question can always influence the respondent's answer.

In addition to these procedures, valuation methods may rely on the penalty costs or allowance credits. Pigovian taxes, named after the welfare economist Pigou, were developed in the mid-twentieth century based on the concept that solutions to the harmful external effects of an activity will be developed and implemented by the driver of this activity if a high enough fee is charged for harmful production practices (Ontario Superbuild Corporation, 2002). Pigovian taxes, therefore, have the potential to internalise the costs of negative externalities, thereby, giving the producer of harmful activities an economic incentive to reduce these practices to minimise the overall costs. This concept has given rise to pollution taxes and effluent discharge fees. Pigovian taxation has evolved into the latest attempts to reduce the harmful external effects of pollution and have given fruit to pollution and emission rights or credits which are managed by different governing agencies and can be sold or traded as a market good. This has greatly facilitated environmental valuation of certain forms of pollution.

Applicability of environmental valuation results from an original study location to another location is still a significant limitation in the applicability of environmental valuation techniques. For example, results of hedonic and stated preference property valuation studies are sensitive to site-specific parameters such as property market type (eg. urban residential, sub-urban residential, industrial, urban commercial, etc.), geographic location (eg. country), and local income levels. The results are specific to the characteristics of the study location and cannot be easily transferred without a loss of reliability – this is known as benefits transfer (USEPA, 2000). This imposes present limitations to valuation methods but general trends can be detected and the results are currently being used internationally for policy development.

3.2 Framework for Total Cost Analysis

This study presents a framework for use by municipalities, utility agencies and contracting firms to quantitatively assess the social, environmental and economic impacts associated with the various construction alternatives for buried pipe renewal in an urban setting. The present project evaluation methods typically account only for the direct costs and ignore the indirect and external costs associated with pipe renewal projects. As the need to renew the nation's municipal infrastructure becomes increasingly urgent, renewal projects are becoming more commonplace and project evaluation methods must be changed to reflect the total cost of a project if the society is to wholly benefit from this renewal effort. Also, with the emergence of trenchless technologies, open trench excavation is no longer the only viable pipeline construction and rehabilitation method. Therefore, engineers are called to evaluate quantitatively the available alternatives.

The framework is designed according to the following success criteria:

- **APPLICABILITY**

Implying minimal time and cost for integration into current municipal project evaluation methods

- **ADAPTABILITY**

Ability to reflect specific needs of any given project

- **RELEVANCE**

Based on best available valuating techniques

- **EVOLUTION**

Easily updated to incorporate emerging improvements in valuating techniques

The framework shown in Figure 10 consists of an initial data collection stage to gather necessary project details, such as duration, excavation volume, work schedule, equipment usage, site setup and characteristics, etc. This input is used, in part, to estimate traditionally direct costs as practiced in preparation of project tenders. The project details are also used for identification and assessment of the socio-economic and environmental impacts specifically associated with the project alternatives being studied. It is important that the entire life cycle of the project and all of its constituents be considered to identify both the immediate and the long-term impacts.

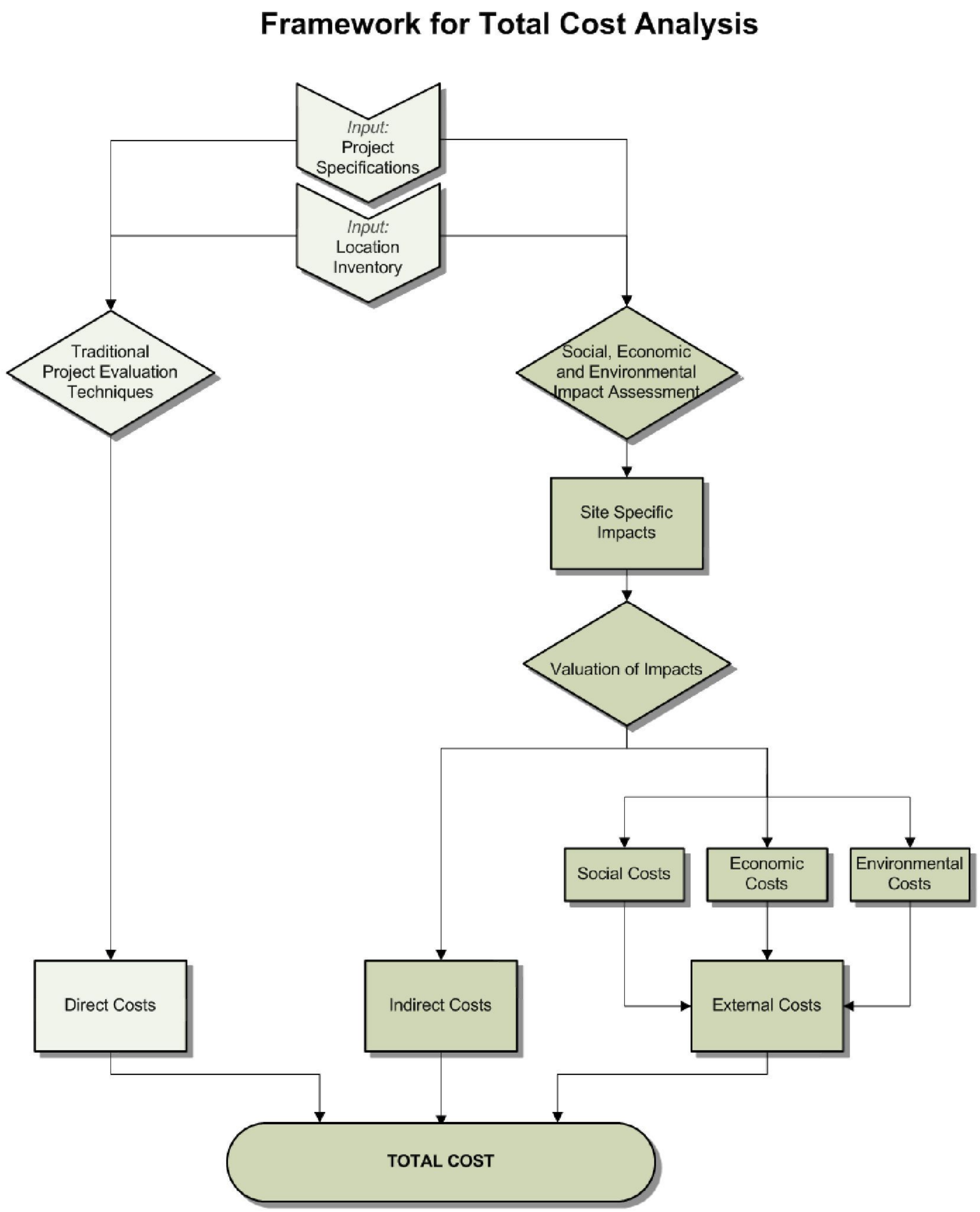


Figure 10. Framework for total cost analysis of construction projects

The most current and relevant valuation techniques are then used to quantify these impacts in terms of monetary costs. Valuation techniques have been selected based on an extensive review of the available literature.

The final segment of the framework is the summation of all costs to obtain the total cost of the evaluated project alternative.

4 Description and Valuation of Indirect and External Impacts

As original research into valuation techniques is quite time consuming and costly, it is common practice to use the cumulative results of the existing research to develop an economic framework in environmental cost-benefit analyses (USEPA, 2000). The framework proposed in this study aggregates appropriate valuation techniques which develop monetary values for social, economic and environmental impacts of construction projects. When it is impossible to quantify the cost of an impact due to lack of empirical data or scientific knowledge in the field, this thesis presents the reader with various techniques to assess qualitatively the impacts of construction alternatives in terms of non-monetary units.

After a detailed review of the literature, the valuation techniques that are pertinent to municipal infrastructure projects have been adopted. These valuation techniques produced by reliable sources either by researchers, or by the municipal construction and engineering industry.

In addition to the techniques developed in Canada, international research on valuation techniques, applicable to the Canadian scene was adopted; this thesis reviews the transferability of the valuating techniques.

4.1 Indirect Costs

4.1.1 Pavement Service Life Reduction due to Excavation (PDE)

Construction activities for repair, rehabilitation or replacement of buried pipe often include cutting and restoration of paved surfaces, which causes significant reduction in the useful life of pavement structure as well as a reduction in the travel comfort due to settlement of the restored area. (Gilchrist and Allouche, 2005)

Access to buried utilities under a roadway requires the removal of the asphalt surface, granular base and sub-base and the subgrade soil. This reduces the lateral support to the uncut volume of dirt along the trench edges and causes this soil to slough into the hole, thereby reducing support of the pavement edges (Khogali and Mohamed, 1999).

The extent of the unsupported area was shown to be in the range of 0.6m to 1.0m from the trench edge (Bodocsi et al., 1995; Lee and Lauter, 1999).

Compaction of restoration fill does not reach the same density levels as in new road construction, as the confined spaces of trenches limit the undertaking of this process to relatively small equipment, most often incapable of attaining the desired levels of compaction. Also, the use of flowable fills and soil modifiers has not been proven to yield consistent, adequate performance. More research is needed in this area (Khogali and Mohamed, 1999).

Metropolitan Toronto has adopted unshrinkable fills as back fill material for utility cut restoration as the result of a study which showed that 65% of a sample of 43 recently restored trenches in their city's center had fallen below the minimum condition rating level when disregarding surface conditions (Emery and Johnston, 1986).

Quality control techniques such as field testing were developed for testing of loose soil, or laboratory-compacted construction materials, and are therefore, inadequate for ensuring proper performance of trench restoration. A study performed by Khogali (1995) has shown that control tests that specify only a field density measure are not sufficient to guarantee performance of a restored trench.

Cost analysis conducted by Tighe et al. (2002) found that open excavation in the first year of a pavement's life in Ontario, Canada, cause a maintenance and rehabilitation cost increase of approximately CA(2002) 146$/$m^2$ over a 30 year life span of the structure. This is largely attributable to the average reduction in a pavement's quality under same conditions which is estimated to reduce by the original service life by approximately 30 percent. These results were found by simulating an open excavation using the Ontario Pavement Analysis of Costs (OPAC) 2000 program for cost modeling throughout the pavement life. Although the results of this study were inconclusive for older pavements with additional maintenance and rehabilitation needs ranging from CA(2002) \$85 to \$140/m^2, it was determined that utility cuts in older pavement produce a lower reduction in the quality of the pavement conditions due to distresses already present in the structure. The authors continue to suggest that the use of trenchless technologies coupled with good construction practices can significantly reduce maintenance and rehabilitation costs and those due to traffic disruption.

The findings by Tighe et al. (2002) are consistent with the findings of a 1999 study conducted by Lee and Lauter (1999) in Ottawa-Carleton which estimate a 32.4 percent reduction in pavement life cycle.

4.1.1.1 VALUATION

This study proposes valuating the loss of service life based on the results obtained by Tighe et al. (2002). A 30 percent reduction in residual service life, including increased costs of maintenance and premature rehabilitation will be assumed. This study acknowledges that pavement deterioration is most likely to behave in a non-linear manner such as the multiple zone Markovian pavement deterioration model proposed by Butt (1991), presented in the work of Shahin (2005) which separated the deterioration rate into several discrete phases, or zones as shown in Figure 11, which identify different condition states. Butt (1991) considered the pavement condition index (PCI) which is a measure reflecting pavement roughness in terms of riding comfort and types of distress. The minimum acceptable PCI in Canada is generally around 50 to 55 at which point rehabilitation of the pavement or replacement is warranted (Tighe et al., 2002).

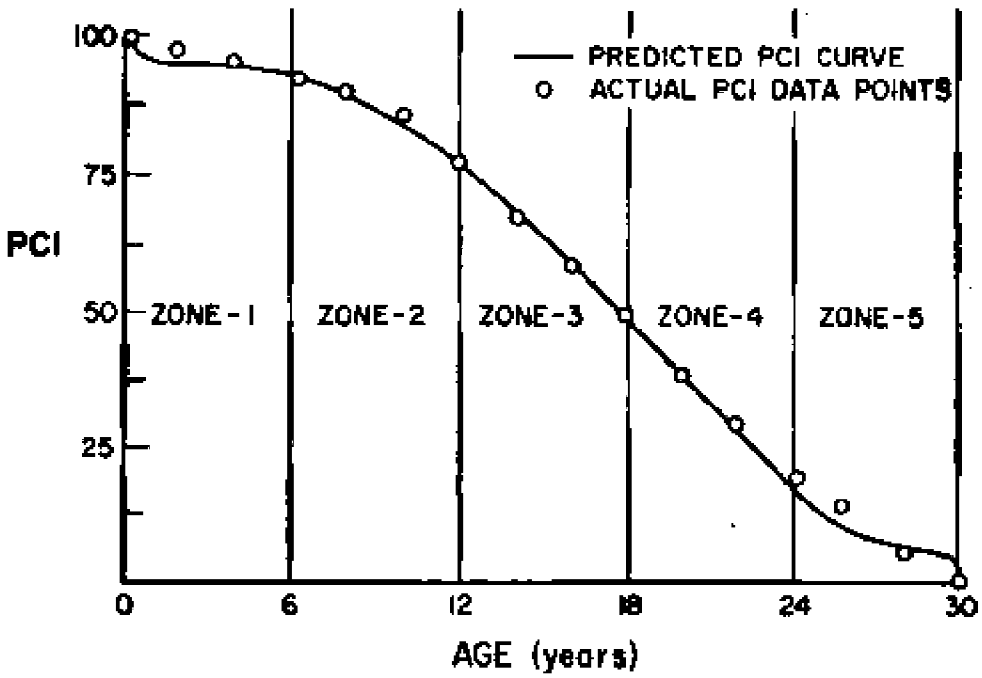


Figure 11. Multiple zone Markovian pavement deterioration model (Butt, 1991)

Because of a lack of conclusive results in the literature, the effects of a utility cut on pavement condition are assumed in this thesis to be a function of pavement age and to decrease linearly to zero at the end of its designed service life as shown in Figure 12. This assumption can be improved when more conclusive studies have been conducted to develop reliable pavement deterioration models in northern climates.

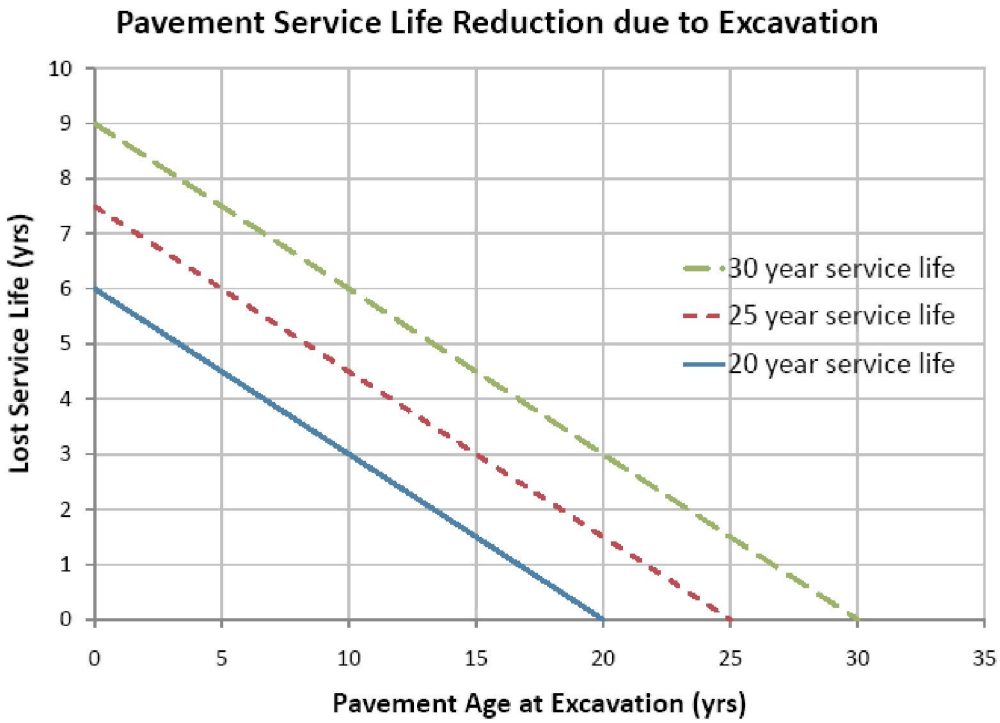


Figure 12. The effect of excavation and restoration on a pavement structure's service life

Using life cycle costing, the value of the pavement asset is depreciated linearly to obtain the present value (PV) of the asset for its original service life and for its reduced service life. The difference between these values is the cost of the pavement service life lost due to excavation (PDE). It can be assumed that salvage value of the pavement is zero (Federal Highway Association, 1997). The equation is a function of the excavated area, initial construction cost per unit area and the timing of excavation and is shown in Equations 8 to 10. The resulting value must be indexed to current dollars since the cost parameter in this equation is relative to the value of the dollar in the initial year of construction. Indexation can be easily done using the Bank of Canada Inflation Calculator.

$$PDE = PV_{original\ service\ life} - PV_{reduced\ service\ life} \quad (8)$$

where

$$PV_{original\ service\ life} = Initial\ Construction\ Cost\ [\$] \times \left(1 - \frac{pavement\ age[yrs]}{service\ life\ [yrs]}\right) \tag{9}$$

$$PV_{reduced\ service\ life} = Initial\ Construction\ Cost\ [\$] \times \left(1 - \frac{pavement\ age[yrs]}{0.3 \times pavement\ age[yrs] + 0.7 \times service\ life\ [yrs]}\right) \tag{10}$$

4.1.2 Pavement Service Life Reduction due to Increased Detour Traffic on Secondary Roads (PDT)

To satisfy traffic demands during construction activities which include partial or total occupancy of road space, detours are often planned and implemented. These detours often redirect traffic onto secondary roads which are not designed for heavy traffic loads (Gilchrist and Allouche, 2005). Consequently, significant damage may be inflicted during projects of long duration, thereby reducing the useful life of the pavement and resulting in premature resurfacing, or repaving needs.

While many motorists respect the traffic control plan by accepting congestion, queuing or detours, others attempt to avoid the traffic impacts of a work zone by traveling along alternate routes, also known as “rat-runs” (Read and Vickridge, 2004). This makes it very difficult to predict the behaviour of motorists affected by a work zone.

4.1.2.1 VALUATION

To quantify the pavement service life reduction on secondary roads (PDT), it would be necessary to collect data on the traffic patterns in urban construction zones. With appropriate research in this area, it would be possible to model the change in traffic patterns and thus quantify the increased load borne by secondary roads. This additional load could be converted to an equivalent loss of the pavement service life, using pavement analysis. The following equation could be used:

$$PDT = PV_{original\ service\ life} - PV_{reduced\ service\ life}$$

(11)

4.1.3 Adjacent Buried Utility Damage (BUD)

In urban areas, water and sewer pipes are typically located in close proximity of other buried utilities, such as gas, power, cable, telecommunications and district heating. A common risk associated with excavation is that of a utility strike. This has been identified by the American Institute of American Constructors as one of the three most important crises that construction crews face along with on-site safety incidents and contractual disputes (Jeong, Abraham, and Lew, 2004). Literature has shown that utility strikes are common and their crippling effects can have negative impacts on thousands of users and can cost millions of dollars in damage. A single utility strike can cause personal injury or death, property damage, lost work opportunity, community disruption, ecological damage and insurance liability (Federal Signal Corporation, 2005).

A 12-month study conducted by the University of Toronto (Osman and El-Diraby, 2005) investigated the costs and benefits of the application of subsurface utility engineering on large scale municipal infrastructure projects for the Ontario Sewer and Watermain Contractors Association. Surveys were developed to assess the extent to which utility strikes had been significant in the three years prior to the study. In total, 52 contractors and 12 municipalities from Ontario responded to the survey questionnaire. It was identified that on average 1.2 buried utility damages occurred per typical project as a result of inaccurate subsurface utility information. Discovery of an unidentified or misidentified buried utility during pre-construction location, or during excavation can result in a range of impacts including a quick redesign, schedule adjustment, modification of construction method and cost, or schedule overruns. The resultant claims were valued at an average of 1.1% of the project cost.

It should be noted, however, that all projects are subject to unique risks which reflect project size, contractor experience and work quality, subsurface utility mapping quality level, construction materials and methods, number and type of buried utility systems in work area, number of service connections, and surrounding traffic.

Additionally, buried infrastructure adjacent to an excavated trench is subject to damage due to loss of stability in its foundation caused by slouching of the neighbouring trench walls. Adjacent utilities which are exposed during excavation are occasionally suspended as the soil beneath them is removed. As compaction cannot be achieved to the same degree as prior to excavation, adjacent utilities may experience settlement-induced damage.

4.1.3.1 VALUATION

The cost of damage to adjacent buried utilities due to municipal construction projects is calculated as a function of the construction cost of the equivalent open trench alternative, the excavated volume required by the selected construction method and design, and the excavation volume associated with an open trench replacement. It is proposed to consider an average number of buried utility strikes of 1.2 per typical project and associated claims valued at a total of 1.1% of the project's construction cost according to University of Toronto's study (Osman and El-Diraby, 2005). However, the definition of a typical project, as understood by the respondents, was not stated in the University of Toronto survey. It would have been useful to have a reference unit such as a linear distance of excavation, or a volume of excavation to enable comparison between open trench and trenchless construction alternatives. It will be assumed in this study that a typical project consists of a 500m distance with an excavation of 6m^2 cross-sectional area. This value is considered to be conservative as it considers only the costs resulting from inadequate subsurface utility mapping, and not the value of impacts on buried utilities caused by the loss of foundation stability or poor excavation practices. The resulting equation is as follows:

$$BUD = Excavated\ volume\ [m^3] \times \frac{Typical\ number\ of\ claims}{Typical\ excavated\ volume\ [m^3]} \times Average\ claim\ value\ factor \times Direct\ costs\ of\ project\ [\$] \quad (12)$$

It is recommended that the excavated volume be assumed to be 3000m^3. Based on the work of Osman and El-Diraby (2005), the typical number of claims per project is recommended to be 1.2, and the average claim value factor to be 1.1 percent of the total project cost.

4.1.4 Lost Parking Meter Revenue (PMR)

It is common for construction sites to prevent access to public parking spaces. These spaces are offered by the municipality as a service to the society for a determined rate. It represents an economic activity which provides revenue for the municipality. Any obstruction to available metered parking spaces should be considered in total cost analysis as it represents a decrease in net social benefit (Boyce and Bried, 1994).

4.1.4.1 VALUATION

The value of the loss of parking meter revenue is calculated as a product of the number of lost parking spaces, the parking meter rate in dollars per hour, the daily operational duration of the metered parking in hours, the average occupancy rate of the spaces in the studied zone and the duration of the obstruction due to the project in days. This is reflected in the following equation.

$$\begin{aligned} PMR = {} & Lost\ metered\ parking\ spaces \times hourly\ rate\ [\$/h] \\ & \times daily\ operation\ duration\ [h/day] \times\ Average\ occupancy\ rate \\ & \times Duration\ of\ the\ obstruction\ [days] \end{aligned} \tag{13}$$

If the parking space value is available from parking management agencies, it is possible to reduce this equation to Equation 14. For example, the City of Montreal allows metered parking spaces to be occupied for reasons such as filming, construction and special events at a charge ranging from 11$/day to 33$/day for parking spaces with hourly rates of one and three dollars, respectively, in addition to a fixed permit fee (Vermette, 2009).

$$\begin{aligned} PM = {} & Lost\ metered\ spaces \times daily\ parking\ space\ value\ [\$/day] \\ & \times Durationof\ the\ obstruction[days] \end{aligned} \tag{14}$$

4.1.5 Lost Parking Ticket Revenue (PTR)

In areas with effective parking restrictions, any obstruction to parking space will not only inconvenience the parking clients, but also the municipality as ticketed infractions constitute a source of revenue for them. Again, the parking space is provided as a service to society and is not enforced. Those who willingly park in these spaces, knowingly accept to pay any fines associated with unlawful behaviour, therefore, it should be considered not simply a transfer of benefits but an effective loss to the municipality.

4.1.5.1 VALUATION

To valuate this cost, the agencies monitoring restricted parking zones must be contacted to obtain the required information. To estimate the loss of parking ticket revenue (PT), it is necessary to obtain information on the ticketing frequency in tickets per day and the average ticket fine amount in dollars as well as the number of spaces affected and the duration of the obstruction due to the project duration in days. This yields the following equation:

$$PTR = \frac{Lost\ restricted\ parking\ spaces}{Total\ spaces\ in\ restricted\ zone} \times Average\ fine\ amount\ [\$/fine] \\ \times Ticketing\ frequency\ in\ restricted\ zone\ [fine/day] \\ \times Duration\ of\ obstruction\ [days] \tag{15}$$

It should be noted that some drivers may tend to take the risk of parking in restricted zones when no other spaces are available. In some instances this may actually result in increased parking ticket revenue for the municipality during times of construction requiring occupation of public parking spaces. This notion should be reflected in ticketing frequency included in the equation of above.

4.1.6 Compensation and Tax Rebates (CTR)

In some locations, it is an acceptable practice for the governing agency to compensate external parties for their losses incurred during a municipal project. In the United Kingdom, businesses are allowed compensation for lost revenue incurred during local sewer works if these losses can be proven (Read and Vickridge, 2004).

Compensation may be in the tangible form of tax rebates, or compensatory payments, or it may be in the form of legislative lenience. To compensate for business lost during the previous year's 13 month infrastructure renewal project, the merchants on Saint-Laurent Boulevard requested permission and were granted the right to rent public space on the city sidewalks to build terraces in front of their businesses to increase sales from the months of April to October.

4.1.6.1 VALUATION

The total value of compensation and tax rebates associated with a BMIRP may be calculated as the sum of all individual compensations and rebates estimated to be forfeited by the municipality as:

$$CTR = \sum_{i=1}^{n} Value\ of\ compensation\ or\ tax\ rebate_i \tag{16}$$

4.2 External Costs - Social

External costs are the hardest of the three total cost components to quantify. They are very difficult to fully consider since tracing causal connection can be very difficult and time-consuming, and furthermore, obtaining payment for incurred damages would often be accompanied by high transaction or litigation costs (USEPA, 2000). The different methods used to valuate economic and socio-environmental impacts were explained in Section 3.1. The social, economic and environmental costs are explained below.

4.2.1 Increased Vehicular Travel Time (VTT)

Construction activities require space for machinery operation and storage, project development, signage, site protection measures and provision of entry and exit corridors (Gilchrist and Allouche, 2005). This space is occasionally provided by occupying existing traffic lanes, which causes congestion, loss of parking spaces and changes in traffic patterns. In turn, these effects result in longer trip times and distances and an increase in accident rates. Traffic delays oblige roadway users to forfeit a certain amount of their time to travelling, which could potentially have been used for other purposes. Economists consider this an opportunity cost (Ministère des Transports Québec, 2009a).

Traffic congestion caused by random conditions, or unique events such as construction work is called non-recurrent, or incident congestion (Ministère des Transports Québec, 2009a; Transport Canada, 2006). From a social point of view non-recurrent traffic deprives society from certain valued commodities such as productive time, leisure time, educational time, fuel and a healthier environment (Ministère des Transports Québec, 2009a). The value of traffic impacts caused by BMIRPs has been shown to represent up to 60 percent of the indirect and external costs associated with this type of construction work (Pucker et al., 2006) and up to 80 times the direct costs of a project (Institute of Civil Infrastructure Systems and Urban Utility Center, 1999). It has even been proposed to use the value of traffic delay costs as a benchmark with which to warrant a total cost analysis. Pucker, Allouche and Sterling (2006) suggested omitting indirect and external costs from project evaluation if traffic delay costs are estimated to be lower than 10 percent of a project's direct costs, and considered analytically if these delay costs surpass 25 percent of the direct project costs.

The value of traffic impacts associated with buried municipal infrastructure renewal projects (BMIRP) is quantified in the following sections in the form of increased vehicular and pedestrian travel time, increased vehicle operating costs, increased collision rates, and obstruction to emergency vehicles. The environmental impacts associated with increased traffic such as greenhouse gas emissions and air pollution will be examined in Section 4.4.1.

Although a few methodologies have been proposed to estimate the cost of congestion in Canada (Manuilova et al., 2008; Transport Canada, 2006; Zhang et al., 2004), this study proposes the use of the most recent methodology presented in a detailed report by Ministère des Transports du Quebec (2009a) to quantify the cost of recurrent urban congestion. Recurrent congestion represents a situation where a roadway is functioning at a reduced service level due to a demand which exceeds capacity. This is often the case during peak hours of operation, commonly known as morning and afternoon rush-hour. Although the focus of the MTQ (2009a) report was on recurrent congestion, the methodology adopted by the author is also applicable for use with non-recurrent congestion such as that arising from BMIRPs.

The MTQ used a two-stepped approach to quantify the cost of urban congestion. The first step involved estimating the amount of recurrent congestion in terms of vehicle-hours and the second, quantifying the recurrent congestion cost to society in monetary terms through value of time (VOT) estimates.

To estimate the total amount of delays in the traffic network of the Greater Montreal Area (GMA), a traffic network simulator, MOTREM03, was developed. A model was created which simulated vehicular flow rates and speeds throughout the entire network for cars, regular trucks and heavy trucks during peak morning and afternoon hours for a typical autumn day. Information for the model was taken from Montreal's transportation agency's (AMT) origin-destination study, conducted in 2003 (Agence métropolitaine de transport, 2003) by telephone surveys with a sample size equivalent to approximately 5 percent of the GMA's population.

To quantify the recurrent congestion cost, the MTQ introduced parameters used in a previous study of cost-benefit analysis of public transport projects (Ferland, 2007) which proposed a method of quantifying delay costs, additional vehicle operation costs, additional fuel costs, and the costs of pollutant and greenhouse gas emissions.

To estimate the cost of increased vehicular travel time due to BMIRPs, two main elements are considered in this thesis: the delay incurred and the value of time of those affected.

4.2.1.1 Measuring Vehicular Travel Time

The extent of traffic disruptions caused specifically by BMIRPs can be measured using either a scientific, or an empirical method, or through field studies. Scientific methods involve capacity and queuing analysis, or micro-simulation of local traffic networks using traffic modelling tools and the inclusion of traffic fleet characteristics. Well executed scientific studies yield accurate and customized results, but require a thorough understanding of traffic analysis using equations such as those from the Highway Capacity Manual (Transportation Research Board, 2000). Simplified scientific methods involving basic acceleration motion equations can be used when traffic conditions are assumed to remain below capacity even during traffic control.

Presently, the empirical method is limited to the studies conducted by Tighe et al. (1999) which allow the calculation of traffic delay costs given AADT, lane width, job duration and a traffic control plan. Empirical formulae proposed by Tighe et al. (1999) are simple to use given minimal input parameters, but their application is limited to two-lane urban highways and the three commonly used traffic control plans for BMIRPs shown in Figure 7. As the scenarios deviate from these settings, relevance of their equations becomes less significant.

Through field studies and trial runs, it is possible to forecast the traffic delays caused by detours on roadways. This method is efficient and requires minimal calculations but should be used only in traffic networks which operate well under capacity and are not subject to daily recurrent congestion. Under these conditions the traffic network will operate at a similar level of service before, during and after the construction activity, and field studies can be conducted to measure the implications on time and traveling distance of a planned detour route. If it is assumed that the planned detour route will operate at a lower level of service during construction then it is necessary to adopt a scientific or a proven empirical method to account for these effects.

In either case, the vehicular traffic delay caused by a work zone in the roadway is calculated as the difference between travel time, with and without the work zone, which may cause slowing, queuing or detouring via an alternate route as seen in Equation 17.

$$\begin{aligned}\Delta\, Travel\ time\ [h] = {} & \left(Travel\ time_{traffic\ controlled} - Travel\ time_{normal\ conditions}\right)[h/trip] \\ & \times Daily\ number\ of\ vehicles\ [veh/day] \\ & \times Vehicle\ occupancy\ [trips/veh] \\ & \times Duration[days]\end{aligned} \tag{17}$$

4.2.1.2 Value of Time

The cost of these delays is calculated based on two parameters, amount of lost time to users and the value of this time (VOT).

A review of the literature reveals that there has not yet been agreement on a single method of establishing VOT. This study proposes the following methodology based on the report by Ministère des Transports du Quebec (2009a).

The value of time is assumed to be dependent on two variables: trip purpose and level of income. Trip purposes are commonly obtained by transportation and transit agencies through origin-destination (O-D) surveys. Trip purposes can be divided into the four principal categories of business trips, commuting between work and home, leisure and shopping trips, and commuting between school and home. An explanation of each of these trip purposes is summarized in Table 4.

Table 4. Trip purposes and associated value of time (Ministère des Transports Québec, 2009a)

Trip Purpose	Description	Value of time
Business	Work-related trips which take place during work hours. Eg. travelling to business meetings and appointments throughout the work day, driving as an occupation (truck driver, courier, chauffeur, etc.)	*Business trip (non-cargo transportation):* value of hourly wage including employee benefits before tax deductions. *Cargo tansportation business trip:* value of hourly wage including employee benefits augmented by a factor for lost productivity in traffic and late deliveries.
Business commuting	Trips to travel between home and work	Average of values for business and other.
Student commuting	Student trips between home and a place of education	25% of the value of time for business trips

Other	Trips to and from activities other than work and school such as leisure and shopping.	Net value of hourly wage (ie after tax deductions)

The VOT of **business trips** is considered to be equal to the full value of the employee's salary as any loss of time during these trips results in a direct loss of productivity. It is obtained by calculating the hourly wage, based on the annual salary, including employer contributions.

Truck trips made for cargo transportation purposes are valued in the same manner, and augmented by a factor to account for the cost of lost productivity in congestion and late deliveries.

The value of time of **student commuting**, trips between home and an educational institution is considered to be 25 percent of the business trip VOT.

Other trip purposes include shopping, leisure and other such activities. The VOT for other trips is associated with the cost of lost opportunity and is representative of the marginal cost allocated to other such activities.

Time lost in traffic during **business commuting**, trips between work and home, are assumed to infringe equally upon time that could be spent on leisure and business. Its value is thus the average between the VOT for business and other trips.

The VOT of **bus passengers** is the weighted average of VOT for the four trip purposes proportioned according to the estimated distribution on the bus.

By manipulation of the Montreal origin-destination survey data from the Agence Métropolitaine de Transport (2003), it is estimated that trip purpose distribution in the city of Montreal is:

- Business: 18.5%
- Student Commuting: 10.0%
- Other: 25.0%
- Business Commuting: 43.0%
- Regular Truck Traffic: 2.5%
- Heavy Truck Traffic: 1.0%

To quantify VOT, it is proposed to consider the median income of roadway users in the affected area. These values may be obtained from data available in the national 2006 Census (Statistics Canada, 2006), adjusted for annual inflation, and updated as current versions of the census are released. These values are publically available and separated according to the census region. The Ministère des Transports du Quebec (2009a) has proposed the following VOT estimates in 2009 Canadian dollars shown in Table 5.

Table (5). Value of Time estimates for the Greater Montreal Area separated by annual income level and trip purpose (MTQ, 2009), indexed to 2009CAD$ from 2003CAD$ using Bank of Canada inflation calculator.

VALUE OF TIME (in 2009 CAD$)				
Level of Income	Business	Other	Business Commuting	Student Commuting
less than 19 999$	7.96	6.61	7.29	1.99
20 000$ to 24 999$	18.05	11.79	14.93	4.52
25 000$ to 29 999$	22.09	14.30	18.20	5.53
30 000$ to 34 999$	26.13	15.95	21.04	6.53
35 000$ to 40 000$	29.73	16.85	23.29	7.43
40 000$ and more	46.39	24.88	35.64	11.60
Cargo Transportation				
Regular truck	24.96	-	-	-
Heavy truck	29.89	-	-	-

The cost of increased vehicular travel time can be calculated according to Equation 18.

$$VTT = \Delta\, Travel\ time\ [h] \times Value\ of\ time\ [\$/trip/h] \qquad (18)$$

4.2.2 Increased Vehicle Operating Costs (VOC)

Vehicle costs are separated into two categories: operating costs and ownership costs. Vehicle operating costs (VOC) are attributable to the additional fuel consumption, oil consumption, tire wear, vehicle maintenance and vehicle depreciation associated with

BMIRPs (Manuilova et al., 2008). Additional traveling distances and reduced traveling speeds associated with BMIRPs inflict greater wear and tear on a vehicle. Ownership costs are not significantly affected by driving type or distance travelled; they are therefore neglected from this study. Along with traffic delay costs, the increased vehicle operating costs have been the most considered cost items seen in existing literature focusing on social impacts of BMIRPs (Boyce and Bried, 1994; Gilchrist and Allouche, 2005; Grondin, 2004; McKim, 1997; Veillette, 2007). Also, transportation authorities have studied these costs extensively (Ministère des Transports Québec, 2009a; Murphy and Delucchi, 1998; Ray Barton Associates Ltd., 2006; Transport Canada, 2006; Zhang et al., 2004)

Vehicle operating costs can be separated into two distinct categories: fuel consumption costs, and non-fuel maintenance and operating costs. Fuel consumption costs are a function of fuel price at the time and location of the study and of the traffic characteristics such as speed, acceleration, deceleration and idling time. Unless traffic is modeled using a simulation program which accounts for gradual stopping and starting, it is very difficult to consider fuel consumption costs. This study will rely on the previous studies by Canadian Automobile Association (CAA) to estimate fuel consumption costs. It is acknowledged that this will not necessarily consider the specific conditions incurred around the construction zone but it does consider stop and start traffic, as will be explained later in this section.

Non-fuel maintenance and operating costs in Canada have been estimated Ray Barton Associates, Ltd. (2006) in a report for Transport Canada and by the Canadian Automobile Association (CAA, 2007b). The latest Canadian research on indirect and external costs of BMIRPs by Manuilova et al. (2008) used the average vehicle operating cost of $0.033 per vehicle-km estimated by Ray Barton Associates, Ltd. (2006). This was calculated based on national driving habits including both highway and city driving. As this research project focuses on renewal of municipal water distribution and wastewater sewerage infrastructure located in urban areas, vehicle operating costs will be estimated using values estimated by CAA (2007b) which considers primarily stop and start traffic conditions. The vehicle operating costs estimated by CAA for a 2.2 litre 4-cylinder 2007 Chevrolet Cobalt LTZ sedan and a 3.3 litre 6-cylinder 2007 Dodge Caravan SE are presented in Table 6 after indexation to current dollars and adjustment for the rise in average Canadian fuel prices. The values were individually indexed to preserve the accuracy of the data, therefore, the total value presented may not actually be the sum of its associated values.

Table 6. Average Canadian vehicle operating costs (CAA, 2007), indexed to 2009CAD$ from 2006CAD$ using Bank of Canada inflation calculator and adjusted to account for rise in average Canadian fuel prices from 92.5 cents/litre in December 2006 to 102.96 cents/litre on June 11, 2009

AVERAGE ANNUAL OPERATING COSTS PER KILOMETRE (in 2009 CAD$) Based on 18,000km driven annually		
Operating Costs	Cost per Year	
	Cobalt LTZ	Caravan
Fuel	$0.0920	$0.1191
Maintenance	$0.0246	$0.0294
Tires	$0.0196	$0.0160
Total	**$0.1361**	**$0.1645**

These values are slightly higher than the results obtained by Ray Barton Associates, Ltd. (2007b). This was to be expected since operating conditions are more resource exhaustive in stop and start driving than in highway conditions.

It is proposed in this study to use the higher average vehicle operating cost associated with the Dodge Caravan to account for the fact that the nation's vehicular fleet does not consist of new vehicles as assumed in the CAA (2007a) values, but rather a mixture of new vehicles and used ones that operate at lower efficiencies, thereby, increasing the operating costs. A more thorough analysis can be conducted using data obtained by Ray Barton Associates, Ltd. (2006) that show VOC as a function of vehicle age. For the sake of this study, vehicle operating costs of $0.1645 per kilometre are considered acceptable.

The total cost of increased vehicle operating costs (VOC) associated with buried municipal infrastructure renewal projects is calculated in Equation 19:

$$VOC = Number\ of\ affected\ vehicles\ daily\ [veh/day] \times Increased\ travel\ distance[km] \times vehicle\ operating\ cost[\$/km/veh] \times duration[days] \tag{19}$$

4.2.3 Increased Pedestrian Travel Time (PTT)

The travel time of pedestrians may be negatively affected in a manner similar to that of the vehicles. Work zones occupying sidewalks or crosswalks compel pedestrians to travel along an alternative path. One of the implications is a loss of time due to detouring delay. Typical sidewalk detours or deviations are shown in Figure 13.

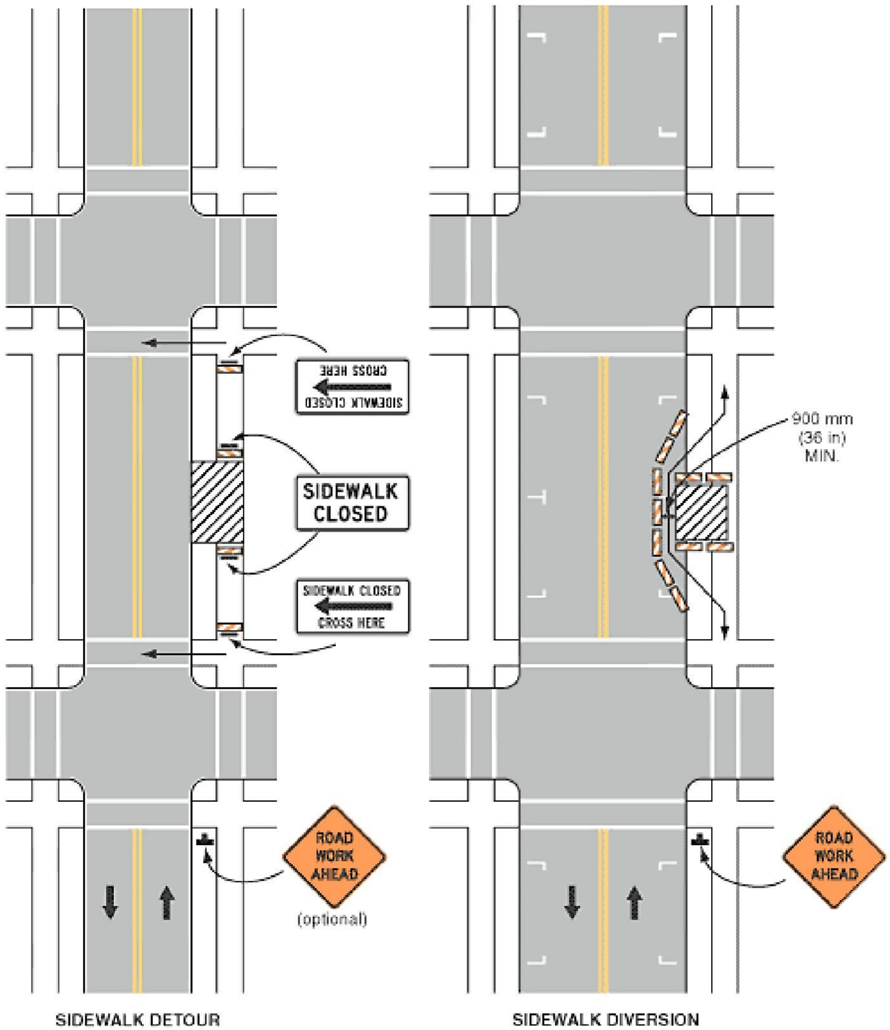


Figure 13. Typical sidewalk detour or diversion traffic control schemes (Federal Highway Association, 2003)

Significant research has been conducted in pedestrian traffic management and engineering. A useful description of the theories developed in this field is available in Transportation Engineering: An Introduction by Khisty and Lall (2003). Many of the theories are based on work found in the Highway Capacity Manual (Transportation Research Board, 2000). These theories have been adopted here to formulate a simplified method of valuating the impacts of increased pedestrian travel time due to BMIRPs. The method proposed is tailored for use by the intended reader, given that no available existing data on pedestrian traffic characteristics in the project location.

This method involves two parts, as mentioned in the previous section: estimation of the total pedestrian travel delay and valuation of this delay in monetary terms based on value of time (VOT) estimates.

4.2.3.1 Estimation of Increased Pedestrian Travel Time

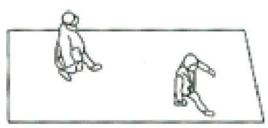
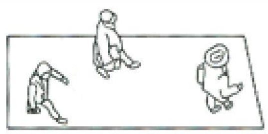
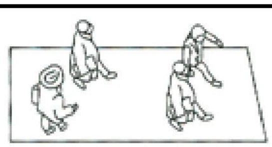
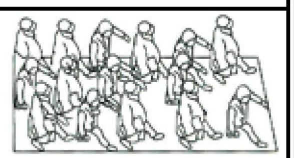
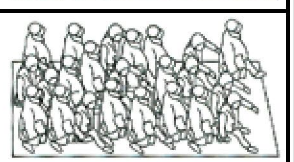
Pedestrian speed, density and flow are inter-related parameters that define a pedestrian traffic network (Khisty and Lall, 2003). Speed of pedestrians in a traffic stream decreases linearly as the density of travelers increases. Pedestrian walking speed also varies according to trip purpose, land use, age and other environmental factors. A maximum pedestrian speed can be approximated at 1.5m/sec.

Density is defined in terms of average number of pedestrians in a unit area. This can be an inconvenient measurement yielding fractions of pedestrians at times. Therefore the reciprocal value is used occasionally as available space per pedestrian (m^2/ped).

Pedestrian flow rate is the number of pedestrians that pass through a walkway section per unit time, usually one minute, or 15 minutes. This parameter is expressed in terms of pedestrians per minute per unit length (ped/min/m).

The level of service (LOS) is a qualitative measure used in the Highway Capacity Manual (2000) to describe operational conditions of a traffic stream and its perception by pedestrians (Khisty and Lall, 2003). Pedestrian traffic LOS is defined by available pedestrian space, flow rate, speed and flow to capacity ratio as shown in Table 7.

Table 7. Walkway Level of Service (Transportation Research Board, 2000)

Illustrated Level of Service	Level of Service	Space (m^2/ped)	Flow Rate (ped/min/m)	Speed (m/sec)
	A	>5.6	≤16	>1.30
	B	>3.7-5.6	>16-23	>1.27-1.30
	C	>2.2-3.7	>23-33	>1.22-1.27
	D	>1.4-2.2	>33-49	>1.14-1.22
	E	>0.7-1.4	>49-75	>0.76-1.14
	F	≤0.7	Variable	≤0.76

It is proposed that the parameters in Table 5 be used in the estimation of increased pedestrian travel time due to buried municipal infrastructure renewal project obstructions. The study can consider the impacts associated at all hours of the day, if traffic flow rate data can be collected at many times of the day. Otherwise, daily times when flow rates are low (LOS A,B) can be neglected from the study leaving only the peak hours of the day to be considered.

1. <u>Determination of Original Level of Service</u>

It is necessary to estimate the current LOS of the walkways in the area affected by construction activity. This will include all walkways that are fully or partially obstructed by construction activities and all walkways that may be used as an alternate route. Alternate routes include planned detour route, planned diverted route and any other routes which may be considered to be selected by the pedestrians in their desire to travel safely, securely, comfortably, conveniently and economically.

The LOS during normal conditions is determined by field studies in which the cumulative flow rate is measured during 15 minute periods at representative times of the day. This value is measured simply by counting the number of pedestrians that cross through a determined line of sight perpendicular to the walkway in a 15 minute period. The average flow rate is then obtained in terms of ped/min/m by first dividing the cumulative flow rate by 15, and then by dividing this value by the measured available width of the walkway. The available width of the walkway is the total cross-sectional width of the walkway, considering any obstructions (parking meters, mailboxes, planter boxes, etc.) at this location. By comparing this flow rate with the level of service values in Table 7, the LOS can be obtained and the walking speed could be interpolated. For example, a 2m walkway with a measured flow rate of 28ped/min/m would be operating at LOS D with a walking speed of approximately 1.25m/sec.

The original time required for a pedestrian to travel along each studied path is calculated as the quotient of travel distance by walking speed on each path as shown in Equation 20.

$$Original\ travel\ time = \frac{travel\ distance\ [m]}{walking\ speed\ [m/s]} \tag{20}$$

2. <u>Determination of Reduced Level of Service</u>

The LOS of alternate pedestrian routes is studied next based on the change in available pedestrian space. The detour or diversion LOS is estimated through manipulations using Table 7. The flow rate is modified in proportion to both the change in pedestrians walking along the given route and the change in available walkway width. The detour or diversion LOS is then obtained along with the equivalent walking speed.

To continue from the previous example, if it is assumed that the roadway is symmetric and that the traffic flow rate is equal on both sides of the road, the effect of detouring one entire side of traffic onto the other (as seen in Figure 13) would effectively double the flow rate on the shared portion of the detour route. Alternately, if the walkway is diverted rather than detoured (as seen also in Figure 13) and the available width of the diverted section is half that of the original walkway the flow rate per unit width would be effectively doubled as well assuming the number of pedestrians entering the travel stream remains the same as in the original case. In both detour and diversion scenarios, the flow rate is doubled from 28ped/min/m to 56ped/min/m and the associated walking speed becomes approximately 0.86m/s.

As for the original level of service, knowing the detour or diversion walking speeds (m/min), the time required per pedestrian to travel along each studied path is calculated as the quotient of travel distance by walking speed on each path as shown in Equation 21. In this case, however, it is necessary to add any additional time lost crossing roadways and waiting at signal lights which is presented in the next section.

$$Detour\ or\ diversion\ travel\ time = \frac{detour\ or\ diversion\ travel\ distance\ [m]}{detour\ or\ diversion\ walking\ speed\ [m/s]} \tag{21}$$

3. Evaluation of Crossing and Signal Delay

If the planned detour requires pedestrians to cross the road, this time must be calculated. It will be assumed that diversions do not significantly lengthen the travel distance and are therefore neglected. The walking speed for the original level of service will be used for simplicity and the effect of other pedestrians at the crosswalk will not be considered. Detoured pedestrians will be delayed by the time taken to cross any roads which is calculated using Equation 22:

$$Crossing\ delay\ per\ person = \frac{road\ width\ [m]}{walking\ speed\ [m/s]} \tag{22}$$

The crossing delay can be calculated as a function of traffic signal cycle timing as seen in Equation 23.

$$Signal\ delay\ per\ person = \left(\frac{green}{cycle}\right) \times 0 + \left(\frac{red}{cycle}\right) \times \frac{red}{2} + \left(\frac{amber}{cycle}\right) \times \left(\frac{amber}{2} + red\right) \tag{23}$$

In this equation *green*, *red* and *amber* are the signal times associated with each of these signals and *cycle* is the total signal cycle time. The terms red, green and amber are used for simplicity but may be replaced by the signal terms appropriate to the location such as *walk*, *don't walk* and *flashing don't walk*. The three elements in the sum represent, respectively:

- proportion of total pedestrians who arrive at a green light and incur no delay prior to crossing the street
- proportion of total pedestrians who arrive at a red light and incur an average delay of half the red signal cycle length
- proportion of total pedestrians who arrive at an amber light meaning do not begin to cross the road and who incur an average delay of half the amber signal cycle time in addition to the full red signal cycle time.

4. Evaluation of Total Daily Delay

The difference between the original travel time and the traffic controlled travel time, including signal and crossing delays is equal to the average total delay per pedestrian on a given path. This value is multiplied by the flow rate, the available walkway width and the daily duration of the obstruction to pedestrian traffic under the selected conditions. The total increase in pedestrian time due to a buried municipal infrastructure renewal project is finally obtained by multiplying this value by the number of days of walkway obstruction. This is shown in Equation 24.

$$Increased\ pedestrian\ travel\ time =$$

$$(Detour\ or\ diverted\ travel\ time + Crossing\ time +$$
$$+ Signal\ delay\ [min] - \ Original\ travel\ time)\ \text{[min]}$$
$$\times Flow\ rate[ped/min/m]$$
$$\times Available\ walkway\ width\ [m]$$
$$\times Daily\ duration\ [min/day]$$
$$\times Obstruction\ duration\ [days]$$

(24)

4.2.3.2 Value of Pedestrian Travel Time

To estimate the pedestrian Value of Time, it is necessary to first make a reasonable assumption of the trip purpose distribution along the studied paths. It is suggested that this be conducted on a case by case basis through observation of the pedestrians and the local neighbourhood characteristics. Certain pedestrian characteristics such as age, clothing, and accessories are clear indications of the trip origin, or destination. The neighbourhood characteristics such as property and land use can be good indicators of trip purposes, such as education, leisure, retail shopping, grocery shopping, business, leisure, etc. The average pedestrian VOT can then be determined based on the values in Table 5.

4.2.3.3 Valuation

The cost of increased pedestrian travel time (PTT) is calculated in Equation 25.

$$PTT = Increased\ pedestrian\ travel\ time[h] \times Average\ Pedestrian\ VOT\ [\$/h]$$

(25)

4.2.4 Increased Collision Rate (ICR)

One third of all highway construction zone accidents are traffic accidents, of which only twenty percent involve a member of the construction crew (Bryden, Andrew, and Fortuniewicz, 1998). Accidents include collision with traffic control devices and safety features, construction features, excavations, materials, construction vehicles, equipment and workers.

Construction zone collisions are not documented adequately to develop any empirical relationship. Research has shown that the likelihood of traffic collisions occurring in construction zones ranges from being 7 to 119 percent more likely than in normal operating conditions (Wilde, Waalkes, and Harrison, 1999). This range is influenced by factors such as driving speed, clarity of signage, available clearance, and road conditions.

Manuilova et al. (2008) have reviewed the available valuation methods associated with the cost of collisions in construction zones. A summary of their findings is presented in Section 2.5.10. The authors adopted the method developed by Zhang et al. (2004) to quantify the costs of collisions in construction zones for the total cost analysis of a buried municipal infrastructure renewal project. This method involved the notion of value of statistical life (VSL) which is valued at CA(2009) 4.79 million dollars. The average costs of collisions per vehicle distance traveled are indexed to current dollars and estimated at

- Urban/interurban vehicle: $161.02/1000veh-km
- Urban/interurban bus: $503.08/1000veh-km
- Freight vehicle/ truck: $172.09/1000veh-km

These values, however, are based on the entire Canadian traffic fleet, which includes a large proportion of highway traffic and no consideration for collision rates in construction zones. Fatal crashes in Canada are approximately 0.6 times as likely on roads with speed limits of 60km/h and lower than on roads with higher speed limits (Transport Canada, 2009).

4.2.4.1 VALUATION

More research is needed in this area to develop accurate estimates of the cost of increased collision rates, however, this thesis proposes to use the results from the Zhang et al. (2004) study factored by 0.6 and 0.63 to reflect the decreased collision rate in urban areas and the average increase in collision rate in construction zones from Wilde et al. (1999), respectively. The results are:

- Urban/interurban vehicle: $60.86/1000veh-km
- Urban/interurban bus: $190.16/1000veh-km
- Freight vehicle/ truck: $65.05/1000veh-km

It is proposed in this study to use Equation 26 to estimate the cost of an increased collision rate (ICR) associated with BMIRPs:

$$ICR = Average\ cost\ of\ collisions\ [\$/km] \times Construction\ zone\ route\ length[km] \times Number\ of\ vehicles\ daily\ [/day] \times Duration\ [days] \tag{26}$$

4.2.5 Obstruction to Passage of Emergency Vehicles (OEV)

Construction work which occupies roadway space has the potential to obstruct the passage of emergency vehicles such as fire, police, ambulance and other emergency first respondent vehicles. In Montreal alone, the fire department responds to 50, 000 calls annually from 66 stations (Ville de Montréal, 2008). In emergency first response, arrival time is critical. A one-minute delay in paramedic arrival time can decrease a cardiac arrest victim's chance of survival by up to 10 percent (Nichol et al., 1996). The impacts of late response may include increased crime, mortality and property damage in fires.

Many cities, however, have sophisticated communication networks which ensure that emergency response crews are supplied with up to date traffic conditions, including the location of construction activities. This can assist emergency response teams to plan the most efficient route by avoiding or minimizing the effects of obstructions such as those caused by BMIRPs (Charrette, 2009). However, not all cities are equipped with communication networks to the same extent, and smaller cities are usually at a disadvantage.

4.2.5.1 VALUATION

At this time, there is insufficient information available in the literature on the subject to accurately assess the cost of obstruction to the passage of emergency vehicles (OEV). A generic equation is proposed for future refinement.

$$OEV = Value\ of\ emergency\ response\ time\ [\$/min] \times Delay[min] \times Trip\ frequency\ [/day] \times Duration\ [days] \tag{27}$$

Further research can assist with valuating the cost of these impacts based on certain existing economic mechanisms such as, but not limited to:

- Ambulance response fees:

These are charges for response to a call which account for services, supplies and vehicle operating costs incurred in response to a call. The ambulance response fees are paid presently by individuals, or their health insurer.

- Late ambulance response penalty charges:

These are penalties charged to ambulance service providers in certain municipalities of North America for exceeding predetermined response times. Ambulance services in Tuscaloosa, Arizona are penalized US(2008) $11 per minute of response time over the predetermined 10 minute emergency run time (Taylor, 2008).

- Value of Statistical Life:

This is a value that is used widely in environmental valuation which places a monetary value on the life of a human being. Other similar techniques exist, such as the human capital approach which considers economic output lost through premature death. These could be used if research is conducted relating response time to mortality and severity of injuries.

4.2.6 Accidental Injury and Death (AID)

Construction endeavours involve many activities which can result in injury, illness or even death of employees, or members of the larger public. Pedestrians travelling through or in close proximity of an active work zone may be subjected to significantly higher risks of accidental injury, or illness due to collision with heavy vehicles, stumbling on construction materials and obstructions, exposure to noise and vibration, and inhalation of dust and exhaust fumes.

From the construction workers' perspective, trenching-related deaths and serious injuries are all too common. The accident rates associated with trenching activities is 112% higher than those associated with general construction (Everett and Frank, 1996). A worker in Oka, a municipality just outside Montreal, died buried in a trench in

October, 2007 (CSST, 2007). These accidents are occasionally the results of cave-ins, toxic fumes, drowning, electrocution and explosions (Williams, 2002). Soil stockpiled on the edge of a trench increases the pressure exerted on the trench wall and the vibrations generated from heavy machinery both increase the risk of cave-ins. Trench wall sloping, shoring and worker shielding are not always sufficient to resist the tremendous earth loads and protect workers from serious injuries or death (Trenchsafety.org, 2007).

The Occupational Safety and Health Administration (OSHA) had identified open-trench sewer, water and pipeline construction as the fourth most dangerous job in the United States in the year 2000. This information results from in the 2001 OSHA Industry Profile report on occupational fatalities, injuries, safety violations and assessed penalties (Williams, 2002). Also, it was shown that the rate of open-trenching accidents are increasing rising and this in major part due to this area's leading role in the construction industry in terms of OSHA safety violations and non-compliance with safety training requirements.

Certain costs of accidental injuries and deaths on a job site are usually included in the direct cost of a BMIRP as workers compensation insurance coverage (Boyce and Bried, 1994). Workers compensation insurance typically covers the costs of medical expenses, transport, damage to property, equipment and plant as well as the cost of lost wages during convalescence(De Saram and Tang, 2005).

The less obvious costs attributable to accidental injuries and deaths include loss of productivity, pain, suffering, investigation and reporting time, etc. (De Saram and Tang, 2005). These are a set of external costs which are normally not considered in insurance clauses. Insurance agencies typically estimate these costs as a factor of the financial costs mentioned previously. This factor is used as a multiplier to augment the aforementioned financial costs to account for non-material losses due to pain, suffering and loss of enjoyment of life undergone by the victim (De Saram and Tang, 2005). Because it is difficult to estimate some impacts of accidental injuries and death, certain less obvious costs are not included in insurance compensation such as the cost of adverse impacts on family (De Saram and Tang, 2005).

Accidents involving members of the public may be covered by insurance only if these accidents are reported. This is not always the case; many personal injuries are settled out of court. These costs are currently borne by the public and should also be considered external costs.

4.2.6.1 VALUATION

The costs associated with accidental injuries and deaths (AID) fall into both the category of direct costs and external costs of BMIRPs. Injuries and deaths resulting from BMIRPs which are reported for insurance purposes, and are not considered in contract costs. Since estimating techniques are not very well developed outside of the realm of insurance coverage, this thesis will not propose a specific method of valuating these costs and instead, propose a simple equation that considers only the external AID costs are shown in Equation 28:

$$\begin{aligned} AID = {} & Accident\ and\ injury\ costs\ settled\ out\ of\ court \\ & + Accident\ and\ injury\ costs\ neglected\ from\ insurance\ policies \end{aligned} \tag{28}$$

4.2.7 Property Damage (PPD)

Excavation and operation of heavy vehicles can cause significant damage to roads, sidewalks, lawns, driveways, street furniture and appurtenances adjacent to the construction zone. While the costs of restoring and repairing these facilities are included in the direct costs of buried municipal infrastructure renewal projects, experience has shown that the properties are not always fully restored to the same condition as that prior to construction. The resulting damage is either restored at the property owner's expense, or restored at the responsible party's expense after court settlement, or is simply not restored but tolerated by the owner. All of these cases represent a cost that is not directly considered but borne as an indirect cost, or an external cost.

Additionally, vibrations from compaction activities can damage buried and aboveground structures. The impact of vibrations on buildings may range from simple nuisance to considerable structural damage. These may be the direct result of the energy absorbed, or the indirect result of vibration-induced settlement. Dewatering operations may also cause settlement of structures. Sensitive equipment in operating rooms of hospitals, or in manufacturing facilities can be negatively impacted by vibrations from construction activities (Gilchrist and Allouche, 2005). These damages may not be immediately detected and therefore the cost of repair or tolerance is left to be borne by the owner at a later date.

Basement flooding as a result of sewer backups during construction activities are a problem that may cause significant damage. Rahman et al. (2005) discuss a case where this type of damage caused 20 to 40 million dollars worth of damage in an Ontario community.

4.2.7.1 VALUATION

The costs of property damage, above and beyond what is included in the restoration costs stipulated in the construction contract, may be estimated using precedents. Stated preference valuation techniques may also be suitable for estimating the cost of tolerating negative impacts. Damage caused by BMIRPs is expected to vary according to construction method, contractor experience, location characteristics, time constraints, spacial constraints and quality of underground utility mapping. Given the fact that property damage associated with BMIRPs are so project specific and that presently there is insufficient data available with which to formulate reasonable property damage cost estimates and only a generic equation will be proposed. It is recommended that studies be conducted to assess the local likelihood of damage in municipalities. Equation 29, based on the equation for risk, can be used to estimate the cost of property damage (PRD) associated with BMIRPs:

$$PRD = Likelihood\ of\ damage \times Likely\ cost\ of\ damage \times number\ of\ occurences \tag{29}$$

4.2.8 Psychological and Physical Ailments (PPA)

Aggravating impacts of construction such as noise and vibrations are likely to induce negative health effects on those who are more susceptible to these disturbances. The public may not feel safe in the presence of high vibration producing activities such as pile driving, dynamic compaction, blasting and the operation of heavy construction equipment. Common health effects of these are high blood pressure, cardiovascular disease, sleep disturbance, fatigue, irritation and stress which may lead to loss of productivity (Gilchrist and Allouche, 2005). Long-term exposure of noise throughout a day may also lead to tinnitus - ringing of the ears - which have the same negative health effects as listed above (Center to Protect Workers' Rights, 2003).

4.2.8.1 VALUATION

The valuation method for this cost item is loss of productivity which consists of measuring the reduced income resulting from the negative impact. The equation used to calculate the loss of productivity due to psychological and physical ailments (PPA) caused by BMIRPs is based on the following equation developed by Gilchrist and Allouche (2005):

$$PPA = number\ of\ employees\ affected \times average\ hourly\ output\ [\$/h] \times productivity\ reduction\ factor \times project\ duration[h] \tag{30}$$

While research in this area is still necessary to improve the accuracy of the loss of productivity method, the available research proposes productivity reduction factors for different industries. The effect of noise pollution on productivity in different industries is shown in Figure 14.

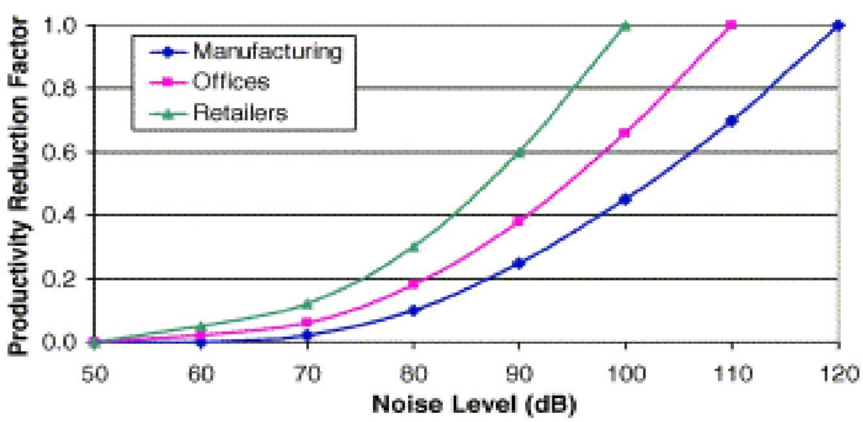


Figure 14. Effect of noise pollution on productivity (Gilchrist and Allouche, 2005)

4.2.9 Water and Wastewater Service Interruption (WSI)

In addition to any utility service interruptions caused by utility strikes (Section 4.1.3), buried municipal infrastructure renewal projects often require partial or complete interruption to water or waste water services, thereby depriving customers of the service amenity. The duration of service interruptions are typically in the range of 15 minutes to 4 hours (Gelly, 2009). The affected population are generally forewarned of scheduled interruptions by the municipality and informed on the related causes, duration and implications.

Water supply may be suspended while temporary services are connected and water pressure may decrease while networks are supplied by them. "Boil water" warnings may be in effect during these times which require residents to either spend time and energy disinfecting water by boiling, or spend time and money buying bottled water. These costs are not considered in current project evaluation. However, when supply of drinking water is expected to be suspended for a significant period, provisions of bottled water are typically assumed by the municipality and included in the direct costs of the BMIRP.

Some facilities such as hospitals and nursing homes are highly dependent on availability of clean water and wastewater services to ensure proper health care for their patients. Water-critical businesses and industries may lose income during service interruptions as well, but the costs associated with these are considered in *Lost Business Income*.

4.2.9.1 VALUATION

While the impacts of water and wastewater service interruptions are diverse, the related cost (WSI) can be based on the cost of lost amenity:

$$WSI = Value\ of\ amenity[\$] \times Amenity\ reduction\ factor \times Affected\ population \times Duration \tag{31}$$

The value of an amenity can be estimated using replacement costs associated with bottled water, time, heating energy and traveling. Alternately, stated preference techniques can be used to estimate the willingness to pay to avoid, or the willingness to accept payment for being subjected to service interruption.

4.3 External Costs - Economic

Economic activities may be greatly affected by the presence of an adjacent construction zone if this inhibits accessibility to the market place or amenity of the good or service being traded. Buried municipal infrastructure renewal projects can negatively impact an individual's level of productivity, municipal income from parking sources, and business income from sales sectors ranging from property to retail sales. These are discussed in this section.

4.3.1 Lost Business Income (LBI)

Business losses can occur as a result of construction activities related to buried infrastructure when accessibility, storefront visibility or appeal becomes compromised, when air pollution, noise pollution or vibration reduces productivity, or when utility services are temporarily interrupted. Business clients may be unable to access the business and incoming and outgoing deliveries may be delayed or temporarily rendered impossible. Also, clients may be deterred from the business due to a lack of amenity from dust, dirt, air, noise, or visual pollution. Similarly, the perception of being unsafe near a construction site may also act as a deterrent. The effects of a BMIRP on business income may outlast the actual project duration as it may take time for business activities to resume and stabilize to the pre-construction norm.

A common debate that arises in discussion with experts in the field of municipal infrastructure is one that questions whether or not business sales that are lost by one company and gained by another within the same municipality are indeed an external cost, or simply a business sales transfer. It is argued that an external cost should result in a decrease in net social benefit, whereas the particular case of business which can be substituted within the municipal boundaries simply involves an economic transfer from one societal party to another without ever leaving the municipal tax base. An exception occurs when either the services provided by one store are not available within the municipal boundaries (Boyce and Bried, 1994), or when the losing business requests a property tax rebate (Rahman et al., 2005).

Although the notion of sales transfer within a municipality is acknowledged in this study, it is proposed that all economic losses be considered in total cost analysis as businesses reliant upon dependable income, and any effect of BMIRPs that negatively disturbs the stability of business income should be considered a cost. Any positive impacts can be considered and compared with those in cost-benefit analysis.

In Montreal, the owner of a coffee shop franchise on a busy commercial street, Saint-Laurent Boulevard, has estimated a 25 percent loss in business sales due to municipal infrastructure renewal work in front of the store location (Benessaieh, 2009). The owner has filed a claim against the utility agency in the name of all of the 650 business owners and the tenants on the nearly 1.5 km long affected section of the roadway which was excavated at more than 40 locations in the peak business periods of spring and summer of 2007 and again in the spring of 2008 (Croteau, 2007). These businesses have been affected differently by the construction work on Saint Laurent Boulevard with owners claiming loss of income ranging from 10% to 60% of the seasonal norm (Lemoine, 2008). Although a settlement has yet to be reached, this is an example of a good and service, which can easily be provided by another merchant at a nearby location, thereby resulting in a benefit transfer. Nonetheless, if the claim is accepted, the result is an indirect cost to the municipality and therefore a decrease in net social benefit. Under current legal practice, the negative effects on certain businesses may be claimed but the added benefits on other businesses will remain unaccounted.

It should also be noted that business sales reduction associated with BMIRPs may have either increasing or decreasing effects on operating costs and expenses. In some instances, it is possible for a business owner to temporarily reduce costs and expenses to offset a reduction in sales, whereas other businesses must maintain steady costs and expenses even throughout times of reduced sales. It was identified in discussion with business stakeholders in Montreal that "just-in-time" industries which rely heavily on timely deliveries may incur greater losses during the duration of an adjacent BMIRP. These activities cause additional expense for priority expedition, or multiple delivery attempts until the roadway is cleared enough to allow access to vehicles associated with complete obstruction of delivery routes, or partial obstruction causing delivery delays. As delivery times increase, freight shipping costs rise, thereby increasing the operating costs and decreasing the net business income and the competitiveness of local businesses (Ministère des Transports Québec, 2000).

4.3.1.1 VALUATION

This case of specific lost business income (LBI) sensitivity to BMIRPs is considered by estimating the percent change in net average income (the difference of gross revenue and the total costs and expenses) over the time period affected by a project. The total LBI associated with a project is the sum of LBI for all affected businesses as shown in Equation 32. The information required for these calculations should be obtained from non-biased surveys of local business owners until further data is available which can be used to derive empirical formulae.

$$\begin{aligned} LBI = {} & (percent\ change\ in\ revenue \times anticipated\ average\ revenue\ [\$]) \\ & -(percentchange\ in\ costs\ and\ expenses \\ & \qquad \times anticipated\ average\ costs\ and\ expenses\ [\$]) \end{aligned} \tag{32}$$

4.3.2 Loss of Property Value due to Noise (LPV)

Construction activities are one of the most common sources of noise in the urban setting. The sounds emitted may be from a variety of sources such as earth moving, paving or pneumatic equipment, vehicle backup alarms, or demolition activities (Gilchrist, Allouche, and Cowan, 2003). Construction noise may have the effect of lowering the residential real estate value for a period of time when the levels are above the ambient norm.

Noise is defined as a sound with the potential to disturb humans, or cause adverse psychological or physiological effects to humans (Schexnayder and Ernzen, 1999). The effects of noise are dependent on noise level and duration. Noise is measured on the logarithmic scale of A-weighted decibels (dBA), which means that a slight increase in decibel values is associated with a major increase in noise (Center to Protect Workers' Rights, 2003).

Jackhammers and backhoes are among the loudest construction equipment on BMIRP sites. Noise levels for various construction equipment and activities as a function of the perceived distance from source is shown in Appendix B. The noise level of a jackhammer is 130 dBA at the source (Center for Hearing and Communication, 2009). In comparison, the noise level in a quiet residential area averages 40 dBA, 60 to 65 dBA on a typical city street with automobile traffic, and 85 dBA with heavy traffic. The noise dissipates in its surroundings resulting in a reduction of the noise level a distance from the emitting source increases. The noise levels of jackhammers and backhoes range decrease from 85 dBA at a distance of 15m to 65dBA at 120m (Gilchrist and Allouche, 2005).

Hedonic pricing research studies (Section 3.1) have shown that noise exposure can reduce property value by 0.4% to 0.9% per dB depending on the noise exposure factor (NEF) which reflects the type of noise and its duration. Although the literature in this area favours research into the effects of airport noise on property values, a significant number of published studies are available on the effects of traffic noise (Bateman et al., 2001; Nelson, 2004; Wardman and Bristow, 2004). A widely used method of valuating the effects of noise on property values is the Noise Depreciation Index (NDI). This method of noise discounting relates noise exposure to reduction in property value in terms of percent loss per dB above ambient conditions. A recent study by Nelson (2004) shows that through meta-analysis of 25 representative traffic noise damage estimates in Canada and the United States, an unweighted mean of 0.57% per dB was obtained.

For the purpose of this study an NDI of 0.55% per dB will be used. This value may be conservative as the Canadian property value has been shown to be more sensitive to airport noise (0.8-0.9% noise discount per dB) than American property value (0.5-0.6% noise discount per dB) which may very well apply to the effects of traffic noise.

4.3.2.1 VALUATION

The loss of property value due to noise is calculated as a function of level and duration of noise generated by construction activities, parameters of the local real estate market and the noise depreciation index which relates the loss of property value to noise pollution levels. This is calculated using Equation 33.

$$LPV = \frac{Number\ of\ affected\ units}{Total\ number\ of\ units\ in\ market\ area}$$

$$\times Average\ daily\ sales\ [/day]$$

$$\times Average\ daily\ sales\ price\ [\$]$$

$$\times Increase\ in\ noise\ level\ relative\ to\ norm[dB]$$

$$\times NDI\ [/dB]$$

$$\times Duration\ of\ noise\ exposure\ [days]$$

(33)

where NDI is the Noise Depreciation Index, in percent change of property value per decibel of noise relative to the norm. Presently, this value is recommended to be taken as 0.55% reduction in property value per dB based on the research by Nelson (2004).

4.4 External Costs - Environmental

4.4.1 Air Pollutant and Greenhouse Gas Emissions (APE)

Air pollutant and greenhouse gas emissions associated with BMIRPs result from operation of construction equipment and heavy machinery, and the additional fuel consumption resulting from traffic congestion and detours.

Operations of construction machinery produce emissions of carbon and nitrogen oxides, toxic substances, dust, heavy metals, chlorofluorocarbons and other greenhouse gases (Gilchrist and Allouche, 2005). These gases contribute to the ground-level ozone and other pervasive air quality problems, which may among other things trigger and aggravate respiratory and cardiac conditions, especially in children, the elderly and the asthmatic; they also result in ozone depletion which indirectly leads to skin-cancer and cataracts, besides harm wildlife, agriculture and the environment (USEPA, 2007). Ground-level ozone is a primary component of smog which is formed principally during the hot summer months. As a result, municipal construction workers are especially susceptible to reduced lung function and respiratory symptoms associated with ground-level ozone as they are highly exposed to this pollutant in the summer months while exerting even moderately (USEPA, 2007).

The additional fuel consumed by vehicles while accelerating and decelerating in traffic congestion and in travelling through detours results in increased air pollutant and GHG emissions. The extent of traffic disruption due to BMIRPs was previously discussed (Section 4.2.1.1) and the reader can consult the studies by Zhang et al. (2004) and Manuilova et al. (2008) for more details on the subject.

Commissioned by the British Columbia Chapter of the North American Society for Trenchless Technology, Knight and Rehan (NASTT-BC, 2007) compared the greenhouse gas emissions associated with the replacement of a hypothetical 250m long, 300mm diameter pipe using trenchless and open-cut pipe renewal techniques. It was found that the use of trenchless technologies achieved a 78 to 100 percent reduction in green house gases emitted due to a shorter job duration for heavy equipment, and little to no traffic disruption. However, it should be noted that a 100 percent reduction in green house gas emissions would require the use of no on-site fuel-powered equipment. As this is not the case in trenchless construction the upper bound estimate of 100 percent green house gas emission reduction should be considered unattainable. Open-cut pipe installation increased fuel consumption due to traffic delays and detours, and required longer heavy equipment operating hours to complete extensive excavation, compaction, backfilling and paving works. The amount of CO_2 emissions calculated in this study is conservative, since material delivery and manufacturing were neglected.

The NASTT-BC further developed this study into a very practical online tool – the Carbon Calculator (Griffin, 2009a). Given basic project details, this tool estimates the CO_2 emissions associated with utility line replacement projects for pipes of 2 inches (50mm) in diameter, or larger. The elements considered in the study are traffic, trucks, machines, pumps and materials. The Carbon Calculator estimates and compares the emissions associated with open trench excavation and three different trenchless construction methods, separated according to their carbon output: horizontal directional drilling (HDD), sliplining and pipebursting, and cured-in-place pipe (CIPP) lining, and spot repair and grouting. The Carbon Calculator is available online at www.nastt-bc.org.

E-Calc is a similar tool which was developed by Vermeer Corporation, a construction equipment manufacturer. Like NASTT-BC's Carbon Calculator, E-Calc requires the input of construction project details to evaluate emission volumes of pollutant gases associated with one of four construction methods: horizontal directional drilling, pipebursting, open cut with excavators or backhoes, and open cut by trenching (Griffin, 2009b). E-Calc, however, calculates only the emissions associated with construction and not with traffic. Six pollutants identified by the EPA are considered in the program:

carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NOx), total organic compounds (TOC), sulphur oxides (SOx), and smoke and particulate matter (PM_{10}). E-Calc is available at www.vermeer.com.

As social, political and regulatory pressures increase to reduce the pollution generated by construction activities, such emissions calculators can prove to be valuable tools for municipalities and contractors. As municipalities strive to reduce their carbon footprint, regulations, such as the one which will require all cities in British Columbia to be carbon neutral by 2012 (Griffin, 2009a), will be assisted by emissions calculators can be useful tools in documenting emissions records for carbon credits (Griffin, 2009b). These tools have their limitations and may be subject to bias, but are currently the best available methods of estimating the harmful emissions associated with BMIRPs.

4.4.1.1 VALUATION

The cost of air pollution and greenhouse gases is proposed to be measured in one of two ways: as a cost per volume of emitted pollutant, or as a cost per vehicular travel distance. When pollution levels associated with traffic and construction activities are available from emissions studies or calculators, the total cost associated with air pollutant and greenhouse gas emissions (APE) is calculated using Equation 34a:

$$APE = \sum_{i=0}^{n} Volumetric\ emissions\ cost_i [\$/metric\ ton] \times Emmitted\ volume\ _i [metric\ tons] \tag{34a}$$

where the pollutant cost is obtained from appropriate environmental valuation studies. The following values shown in 2009 Canadian dollars are proposed for use in Equation 34a (Ministère des Transports Québec, 2009b):

- 37.03 \$/metric ton CO_2
- 1 680 \$/metric ton CO
- 6 110 \$/metric ton TOC
- 7 793 \$/metric ton NO_x
- 3 319 \$/metric ton SO_x

- 4 622 \$/metric ton PM_{10}

Pollutant gases can be can be converted to carbon dioxide equivalent (CO_2e) units to simplify calculations by considering their global warming potential (GWP) in terms of that of CO_2. More information on this topic can be found at the International Emissions Trading Association (2009) website.

Additionally, values from the Canadian carbon market may be used for valuation of air pollutant and greenhouse gas emissions. Currently the Montreal Climate Exchange (2009), a joint venture with the Chicago Climate Exchange, is a platform for trade of carbon emitters' and offset credits. The current market price according to the Montreal Climate Exchange is 40 dollars. Currently, environmental restrictions are only slowly entering the market place. It is believed that when environmental regulation becomes more stringent emissions trading will become more prevalent leading to an increasingly relevant indication of the value of gaseous emissions.

When available data is limited to the increased vehicular travel distance, the total cost associated with both air pollutant and greenhouse gas emissions (APE) is calculated using Equation 34b:

$$APE = \sum_{i=0}^{n} Passenger\ emissions\ cost_i[\$/passenger/km] \times Increased\ travel\ length\ _i[km] \times Average\ vehicle\ occupation[passengers] \qquad (34b)$$

where the emission cost is obtained from appropriate environmental valuation and transportation studies. The values in 2009 Canadian dollars are proposed for use in Equation 34b (Zhang et al., 2004):

- Urban private vehicle: 0.0110 \$/passenger-km
- Urban transit : 0.0043 \$/passenger-km
- Freight transport (truck) : 0.0064 \$/passenger-km

4.4.2 Environmental Damage and Contamination (EDC)

Construction activities may disturb the natural hydrological, geological and ecological environment. The footprint of buried municipal infrastructure renewal projects may extend beyond the physical boundaries of the construction site when the negative environmental impacts associated with them propagate through water, soil and air.

Soil and water contamination can occur during BMIRPs as fuel, oil and chemical fluids necessary to run on-site machinery and heavy vehicles can easily leak, spill or be released through exhaust fumes onto the exposed ground. Uncracked paved surfaces inhibit, or considerably slow down the propagation of contaminants to the underlying soils, however, during excavation this paved layer is removed and the soil is directly exposed to these pollutants.

Strict environmental laws are currently in place to enforce removal of contaminated soils and fill material from a job site and their treatment prior to disposal in an authorized facility. The costs of loading, transporting, treating and disposing contaminated soils are normally considered in the direct costs of BMIRPs.

When dewatering operations are necessary for trench work and pipe installation, the local water table is affected. Gilchrist and Allouche (2005) explain that if this impact is significant, it may harm plant life and reduce the availability of water for agricultural use. They suggested that BMIRPs may cause bank erosion, flooding, alteration of watercourses, and loss of water quality by sedimentation, dust and fuel.

4.4.2.1 VALUATION

Environmental restoration costs such as treatment and disposal costs for contaminated soils and clean-up costs for water contamination can be estimated based on the associated market costs. However, it is arguable that the full environmental costs should be considered in market prices. For example, the long term impacts of exhausting landfill space for soil disposal and the cost of permanent damage to aquatic life are neglected in market prices. To achieve sustainable development, these impacts must be considered in project evaluation. Otherwise, by meeting current needs the society will compromise the environmental quality for future generations.

As discussed previously, by using available environmental valuation techniques such as stated and/or revealed preference and travel costs (Section 3.1), it is possible to attempt to valuate these negative impacts but the relevance of these results is open for debate. It is clear, however, that in the absence of market prices, it is difficult to draw conclusive results. Estimation of environmental costs and benefits will be improved as these items continue to enter into the market place through policies such as pollution rights and taxes. An equation to calculate these costs will not be proposed here as considerably more research is required in this field.

4.4.3 Dust and Dirt Pollution (DDP)

Pavement cutting, excavation, earth moving and site cleaning operations generate significant amounts of dust which can cause negative health impacts ranging from minor skin irritations to cancer with the degree of risk dependent on the nature and degree of exposure (Ferguson, 1995).

Additionally, dust and dirt generated by construction activities can settle on neighbouring residential and commercial property, resulting in dust pollution. It has been shown that the effects of construction dust can be observed up to 150m from the job site (Watkins, 1980). Additional cleaning of such surfaces may be required during project phases which are known to generate much dust and dirt.

4.4.3.1 VALUATION

The health impacts associated with construction-related dust is considered through valuation of particulate matter (PM_{10}) in Section 4.2.3.1. Only the additional costs of cleaning will be considered in this cost item. This is calculated as the product of the daily increase in cleaning needs in hours, the local hourly rate paid for cleaning services in dollars per hour and the job duration in days. If certain phases of construction are known to produce relatively insignificant amounts of dust and dirt pollution then these should be omitted from the job duration. The dust and dirt pollution costs (DDP) can be calculated using the following equation:

$$DDP = Increased\ daily\ cleaning\ needs\ [h/day] \times Cost\ of\ local\ cleaning\ services\ [\$/h] \times Duration\ [days]$$

(35)

4.4.4 Damage and Loss of Amenity of Recreational Facilities (LOA)

Construction activities may have the negative effect of causing significant disturbance to recreational facilities such as parks and sites of natural importance. BMIRPs generate noise, dust, vibrations and other forms of visual pollution which negatively affect these sites (Gilchrist and Allouche, 2005). Additionally, smells emitted from the construction materials and machinery may compromise the amenity and recreational value of these facilities. Ecological damage may last for decades after the completion of the project as the natural habitat takes time to restore balance and rejuvenate plant life (Gilchrist and Allouche, 2005).

4.4.4.1 VALUATION

The value of these facilities and any associated negative impacts are difficult to estimate. Environmental valuation methods such as travel cost, revealed and/or stated preference (Section 3.1) would be best suited to quantify the monetary cost of loss of amenity of recreational facilities (LOA). No studies exist to guide the valuation of this cost item. A generic formula is proposed for use until further data is available. More research is needed in this area.

$$LOA = Value\ of\ facility \times Percent\ reduction\ of\ amenity \times Duration\ of\ impact \tag{36}$$

5 Case Study

5.1 Project Background

A case study on a water main rehabilitation project in the city of Montreal's borough of Saint Leonard is presented. The project consisted of lining an 1100m-long section of 8 inch (200mm) diameter pipe, using cured-in-place pipe (CIPP) lining technology. A local contractor specialized in this trenchless technology was selected for implementation of the project. This method consisted of excavating 20 pits to access the pipe buried at an average depth of 1.8m below grade. The pit areas varied from approximately $4m^2$ to $8m^2$ and were typically located at all intersections, fire hydrants and valves. The Saint Leonard project was completed in 44 working days from July to September, 2008. The working hours were typically from 7:30 a.m. to 5:00 p.m.

The direct costs of the Saint Leonard project amounted to $540,000, which included costs for temporary services, pavement cutting and excavation to the pipe at access pits, construction costs for CIPP pipe lining, valve and valve chamber replacement, hydrant replacement, reinstatement of water supply service and restoration of project site. The contract did not include the removal cost of debris such as asphalt pavement, abandoned hydrants and valves. This cost was assumed by the City of Montreal.

5.2 Location Profile

The project was located in Montreal's borough of Saint Leonard. The land use at the project location was primarily for industrial economic activity. Local businesses included manufacturing plants, construction material distribution facilities, food manufacturers, automobile garages, headquarters of a limousine service and a head stone distributor.

Most businesses relied heavily on daily deliveries for supplies and expedition of goods. Truck traffic was permitted on the roadway at all times during the day. Alternate routes were readily available for through traffic. Truck traffic was significantly higher than the urban norm. Trucks with 53 foot (16m) long trailers were commonly observed to stop at businesses along the street. The roadway consisted of a two lane urban highway with lane-side parking on either side. The total road width was 40 feet (12.2m).

Pedestrian traffic was light as most industries delivered their goods and services. Walk-in business was relatively insignificant.

5.3 Total Cost Analysis

The total cost of the Saint Leonard buried municipal infrastructure renewal project (BMIRP) will be estimated using the total cost evaluation framework proposed in this thesis. This section will look at the total cost analysis using data collected from several sources, among others: field studies, online documentation, and personal communications with industry experts (Charrette, 2009; Di Fruscia, 2009; Gelly, 2009; Girard, 2009; Tardif, 2009; Vermette, 2009). All monetary values are in 2008 Canadian dollars unless otherwise specified.

Saint Leonard Project Data and General Assumptions

- Direct costs: $540,000
- Project duration: 44 days
- Number of excavated access pits: 20
- Pavement cut and restored surface area: $136m^2$
- Excavated volume: $2448m^3$
- ADT: 8121 vehicles per day
- Pedestrian traffic flow rate: 2ped/min/m
- Parking space occupancy: Low
- Number of businesses affected: 60 businesses
- Average annual local business income: $65 000
- Residential properties affected : 0
- Average local income: $30,132 (Ville de Montréal, 2009)

5.3.1 Indirect Costs

5.3.1.1 Pavement Service Life Reduction due to Excavation

The 1.1km long roadway and sidewalk had been reconstructed in the year 2000 with an initial construction cost estimated at CA(2000) $4.4 million and an anticipated 25 year service life. The excavated area is $136m^2$, or 0.8 percent of the total paved surface. Therefore the initial construction cost of the paved surface to be cut in this project is CA(2000) $35 789.

$$PV_{original\ service\ life} = 35\ 789\$ \times \left(1 - \frac{8\ yrs}{25\ yrs}\right) = 24\ 337\$$$

$$PV_{reduced\ service\ life} = 35\ 789\$ \times \left(1 - \frac{8\ yrs}{0.3 \times 8\ yrs + 0.7 \times 25\ yrs}\right) = 21\ 401\$$$

$$PDE = 24\ 337\$ - 21\ 401\$ = \text{CA}(2000)\ \$2\ 936$$

$$\text{CA}(2000)\ \$2\ 936 \rightarrow \text{CA}(2008)\$3\ 545$$

The cost of pavement service life reduction due to excavation (PDE) is $3,545.

5.3.1.2 Pavement Service Life Reduction due to Increased Detour Traffic on Secondary Roads

The cost of pavement service life reduction due to increased detour traffic on secondary roads (PDT) is estimated to be zero because no detour was required and not much through-traffic was present on the roadway.

Furthermore, alternate routes in the area serving a similar route were designed for heavy truck traffic and operating under capacity, they would not be significantly affected.

5.3.1.3 Adjacent Buried Utility Damage

This value estimates the cost of damage to buried utilities during excavation and restoration. Trench depth was typically 1.8m. Total excavated volume was estimated as $244.8m^3$ and the direct cost of the project was $540,000.

$$BUD = 244.8m^3 \times \frac{1.2}{3000m^3} \times 0.011 \times 540000\$ = \$581$$

The cost of damage to adjacent buried utilities (BUD) is $581.

5.3.1.4 Lost Parking Meter Revenue

There is no metered parking on the street, therefore the cost of lost parking meter revenue (PMR) is zero.

If it is necessary, information for calculation of this cost in the Montreal area is available through Montreal's parking agency, Stationnement de Montréal. Presently, the cost of obstructing a metered parking space in the city is $11/day, $22/day and $33/day for parking spaces with hourly rates of 1$, $2 and $3, respectively, in addition to a fixed permit fee (Vermette, 2009).

5.3.1.5 Lost Parking Ticket Revenue

Parking does not generally approach capacity along the studied road. Furthermore, half of the access pits were located around a fire hydrant where parking is normally forbidden. It is, therefore, assumed that the cost of lost parking ticket revenue (PTR) is zero.

5.3.1.6 Compensation and Tax Rebates

It is rare for the City of Montreal to provide any form of compensation or a tax rebate (CTR) for infrastructure renewal projects. The value of this cost is zero.

5.3.2 External Costs

5.3.2.1 Increased Vehicular Travel Time

The driving speed limit on the concerned roadway is 50km/h during normal conditions. The speed limit was not reduced during the project implementation. Traffic obstructions consisted of 20 pits scattered along the 1.1km stretch of roadway. They were barricaded using movable traffic control devices which occupied an estimated 4m of the 12.2m road widths and traffic was able to drive around them with minor speed adjustment. It is estimated that the average vehicular speed during normal operating conditions (prior to construction) was 50km/h, and 40km/h throughout the project duration. This is associated with a 22 second delay per passenger vehicle assuming a $3m/s^2$ vehicular acceleration rate and a $4m/s^2$ deceleration rate.

Three access pits were located in the center of an intersection. These caused significant disruption to trucks, often pulling a 53 foot (16m) trailer. It is estimated that regular and heavy trucks were delayed 1.5 and 3 times longer than passenger vehicles, respectively. Therefore, regular truck delays were estimated at 33 seconds, and heavy trucks delays at 66 second.

The average daily traffic was measured to be 8121veh/day in a 72-hour continuous traffic volume count. The average vehicular occupancy is 1.23passengers/vehicle based on the Montreal Origin-Destination Survey results shown in Appendix C (Agence métropolitaine de transport, 2003). Trip distributions were based on this same survey, but modified to reflect the industrial nature of the setting. Therefore, all "student commuting" trips and half of the "other" trips were substituted with "business" trips since the route is not used as a commuting route to educational, or shopping facilities. Additionally, regular and heavy truck traffic was increased from the Montreal survey results to represent 10 and 20 percent of the total traffic fleet, respectively. The trip distribution data from the Montreal survey is available in terms of work, student commuting, other trips, and returns home. The distribution of this available data is such that business commuting trips departing from home, destined to a place of work, are considered in the "business" category. When estimating the value of time (VOT) spent on these trips it is, therefore, assumed that business commuting trips departing from home are valued as "business trips". The VOT of business commuters returning from work, destined for home, is then valued as "other trips" as shown below. The values from Table 5 are indexed to 2008 Canadian dollars and are adopted for use in this case study. The VOTs are based on an average level of income in Montreal of CA(2008) $30,132 obtained from the City of Montreal's online statistical report (Ville de Montréal, 2009). The trip distributions and values of time (VOT) are as follows:

- Business: 50.2% VOT= (2009) $26.13 → (2008) $26.11
- Student commuting: 0.0% VOT= (2009) $6.53 → (2008) $6.52
- Other trips: 9.8% VOT= (2009) $15.95 → (2008) $15.94
- Return home: 15.0% VOT= (2009) $15.95 → (2008) $15.94
- Regular truck: 15.0% VOT=(2009) $24.96 → (2008) $24.94
- Heavy truck: 10.0% VOT= (2009) $29.89 → (2008) $29.86

$\Delta\ Travel\ time_{business\ vehicles}[h]$

$$= \left(\left(\frac{91s}{trip} - \frac{69s}{trip}\right)\left(\frac{1h}{3600s}\right)\right) \times \left(\frac{8121veh \times 0.502}{day} \times \frac{1.23trips}{veh}\right) \times 44days$$

$$= 1348.3h$$

$VOT_{business\ vehicle} = 26.11\$/h$

$ITT_{business\ vehicle} = 1348.3h \times 26.11\$/h = \$35{,}204$

This methodology is used for all trip purposes yielding a total cost of increased vehicular travel time (ITT) of $84,960.

5.3.2.2 Increased Vehicular Operating Costs

This project did not require any detours, therefore, the increased travel distance is zero resulting in zero increased vehicle operating costs (VOC). This value assumes that no extra strain was put on the vehicle by operating at a reduced speed.

5.3.2.3 Increased Pedestrian Travel Time

The pedestrian traffic flow rate along the two sidewalks measuring 5 feet (1.5m) each was measured to be very low: 2ped/min/m. Pedestrian trips were generally from a parked location to a nearby business. For the sake of demonstration, an average delay is estimated as one second per pedestrian to account for one out of five pedestrian trips being delayed five seconds by an access pit at the location of a fire hydrant replacement. Pedestrian traffic is considered to be half “business”, and half “other” for shopping purposes. The average value of time is therefore $18.91.

$Increased\ pedestrian\ travel\ time =$

$$1s \times \frac{1min}{60s} \times 2ped/min/m \times 3m \times 9.5h/day \times 60min/h \times 44days = 2\ 508s$$

$PTT = 2508s \times \frac{1h}{3600s} \times 18.91\ \$/h$ =13$

The cost of increased pedestrian travel time (PTT) is $13. This value is nearly negligible which can be explained by two factors: a very low pedestrian traffic flow rate and very little obstruction on the walkway.

5.3.2.4 Increased Collision Rate

The construction zone consists of twenty excavated access pits, each delineated with lightweight temporary fencing. The construction barriers are not very intrusive as the roadway is relatively large. It will be assumed that only heavy truck traffic experienced an increased risk of collision due to their limited manoeuvrability. Average collision costs are $65.05/1,000veh-km for freight trucks.

$$ICR = \frac{65.05\$}{1000veh - km} \times 1.1km \times \frac{8121veh}{day} \times 0.30 \times 44\ days = \$7\ 670$$

The cost of increased collision rates (ICR) is $7,670.

5.3.2.5 Obstruction to Passage of Emergency Vehicles

Not enough research is available to scientifically estimate the cost of obstruction to passage of emergency vehicles (OEV). However, the fire department responded to a call to one of the businesses along the construction site during the project period. It was noted that the traffic control system had no impact on their response time, and the temporary water service had no negative impact on the fire fighting capability.

The cost of obstruction to passage of emergency vehicles (OEV) is, therefore, zero.

5.3.2.6 Accidental Injury and Death

The cost of accidental injuries and death (AID) will not be considered in this study because of a lack of available literature on the subject.

5.3.2.7 Property Damage

It is assumed that no private property damage occurred because the work zone was well confined within the public domain. Ample room was available for operation of heavy equipment with little risk of damage to nearby above-ground infrastructure.

The cost of property damage (PPD) is assumed to be zero.

5.3.2.8 Psychological and Physical Ailments

The project was undertaken in an industrial zone where ambient noise is regularly high. It is assumed that the construction noise did not significantly contribute to the area's general noise level.

The costs of psychological and physical ailments (PPA) are zero.

5.3.2.9 Water and Wastewater Service Interruption

Through discussions with the local business owners, it was concluded that water interruption was minimal and did not present an inconvenience.

The cost of water and wastewater service interruption (WSI) is zero.

5.3.2.10 Lost Business Income

There are approximately 60 businesses on that will be affected by the BMIRP. In discussions with the local business owners, it was concluded that the construction work caused a 5 percent decrease in net income due solely to freight delays; in contrast respondents estimated that open trench construction would have reduced revenues by 25 to 100 percent. Businesses in this area were especially susceptible to losses due to any obstruction because the majority of the businesses are "just-in-time" businesses that rely on daily shipment of goods and services.

The average net income for small and medium sized businesses (PME) in the province of Quebec is $65 000 (Government of Canada, 2000). This amount is selected as the average net income of the local businesses and it is assumed that there are 250 working days in the year. A more thorough investigation could assess the true net income of the local sector through a survey.

$$LBI = 0.05 \times \frac{\$65\,000}{business} \times 60\ businesses \times \frac{44}{250} = \$34\,320$$

The cost of lost business income (LBI) is $34,320.

5.3.2.11 Loss of Property Value due to Noise

The cost of lost property value due to noise (LPV) is zero because no residential homes were located within one hundred metres of the project.

If it is necessary, information for calculation of this cost for case studies in Montreal can be obtained from the following locations:

- Number of affected units:
  - field study
- Total number of units in market area:
  - Socio-Demographic Profile of Montreal Boroughs (Appendix D)
  - Available at ville.montreal.qc.ca/montrealenstatistiques
- Average daily sales and price:
  - Analysis of the Resale Market : Montreal Metropolitan Area (Appendix E)
  - Available at www.cmhc-schl.gc.ca/en/inpr/homain/foan/index.cfm
- Increase in noise level relative to norm, NDI, duration
  - As seen in Section 4.2.2.2

5.3.2.12 Air Pollutant and Greenhouse Gas Emissions

Carbon dioxide (CO_2) emissions associated with material, equipment operation and materials transportation are estimated using the NASTT-BC Carbon Calculator (2008). The effects of reduced speed of traffic on emissions were not considered in this case study since the necessary tools for modeling this phenomenon were unavailable to the authors at the time of the study. The project details were entered into the program and it was estimated that 1.647 metric tonnes of CO_2 are emitted as a result of the BMIRP using CIPP technology, in contrast to more than 80 metric tonnes of CO_2 emissions associated with open trench construction. The emission volume of air pollutant gases cannot be calculated by this program and are not considered.

Adopting the CO_2 value proposed by the Ministère des Transports du Québec (2009) we obtain the following:

$$APE = \frac{37.03\$}{tonne} \times 1.6740 tonnes = \$62$$

The cost of greenhouse gas emissions associated with material, equipment operation and material transportation is $62. This number is considerably low. It would have been nearly 50 times greater, however, had the project been completed using open trench construction. Furthermore, the Carbon Calculator only estimates the amount of CO_2 emitted from a project and does not consider other air pollutant gases.

5.3.2.13 Environmental Damage and Contamination

The water main renewal project minimized excavation through the use of trenchless technologies. Excavation in an industrial location may occasionally present an increased environmental risk when contaminants are located in nearby soils or on surfaces that could potentially be transported through runoff water into an open trench. At this point there is insufficient data to support this circumstance.

The cost of environmental damage and contamination (EDC) is assumed to be zero.

5.3.2.14 Dust and Dirt Pollution

A local survey of the business owners revealed that only one business was bothered by the dust and dirt generated in the construction process. The headquarters of a limousine service was located along the construction site and the owner estimated that one extra hour of car-washing was required daily to remove the dust settled on the vehicles. It will be assumed that cost of car washing is the $8.50/h, the Quebec minimum wage in the year 2008, plus an additional $1.00/h for materials.

$$DD = 1h/day \times 9.50\$/h \times 44days = \$418$$

The cost of dust and dirt pollution (DDP) is $418.

5.3.2.15 Damage and Loss of Amenity of Recreational Facilities

No recreational facilities or parks are located near the project location. The cost of damage and loss of amenity (LOA) is, therefore, zero.

5.4 Total Cost of the Project

The total cost of the project is $671,299 calculated as the sum of all the direct, indirect and external costs. Table 8 summarizes the results.

Table 8. Summary of total cost of Saint Leonard pipe rehabilitation project

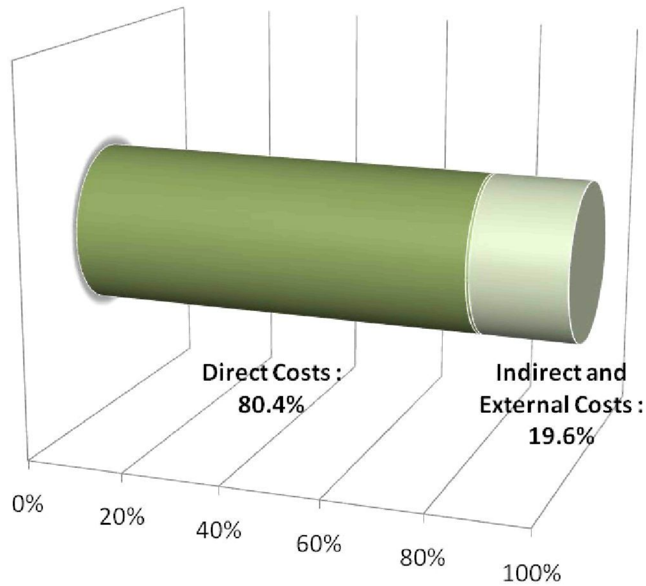
	ID	Cost ($)	%DC (%)	%TC (%)
Direct Costs (DC)		**540,000**	**100.0**	**80.4**
General	-	540,000	100.0	80.4
Indirect Costs (IC)		**4,126**	**0.8**	**0.6**
Pavement damage due to excavation	PDE	3,545	0.7	0.5
Pavement damage on alternate routes due to increased traffic	PDT	0	0.0	0.0
Adjacent buried utilities damage	BUD	581	0.1	0.1
Lost parking ticket revenue	PTR	0	0.0	0.0
Lost parking meter revenue	PMR	0	0.0	0.0
Compensation and tax rebates	CTR	0	0.0	0.0
External Costs (EC)		**127,173**	**23.6**	**18.9**
Social Costs		***92,373***	***17.1***	***13.8***
Increased vehicular travel time	VTT	84,690	15.7	12.6
Increased vehicle operating costs	VOC	0	0.0	0.0
Increased pedestrian travel time	PTT	13	0.0	0.0
Increased collision rate	ICR	7,670	1.4	1.1
Obstruction to emergency vehicles	OEV	0	0.0	0.0
Accidental injury and death	AID	0	0.0	0.0
Property damage	PPD	0	0.0	0.0
Water and wastewater service interruption	WSI	0	0.0	0.0
Psychological and physical ailments	PPA	0	0.0	0.0
Economic Costs		***34,320***	***6.4***	***5.1***
Lost business income	LBI	34,320	6.4	5.1
Lost property value due to noise	LPV	0	0.0	0.0
Environmental Costs		***480***	***0.1***	***0.1***
Air pollutant and greenhouse gas emissions	AP/GHG	62	0.0	0.0

Environmental damage and contamination	EDC	0	0.0	0.0
Dust and dirt pollution	DDP	418	0.1	0.1
Damage and lost amenity of recreational facilities	LOA	0	0.0	0.0
Total Cost (TC)		**671,299**		

5.5 Summary

In summary, the framework proposed in this thesis was applied to evaluate the total cost of a 250mm, trenchless water main rehabilitation project using cured-in-place pipe technology with direct costs known to be $540,000. The indirect costs were estimated at $4,126, and the external costs amounted to $127,173, that represent together nearly 25 percent of the direct costs and 20 percent of the total cost. Figure 15 presents a specific breakdown of the total project cost. The individual contribution of all indirect and external costs is shown in Figure 16. The most significant indirect and external costs were estimated to be the costs of increased vehicular travel time (VTT) and lost business income (LBI). The cost of increased travel time was based on the assumption that the average speed of traffic would be 10km/h lower than the norm, even without a reduced speed limit. The cost of lost business income was estimated considering a 5 percent income reduction of the 60 businesses affected by the project. The cost of greenhouse gas emissions was estimated considering a value of $37.03 per metric ton; the resulting cost was surprisingly low ($62). However, it was estimated that this cost component would have been nearly 50 times greater, if the project had been implemented using an open trench construction.

This case study can be used as a foundation for further development. Several assumptions were made because of a lack of available data. In future, it is recommended that information pertinent to the total cost analysis proposed in this thesis such as income levels of affected businesses be gathered prior to project evaluation such that the total cost to society may be considered with a higher level of confidence. As research is undertaken in this subject area, indirect and external cost estimates will increasingly improve.



	1
Direct Costs (DC)	540,000
Indirect Costs (IC)	4,126
External Costs (EC)	127,173

Figure 15. Distribution of total cost components in the Saint Leonard rehabilitation project

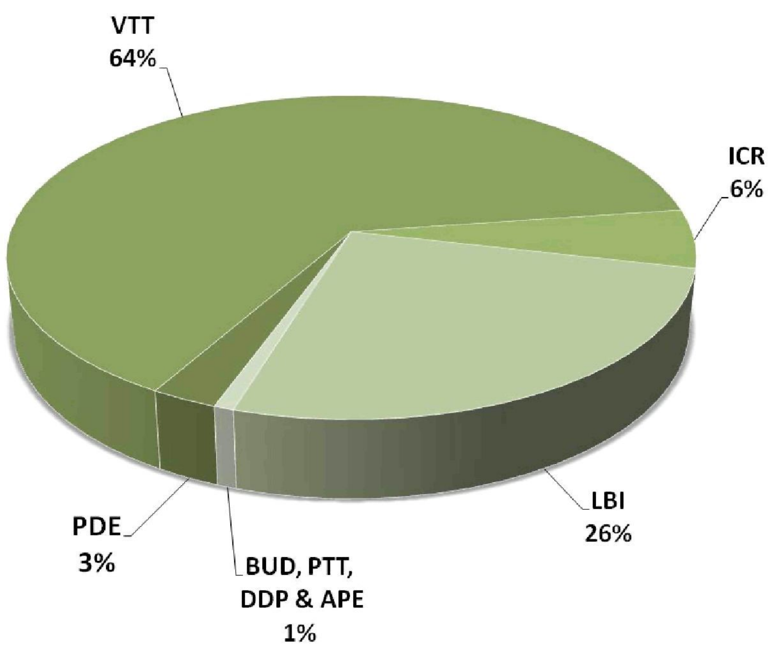


Figure 16. Contribution of the individual indirect and external cost components

6 Conclusions

The rapidly increasing needs for renewal of North America's buried municipal water and wastewater infrastructure has prompted discussion of the associated economic, social and environmental impacts of the methods currently used to repair, rehabilitate and replace buried pipe. Industry members generally accept that trenchless technologies offer the advantage of reducing these impacts. Open trench construction, however, is still the most often selected method for buried municipal infrastructure renewal projects (BMIRP) in Canada and the United States since the current project evaluation methods do not consider the total cost. The main objectives of this thesis are to study the existing literature, explain the social, environmental and economic impacts of BMIRPs, and propose a methodology to analyse the costs associated with these impacts.

Total cost valuation is the process of placing a monetary value on the impacts of an activity. This practice is commonly used in environmental cost-benefit analyses of projects such as heavy dam, airport and highway construction. The methods such as revealed preferences, travel cost method and stated preference developed in previous research can be used to estimate the total cost associated with BMIRPs. Precedents, averting behaviour, replacement costs and environmental taxes can also be used to estimate the monetary value of certain assets and activities.

Much debate exists over the definitions of "social cost" and "total cost". The **total cost** of a project is defined here as the sum of all costs borne by the municipality and those borne by the society at large as a result of the project initiation and development. The total cost is separated into three categories: direct costs (project implementation costs borne directly by the municipality), indirect costs (borne by the municipality through costs generally beyond the contract scope) and external costs (borne by the society in a multitude of ways).

Besides the direct costs, the most notable total cost components are associated with traffic impacts such as increased vehicular travel time and operating costs, impacts to neighbouring infrastructure such as damage to pavement structures and buried utilities, economic impacts such as loss of business income, and socio-environmental impacts such as construction related injuries and deaths and the emission of air pollutants and greenhouse gases.

The value of traffic delays caused by BMIRPs comprises the most significant external cost. Valuation of vehicle travel time is reliant the estimation of the value of time (VOT) of the vehicle occupants. This value is a function of the trip purpose. This thesis adopts the VOT values used in the Ministère des Transports du Québec (2009b) based on average local income levels: full average local hourly wage plus employer contributions, before tax deductions for business trips, the business trip VOT after tax deductions for other trip purposes such as leisure and shopping, one quarter of the business trip VOT for educational commuting; and the average value of time from business and other trips for business commuting trips.

Utility strikes during excavation operations are estimated to cause damage worth 1.1 percent of the direct costs at an average occurrence of 1.2 times per project (Osman and El-Diraby, 2005). Disturbance of the foundation soil density due to utility cuts and excavation in the pavement is assumed to reduce the residual life of pavements by 30 percent (Tighe et al., 2002).

Lost amenity and reduced accessibility of business locations due to construction activities can cause loss of up to a 60 percent of the business income (Lemoine, 2008). There is a pressing need to study the economic impacts associated with BMIRPs.

This thesis proposes the negative psychological and physical effects such as headaches, sleep deprivation and high blood pressure associated with construction noise and vibrations be considered using the loss of productivity approach. Noise may also temporarily reduce property values by a factor of 0.55 percent per decibel of noise above the ambient norm (Nelson, 2004).

While the social and environmental impacts of BMIRPs are difficult to quantify, interest in this area has generated practical tools such as carbon and emissions calculators which allow quantitative estimation of emission levels associated with different trenchless and open trench construction methods (Griffin, 2009a, 2009b; NASTT-BC, 2007). This thesis also discusses the increased risk of accidental injury and death associated with trenching construction. The risk of injury in trench work is 112 percent higher than the construction industry norm (Everett and Frank, 1996).

Finally, the results of a case study on a project involving a water main rehabilitation undertaken using cured-in-place (CIPP) lining in an industrial area of the city of Montreal are presented. Using the framework and the valuation techniques developed in this thesis, it was shown that the indirect and external costs accounted for approximately 25 percent of the direct costs. Indirect, social, economic and environmental costs accounted for 0.8, 17.1, 6.4 and 0.1 percent of the direct costs. In comparison with the results of previous studies, this is an indication that trenchless methods can successfully minimize the negative social, economic environmental impacts associated with buried municipal infrastructure renewal projects.

7 Recommendations for Future Research

Interest in the total cost of buried municipal infrastructure renewal projects (BMIRP) is increasing exponentially. Research in this area is essential to sustainably manage the nation's municipal infrastructure. Municipal decision-makers and infrastructure researchers are interested in studying the area of total cost to better understand the monetary implications of the long and short term impacts of BMIRPs. Leaders in the trenchless technology industry are promoting research in this area as a method of quantitatively proving the advantages of trenchless construction methods over open trench construction.

However, considerably more research is needed in this area to appropriately consider the total cost of BMIRPs. Collection of data specific to water and wastewater renewal projects is urgently needed. Future field studies could focus on measuring traffic behaviour in construction zones and the surrounding areas, the likelihood and impacts of utility and property damage, and the economic impacts of BMIRPs on local businesses according to the business type, level of income and timing of construction work. To improve damage cost estimates, scientific studies could further explore the life cycle implications of excavation and heavy traffic on pavement and utility service life.

Current socio-environmental parameters exhibit high variability internationally and even on the Canadian scene. Estimation of total cost would benefit greatly from future research which would establish nationally accepted values of time as a function of income, the value of statistical life in Canada as a function of income, the value of pain, suffering and lost enjoyment of life due to injury, and the value of air pollutant and greenhouse gas emissions. The variability of these parameters should be studied and methods a sensitivity analysis of the total cost of BMIRPs should be conducted to identify critical parameters.

Furthermore, it would be useful to develop empirical formulae to relate the indirect and external costs of a BMIRP with the direct costs estimated using traditional project evaluation. This would allow practitioners to easily anticipate the significance of negative impacts associated with a pipe renewal project. It is proposed that the relation between indirect and external costs, direct costs, and average daily traffic (ADT) be further researched.

In summary, considerable research is needed in this field to improve the estimation accuracy and reliability of total cost analysis. The first step, however, is to identify all of the impacts of a BMIRP which are addressed in this thesis. It is important to continue to build on the notions presented in this work through the refinement of valuation techniques and development of empirical relationships to ultimately achieve a high level of confidence in total cost analysis. A sufficient confidence level in the valuation techniques will provide grounds to support policy and legislative actions to improve the sustainability of efforts to renew the nation's aging underground municipal infrastructure.

8 References

Abraham, D., Baik, and Gokhale, S. (2002). *Development of a Decision Support System for Selection of Trenchless Technologies to Minimize Impact of Utility Construction on Roadways*. West Lafayette, IN: Transportation Research Board.

Agence métropolitaine de transport. (2003). *L'enquête Origine-Destination 2003: La mobilité des personnes dans la région de Montréal*: AMT, STM, RTL, STL, Association des CIT, MTQ, MAMSLQ.

Allouche, E. N., Ariaratnam, S. T. and AbouRizk, S. M. (2000, February 20-22). *Multi-Dimensional Utility Model for Selection of a Trenchless Construction Method.* Paper presented at the Construction Congress VI, Orlando, FL.

American Water Works Association (AWWA). (2001). *The dawn of the replacement era. Reinvesting in drinking water infrastructure*. Denver, CO.

Ariaratnam, S. T., Leueke, J. S. and Allouche, E. N. (1999). Utilization of Trenchless Construction Methods by Canadian Municipalities. *Journal of Construction Engineering and Management, 125*(2), 11.

Bateman, I., Day, B., Lake, I. and Lovett, A. (2001). *The Effect of Road Traffic on Residential Property Values: A Literature Review and Hedonic Pricing Study.* Scottish Executive Development Department.

Benessaieh, K. (2009, February 17). Gaz Métro poursuivie. *La Presse.*

Bodocsi, A., Pant, P. D., Aktan, A. E. and Arudi, R. S. (1995). *Final Report: Impact of Utility Cuts on Performance of Street Cuts*. Cincinnati, OH: City of Cincinnati and the American Public Works Association.

Boyce, G. M. and Bried, E. M. (1994). *Benefit-cost analysis of microtunneling in an urban area.* Paper presented at the Proceedings of North American No-Dig '94.

Boyce, G. M. and Bried, E. M. (1998, August 2-6, 1998). *Social Cost Considerations When Planning a Project.* Paper presented at the 4th National Conference on Trenchless Technology, Brisbane.

Bryden, J. E. andrew, L. B. and Fortuniewicz, J. S. (1998). Work Zone Traffic Accidents Involving Traffic Control Device, Safety Features, and Construction Operations. *Transportation Research Record*(1650), 71-81.

Bueckert, D. (2004, March 30). More Water Shortages Forecast for Communities Across Nation. *London Free Press.*

Butt, A. A. (1991). *Application of Markov Process to Pavement Management Systems at the Network Level.* University of Illinois.

Button, K. (1993). Overview of Internalising the Social Costs of Transport. In *Internalising the Social Costs of Transport*. Paris: Organisation for Economic Co-operation and Development.

CAA. (2007a). Average Canadian Vehicle Operating Costs. Ottawa, ON.

CAA. (2007b). Driving Costs. Ottawa, ON.

Canadian Mortgage and Housing Corporation (CMHC). (2008). *Analysis of the Resale Market – Third Quarter.* Retrieved December 10, 2008, from at www.cmhc-schl.gc.ca/en/inpr/homain/foan/index.cfm

Canadian Vehicle Survey (CVS). (2000). *Motor Vehicle Fleet and Use Characteristics*: Transport Canada.

Center for Hearing and Communication. (2009). Noise Level in our Environment Fact Sheet. *Facts on Noise.* Retrieved June 13, 2009, from www.ihh.org

Center to Protect Workers' Rights. (2003). Construction Noise: Hazard Alert. Silver Spring, MD.

Charrette, M. (2009). Chief of Operations, Service de Sécurité Incendie Montréal. Personal communication.

Chicago Climate Exchange. (2007). CCX Market Report. Retrieved March: www.chicagoclimatex.com

City of Winnipeg. (2001). *Sewer Management Study - Technical Memoranda for Sewer Condition Assessment*. Winnipeg: report prepared by UMA Consultants.

Croteau, M. (2007, October 18). Les travaux achèvent sur la rue Saint-Laurent. *La Presse*, from www.cyberpresse.ca

Croteau, M. (2009, January 19). Les tuyaux fuient partout. *La Presse,* pp. A1-A7,

CSCE, CCPE, CPWA and National Research Council Canada. (2003). Technology Road Map: 2003-2013.

CSST. (2007). Accident mortel d'un travailleur de la municipalité d'Oka: la CSST rend public son rapport d'enquête. Retrieved June 5, 2009, from www.csst.qc.ca

De Saram, D. and Tang, S. L. (2005). Pain and Suffering Costs of Persons in Construction Accidents: Hong Kong Experience. *Construction Mangement and Economics, 23*(6), 14.

Di Fruscia, T. (2009). Engineer, City of Montreal. Personal communication.

Emery, J. J. and Johnston, T. (1986). Unshrinkable fill for utility cut restorations. *1986 American Concrete Institute (SP)*, 187-212.

Environment Canada. (2004). *Threats to Water Availability in Canada*. Burlington, ON.

Everett, J. G. and Frank, P. B. J. (1996). Costs of accidents and injuries to the construction industry. *Journal of Construction Engineering and Management, 122(2)*, 158-164.

Federal Highway Association. (1997). *Pavement Recycling Guidelines for State and Local Governments*. Washington, D.C.: U.S. Department of Transportation.

Federal Signal Corporation (2005). Hydro-Excavation: A safe, cost-effective alternative for underground construction and municipal use, Available from federalsignal.com/pdf/whitePapers/Hydro-Excavation%20for%20municipal%20and%20construction%20use.pdf

Feitelson, E., Hurd, R. and Mudge, R. (1996). *The impact of noise on willingness to pay for residences*. Washington, D.C.

Ferguson, I. (1995). *Dust and Noise on the Construction Process*.

Ferland, A.-M. (2007). *Guide de l'analyse avantage-coûts des projets publics en transport - Partie 3: Paramètres.* Ministère des Transports Québec.

Gagnon, M., Gaudreault, V. and Overton, D. (2008). *Age of Public Infrastructure: A Provincial Perspective*. Ottawa, ON: Statistics Canada.

Gelly, S. (2009). Project Engineer, Genivar. Personal communication. Montreal.

Gifford, J. (1993). Toward the 21st Century. *The Wilson Quarterly*(17), 40-47.

Gilchrist, A. and Allouche, E. N. (2005). Quantification of social costs associated with construction projects: state-of-the-art review. *Tunneling and Unerground Space Technology, 20*(2005), 89-104.

Gilchrist, A., Allouche, E. N. and Cowan, D. (2003). Prediction and mitigation of construction noise in an urban environment. *Canadian Journal of Civil Engineering, 20*(4), 659-672.

Girard, R. (2009). Project Engineer, City of Montreal. Personal communication.

Government of Canada. (2000). Financement des petites et moyennes entreprises au Canada - Partie II - Structure financière des PME canadiennes. Retrieved June 17, 2009, from www.pme-prf.gc.ca/eic/site/sme_fdi-prf_pme.nsf/fra/01045.html

Griffin, J. (2009a). Carbon Calculator Determines Trenchless Benefits. Retrieved from www.pwtrenchless.com/carbon.pdf

Griffin, J. (2009b, April 2009). First Look: Software Compares Carbon Footprint of Trenchless, Open-Cut Construction Methods. *Underground Construction, 64*.

Grondin, B. (2004). *Analyse économique d'un projet de réhabilitation par étude comparative avec les travaux en tranchée en incorporant certans [sic] coûts associés aux impacts sociaux.* Paper presented at the Infra, Montréal.

He, Z., Cai, Y. and Haas, R. (1996). *"OPAC2000 engineering document, the updated system of Ontario pavement analysis of costs (OPAC)."*. University of Waterloo, Waterloo, ON, Canada.

Institute of Civil Infrastructure Systems and Urban Utility Center. (1999). *Summary Report of the 1999 Life Extension Technologies Workshop*. Queens, NY.

International Emissions Trading Association. (2009). What are Carbon Dioxide Equivalents. Retrieved June 17, 2009, from www.ieta.org/ieta/www/pages/index.php?IdSitePage=123

International Society for Trenchless Technology. (2009). Glossary of Terms. Retrieved April 27, 2009, from www.istt.com

Iseley, D. T. and Tanwani, R. (1990). *Social Costs of Traditional Methods of Utility Installation.* Paper presented at the Microtunneling and Horizontal Directional Drilling Symposium, Houston, Texas.

Jeong, H. S., Abraham, D. M. and Lew, J. J. (2004). Evaluation of an Emerging Market in Subsurface Utility Engineering. *Journal of Construction Engineering and Management*(130:2).

Jones, C. J. F. P. (1999). *Policy, Incentives and Barriers to the Use of Trenchless Technology*. Paper presented at the Life Extension Workshop.

Jung, Y. J. and Sinha, S. K. (2007). Evaluation of trenchless technology methods for municipal infrastructure system. *Journal of Infrastructure Systems, 13*(2), 144-156.

Khisty, C. J. and Lall, B. K. (2003). Local Area Traffic Management. In *Transportation Engineering: An Introduction*

(3rd ed.). Upper Saddle River, NJ: Pearson Education, Inc.

Khogali, W. and Mohamed, E. H. (1999). *Managing Utility Cuts: Issues and Consideration.* Paper presented at the APWA International Public Works Congress, New York City, August 25-26, USA.

Kolator, R. (1998). *Soziale Kosten im Leitungs - und Kanalbau.* Vienna Univeristy of Technology, Vienna, Austria.

Lee, S. Q. S. and Lauter, K. A. (1999). *Impact of Utility Trenching and Appurtenances on Pavement Performance in Ottawa-Carleton*. Ottawa, ON: Environment and Transportation Department, Regional Municipality of Ottawa-Carleton.

Lemoine, D. (2008). Boul. Saint-Laurent: plans de relance compromis. Retrieved from www.lesaffaires.com

Manuilova, A., Dormuth, D. W. and Vanier, D. J. (2008). *MIIP Report: A Case Study of User and External Components of Social Costs that are related to Municipal Infrastructure Rehabilitation*: unpublished draft, National Research Council Canada.

McKim, R. A. (1997). Bidding strategies for conventional and trenchless technologies considering social costs. *Canadian Journal of Civil Engineering, 24*(5), 819-827.

McKim, R. A. and Kathula, V. S. (1999). *Social Costs and Infrastructure Management.* Paper presented at the INFRA 99 International, Montreal, Canada.

Ministère des Transports Québec (2000). Transportation Management Plan: Priority Intervention Strategy. Retrieved from www.mtq.gouv.qc.ca

Ministère des Transports Québec. (2009a). *Évaluation des coûts de la congestion routière dans la région de Montréal pour les conditions de référence de 2003*: Conseillers ADEC inc.

Ministère des Transports Québec. (2009b). Value of Time Estimate for Greater Montreal Area.

Mirza, M. S. (2006). Durability and Sustainability of Infrastructure: A State-of-the-Art Report. *Canadian Journal of Civil Engineering, 33*(6), 639-649.

Mirza, M. S. (2007). *Danger Ahead: The Coming Collapse of Canada's Municipal Infrastructure.* Ottawa, Ontario: Federation of Canadian Municipalities.

Mirza, M. S. and Sipos, C. (2008, Winter 2008). Canada's Infrastructure Deficit: A Sad Legacy for Future Generations. *Western Canada Water, 60,* 3.

Montréal Climate Exchange. (2009). Montréal Climate Exchange. Retrieved June 17, 2009, from www.mcex.ca/index_en

Murphy, J. and Delucchi, M. (1998). A Review of the Literature on the Social Cost of Motor Vehicle Use in the United States. *Journal of Transportation and Statistics*(January), 15-42.

Nankivil, M. and Nichols, D. J. (1997). *Extending life and adding control - the rehabilitation of a 70 year old water transmission main.* Paper presented at the Trenchless Pipeline Projects: Practical Applications, Boston, MA.

NASTT-BC. (2007). *Do Trenchless Pipeline Construction Methods Reduce Greenhouse Gas Emissions?* : North American Society for Trenchless Technologies - British Columbia.

NASTT-BC. (2008). NASTT Carbon Calculator. Retrieved June 17, 2009, from www.nastt-bc.org/carboncalculator/nastt00.php

NASTT. (2007). Glossary of Terms. Retrieved June 5, 2009, from www.nastt.org

Nelson, J. (2004). Hedonic Property Value Studies of Transportation Noise: Aircraft and Road Traffic. Retrieved from www.envirovaluation.org/index.php/2007/12/11/pennsylvania_state_university_department

Nichol, G., Laupacis, A., Boiley, H., Stiell, I., O'Rourke, K., Anis, A., et al. (1996). Cost-Effectiveness Analysis of Potential Improvements to Emergency Medical Services for Victims of Out-of -Hospital Cardiac Arrest. *Annals of Emergency Medicine, 27(6)*, 711-720.

Ontario Superbuild Corporation. (2002). *Economic Principles and Concepts as Applied to Municipal Water Utilities*. Toronto, ON.

Osman, H. and El-Diraby, T. E. (2005). *Subsurface Utility Engineering in Ontario: Challenges and Opportunities*: University of Toronto.

Parker, C. (2007). *Trenchless Pipe Bursting vs Conventional Open Cut Methods.* Paper presented at the 80th Annual Water Environment Federation Technical Exhibition and Conference.

Peters, D. C. (1984). The social costs of sewer rehabilitation. *International conference on the planning, construction, maintenance and operation of sewerage systems*.

Pucker, J., Allouche, E. N. and Sterling, R. L. (2006). *Social Costs Associated with Trenchless Projects: Case Histories in North America and Europe*. Paper presented at the No-Dig 2006.

Radio-Canada (Writer) (2009). Des canalisations vétustes, *Le téléjournal Montréal*. Canada.

Rahman, S., Vanier, D. J. and Newton, L. (2005). MIIP Report: Social Cost Considerations for Municipal Infrastructure Management. National Research Council Canada.

Ray Barton Associates Ltd. (2006). *Estimation of Costs of Cars and Light Trucks Use per Vehicle-Kilometre in Canada*: Transport Canada

Read, G. F. and Vickridge, I. G. (1997). Social or Indirect Costs of Public Utility Works. In G. F. Read (Ed.), *Sewers : rehabilitation and new construction : repair and renovation*. London : New York. Arnold , Wiley.

Read, G. F. and Vickridge, I. G. (2004). Social or Indirect Costs of Public Utility Works. In E. Ltd. (Ed.), *Sewers, Replacement and New Construction* (pp. 339-373). UK.

Schexnayder, C. and Ernzen, J. (1999). *Mitigation of nighttime construction noise, vibrations, and other nuisances.* Washington, D.C.

Shahin, M. Y. (2005). Pavement Condition Prediction Models. In *Pavement Management for Airports, Roads, and Parking Lots* (pp. 141-158).

Statistics Canada. (2006). 2006 Census, Income and Earnings Highlight Tables. Retrieved February 26, 2009, from www12.statcan.gc.ca/english/census06/data/highlights/income/index.cfm ?Lang=E

Sterling, R. L. (1997). *Trenchless Technologies and their Impact on Urban Utility Systems*. Paper presented at the International Conference on Underground Space: Indoor Cities of Tomorrow.

Tardif, I. (2009). Director, CERIU. Personal communication. Montreal.

Taylor, S. (2008, February 18). Emergency Vehicles Deployed Strategically. Retrieved February 26, 2009 from Tuscaloosanews.com

The Economist Newspaper Limited. (2009). Economics A-Z. Retrieved April 21, 2009, from Economist.com

Tighe, S., Knight, M., Papoutsis, D., Rodriguez, V. and Walker, C. (2002). User cost savings in eliminating pavement excavations through employing trenchless technologies. *Canadian Journal of Civil Engineering, 29*(5), 751-761.

Tighe, S., Lee, T., McKim, R. A. and Haas, R. (1999). Traffic delay cost savings associated with trenchless technology. *Journal of Infrastructure Systems, 5*(2), 45-51.

Transport Canada. (2006). *The Cost of Urban Congestion in Canada*. Ottawa: Environmental Affairs

Transport Canada. (2009, January 19). Canadian Motor Vehicle Traffic Collision Statistics: 2004. Retrieved June 17, 2009, from www.tc.gc.ca/roadsafety/tp/tp3322/2004/page8.htm

Transportation Research Board. (1994). *Highway Capacity Manual* (3rd ed.). Washington, D.C.: National Research Council.

Transportation Research Board. (2000). *Highway Capacity Manual*. Washington, D.C.: National Research Council.

Trenchsafety.org. (2007, September 28, 2007). Trench Safety version 4.0. Retrieved June 6, 2009, from www.trenchsafety.org

USEPA. (2000). *Guidelines for Preparing Economic Analyses*. Research Triangle Park, NC.

USEPA. (2007). *The Plain English Guide to the Clean Air Act*. Research Triangle Park, NC.

Veillette, M.-A. (2007). *Coûts sociaux: Revalorisation des systèmes d'aqueducs*. Paper presented at the INFRA.

Vermette, C. (2009). Director of Operations, Stationnement de Montréal. Personal Communication.

Ville de Montréal. (2008). *Synthèse: Schéma de couverture de risques en sécurité incendie pour l'agglomération de Montréal*. Montréal, QC: Service de Sécurité en Incendie de Montréal.

Ville de Montréal. (2009, January). Profil sociodémographique: Ville de Montréal. from ville.montreal.qc.ca/montrealenstatistiques

Wardman, M. and Bristow, A. L. (2004). *Traffic Related Noise and Air Quality Valuations: Evidence from Stated Preference and Residential Choice Models.*

Watkins, L. H. (1980). *Some Research into the Environmental Impact of Roads and Traffic, Transport Research for Social and Economic Progress.* Paper presented at the World Conference on Transport Research.

Wilde, W. J., Waalkes, S. and Harrison, R. (1999). *Life Cycle Cost Analysis of Portland Cement Concrete Pavement*. Arlington, TX: Center for Transportation Research, The University of Arlington.

Williams, D. (2002). Open Trench Failure Continue to Rise. *Water and Engineering Management, 149*(3).

Zhang, A., Boardman, A. E., Gillen, D. and Water II, W. G. (2004). *Towards Estimating the Social and Environmental Costs of Transportation in Canada*. Vancouver, Canada: Transport Canada, Centre for Tranportation Studies, Sauder School of British Columbia

Zhao, J. Q. and Rajani, B. (2002). *Construction and Rehabilitation Costs for Buried Pipe with a Focus on Trenchless Technologies*: Institute for Research in Construction.

Appendix A

Information and References for Trenchless Methods (Ariaratnam et al., 1999)

Technology (1)	Length (2)	Diameter (3)	Summary of method (4)	Cost (5)	Applications (6)	References (7)
			(a) New Construction			
Horizontal directional drilling	120–1,800 m	25–900 mm	Two-stage process: small diameter directional hole is drilled to provide pilot hole; back reamer and product are then pulled back through pilot hole. No excavation required for installation.	$0.50–$0.90/mm/m length	Force mains, gravity sewers, utility conduits, geotechnical investigaton, pipelines	Kirby et al. (1997); Allouche et al. (1997); Iseley and Gokhale (1997)
Microtunneling	25–225 m	250–3,050 mm	Remotely controlled, guided pipe jacking process that provides continuous support to excavation face. Pipe installed from drive shaft to reception shaft. No person entry required in pipe.	$1.20–$4.00/mm/m length	Gravity sewer installations	Atalah (1997); Iseley and Gokhale (1997); Iseley and Najafi (1997); Stein et al. (1989)
Pipe jacking	Up to 490 m achieved	1,060–3,050 mm	Pipe is jacked horizontally from drive shaft to reception shaft. Workers required in pipe to perform excavation and/or remove spoil. Excavation performed either manually or mechanically.	$0.40–$1.90/mm/m length	Large diameter gravity sewers, force mains, diversion chambers	Miller (1996) Iseley and Najafi (1997); Tanwani (1996); Committee (1991)
Auger boring	12–150 m	200–1,500 mm	Pipe pushed from drive shaft to reception shaft, while rotating flight auger simultaneously removes spoil. This method does not apply pressure to cutting face.	$0.10–$0.30/mm/m length	Relatively short crossings (pipes and conduits)	Iseley and Najafi (1997); Committee (1991)
Pipe bursting	100–900 m	75–1,060 mm	Existing pipe is burst or split with use of conical shaped bursting head, while simultaneously new pipe of equal or greater diameter is pulled behind bursting head.	$0.15–$0.30/mm/m length	Replacement of force mains and gravity sewers	Strychowskyj (1997); Howell (1995); Everett (1997); Committee (1991)
			(b) Rehabilitation			
Lining of pipe	Up to 1000 m	100–1,500 mm	Pipe can be relined though various methods depending on application. Lining methods can be, categorized as replacement or relining methods. Replacement methods refer to insertion of new pipe inside old line, these include sliplining and spiral winding; while cured in place pipe and fold and form methods are categorized as relining method. Relining extends useful life of pipe but is not intended as structural enhancement.	Varies by method	Relining of water, sewer and natural gas lines	Brand (1997); Reyna et al. (1994); McAlpine (1991); Larsen et al. (1997); Wells (1996)
Pipe scanning and evaluation	Varies	Varies by method	Classified as group of nondestructive methods for inspecting pipes to determine their condition. Methods include sonar, impulse radar, seismic transmission, radio electromagnetic and closed-circuit television. Usually first step in evaluating existing distribution systems.	Varies by method	Inspection of existing infrastructure systems, as well as a "snap shot" of the pipe condition.	Martindale (1997); Hutchinson (1997); Russell and Davies (1997); Staples (1994); Tenove (1997)
Robotic spot repair	Varies	Varies by method	Involves use of remotely controlled systems for structural repair or leak control of pipes. Uses inflatable "shoes" as temporary forming while epoxy is injected in damaged sections and allowed to cure.	Varies by method	Repair of sewer and water lines where structural enhancement is required.	Bauhan et al. (1997)

Note: mm/m = cost in Canadian dollars/mm diameter/linear meter.

Appendix B

Maximum equivalent noise levels associated with construction equipment (Gilchrist and Allouche, 2005)

	Maximum equivalent noise level, L_{eq} (dBA)					
	15m	30m	45m	60m	90m	120m
Equipments						
Backhoe	85	79	75	72	68	65
Compactor	82	71	67	64	61	57
Concrete mixer	85	69	65	62	59	56
Concrete vibrator	78	54	51	49	47	44
Dozer	85	78	76	71	67	64
Excavator	83	77	73	70	66	63
Jack hammer	88	79	74	72	69	65
Roller	86	70	66	64	61	58
Activities						
Handling formwork	90	52	50	48	46	44
Truck discharge	90	46	44	42	41	39

Appendix C

Montreal Origin-Destination Survey, Profile of the Greater Montreal Area (Agence métropolitaine de transport, 2003)

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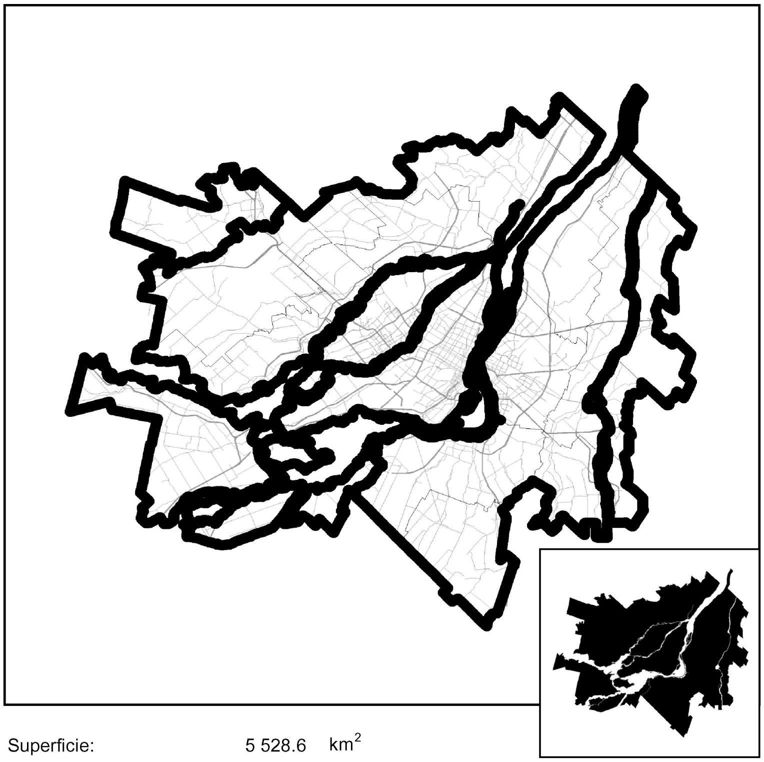
ENQUÊTE ORIGINE-DESTINATION 2003

La mobilité des personnes dans la région de Montréal

Territoire complet

Population:	3 605 996	Hommes	49.2%	Femmes	50.8%
Nombre de logis:	1 489 597	Âge	%	Nb logis avec:	%
Logis enquêtés:	70 418	0-19	24.1%	0 auto	21.2%
Autos:	1 803 434	20-34	20.9%	1 auto	44.8%
Personnes/logis:	2.42	35-49	25.1%	2 autos	28.0%
Autos/logis:	1.21	50-64	17.3%	3 autos	4.6%
Autos/personne:	0.50	65 et +	12.7%	4 autos et +	1.4%



Superficie: 5 528.6 km^2

DÉPLACEMENTS DES RÉSIDANTS DU SECTEUR

Nombre de déplacements effectués par les résidants:	7 850 172
Nombre de déplacements internes:	7 692 397
Nombre de résidants (5 ans et +) ne se déplaçant pas:	571 806
Déplacements par personne (5 ans et +):	2.30

Par MOTIF *(tous modes - 24 heures)*	Produits	Attirés	Externes
- Travail	19.3%	18.9%	18.6%
- Études	10.2%	10.1%	4.4%
- Loisir	7.7%	7.5%	42.6%
- Magasinage	7.9%	7.9%	2.7%
- Autres (sauf retour)	10.7%	10.6%	29.4%
- Retour au domicile	44.2%	45.1%	-
TOTAL (nb)	**7 767 549**	**7 773 102**	**1 918**

DÉPLACEMENTS PRODUITS ET ATTIRÉS PAR LE SECTEUR

Par MOTIF - 24 hres *(tous modes)*	Produits	Attirés
- Travail	19.3%	18.9%
- Études	10.2%	10.1%
- Loisir	7.7%	7.5%
- Magasinage	7.9%	7.9%
- Autres (sauf retour)	10.7%	10.6%
- Retour au domicile	44.2%	45.1%
TOTAL (nb)	**7 767 549**	**7 773 102**

Par MODE - 24 hres *(tous motifs sauf retour)*	Produits		Attirés	
- Motorisés (nb)	3 837 062	88.5%	3 773 107	88.4%
- Automobile (nb)	3 028 450	69.9%	2 969 404	69.5%
- Conducteur	*79.9%*		*79.9%*	
- Passager	*20.1%*		*20.1%*	
- T.C. Public (nb)	648 200	15.0%	647 348	15.2%
- Métro	*56.7%*		*56.7%*	
- STM (bus)	*57.6%*		*57.7%*	
- Train	*5.9%*		*5.9%*	
- STL, RTL, CIT	*17.3%*		*17.2%*	
- Bimodal	*8.5%*		*8.5%*	
- Autres motorisés (nb)	218 429	5.0%	214 095	5.0%
- Non motorisés (nb)	496 170	11.4%	495 974	11.6%
- Autres (nb)	2 368	0.1%	822	0.0%
TOTAL (nb)	**4 335 152**		**4 270 308**	

Par MODE - PPAM *(tous motifs sauf retour)*	Produits	Attirés
- Motorisés	89.4%	89.2%
- Automobile	*63.1%*	*62.7%*
- T.C. Public	*19.0%*	*19.3%*
- Bimodal	*2.2%*	*2.2%*
- Autres motorisés	*9.7%*	*9.6%*
- Non motorisés	10.5%	10.7%
- Autres	0.1%	0.0%
TOTAL (nb)	**1 858 900**	**1 828 052**

Par PÉRIODE *(Motorisés tous motifs)*	Produits	Attirés
- PPAM	25.2%	24.8%
- Jour	28.6%	28.6%
- PPPM	27.9%	28.3%
- Soir	15.3%	15.5%
- Nuit	2.9%	2.9%
TOTAL (nb)	**6 827 710**	**6 833 295**

Appendix D

Socio-demographic profile of Montreal's borough of Saint Leonard (Ville de Montreal, 2009)

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► Données sociodémographiques

- Population
- Immigration
- Familles
- Ménages privés
- Logements privés
- Langues
- Mobilité
- Citoyenneté
- Âge et sexe
- Minorités visibles
- Activité économique
- Travail
- Professions
- Scolarité
- Revenus
- Déplacement des personnes

Profil sociodémographique

Montréal en statistiques

Saint-Léonard

Édition mai 2009

Incluant les données du recensement 2006 de Statistique Canada

Mise en valeur du territoire et du patrimoine
Montréal

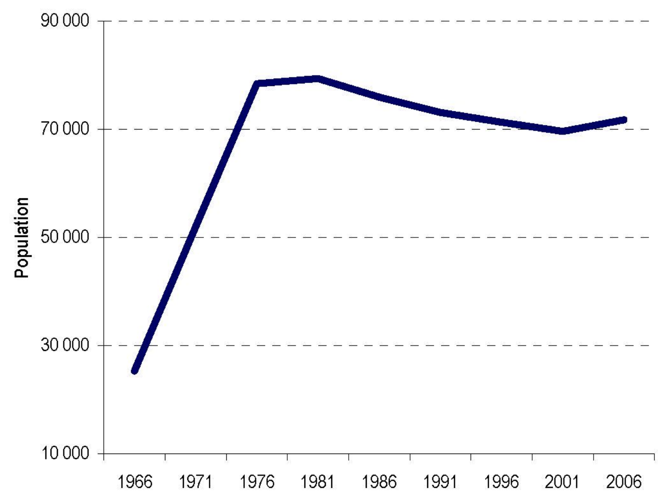
Population

- 71 730 habitants en 2006, en croissance de 3,1 % par rapport à 2001
- 12e arrondissement le plus populeux de la ville de Montréal
- 4,4 % de la population de la ville et 3,9 % de la population de l'agglomération de Montréal
- Territoire de 13,5 km^2
- Densité de population de 5 317 habitants au km^2

Répartition de la population en 2006

Variation de la population de 1966 à 2006

- Avec une croissance de 183,2 % de sa population entre 1966 et 2006, Saint-Léonard fait partie des huit arrondissements de Montréal qui affichent un taux de croissance positif pour cette période.
- Au cours des quarante dernières années, la croissance démographique de l'arrondissement a été fortement concentrée à la fin des années 60 et au début des années 70.
- Après un plafonnement de la population entre 1976 et 1981, une phase de décroissance a été observée entre 1981 et 2001, alors que Saint-Léonard a perdu 12,4 % de ses habitants.
- La dernière période intercensitaire 2001-2006 marque toutefois un certain rattrapage démographique, alors que la population s'est accrue de 3,1 %.



	1966	1971	1976	1981	1986	1991	1996	2001	2006
Saint-Léonard	25 328	52 035	78 452	79 429	75 947	73 120	71 327	69 604	71 730
Taux de croissance en %	--	105,4	50,8	1,2	-4,4	-3,7	-2,5	-2,4	3,1

Logements privés

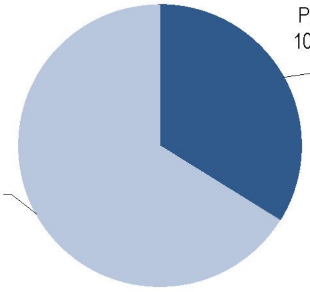
Caractéristiques des logements

	Nombre	%
Nombre de logements privés occupés	29 985	--
Nombre moyen de pièces par logement	5,0	--
Nombre moyen de chambres à coucher par logement	2,3	--
Type de constrution résidentielle		
Maison individuelle non attenante	1 860	6,2
Maison jumelée	790	2,6
Maison en rangée	5	0,0
Appartement, duplex	3 315	11,1
Appartement, immeuble de cinq étages ou plus	1 660	5,5
Appartement, immeuble de moins de cinq étages	22 285	74,3
Autre maison individuelle attenante	55	0,2
Logement mobile	10	0,0

- On dénombre 29 985 logements sur le territoire de l'arrondissement.
- Un logement compte en moyenne 5 pièces dont 2,3 chambres à coucher.
- Le type de logement le plus répandu est l'appartement dans un immeuble de moins de cinq étages : on en dénombre 22 285, ce qui représente 74,3 % de l'ensemble des logements.

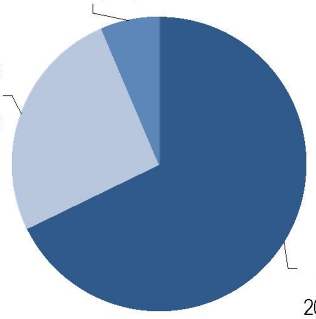
Mode d'occupation des logements

- Parmi les 29 985 logements de l'arrondissement, 19 820 sont occupés par des locataires, soit 66 % de l'ensemble.
- En complément, on compte 10 205 logements dont l'occupant est propriétaire, ce qui représente 34 % de l'ensemble des logements.



État du logement

- Lors du recensement de la population, l'état du logement est évalué par l'occupant. Ainsi, 20 315 logements, soit 68 % de l'ensemble des logements sur le territoire nécessitent un entretien régulier seulement, selon l'occupant.
- Des réparations mineures seraient souhaitables pour 7 770 logements (26 % de l'ensemble), alors que 1 915 logements, soit 6 %, exigeraient des réparations majeures.



Appendix E

Canadian Mortgage and Housing Corporation Analysis of the Resale Market: Montreal Metropolitan Area (CMHC, 2008)

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2008

Date Released: Fourth Quarter 2008

Analysis of the Resale Market - Third Quarter 2008

Montréal Metropolitan Area

Chambre immobilière du Grand Montréal
Greater Montréal Real Estate Board

lagentfaitlebonheur.com

notwithoutmyagent.com

SCHL CMHC

Canada

Montréal Market

3rd Quarter 2008

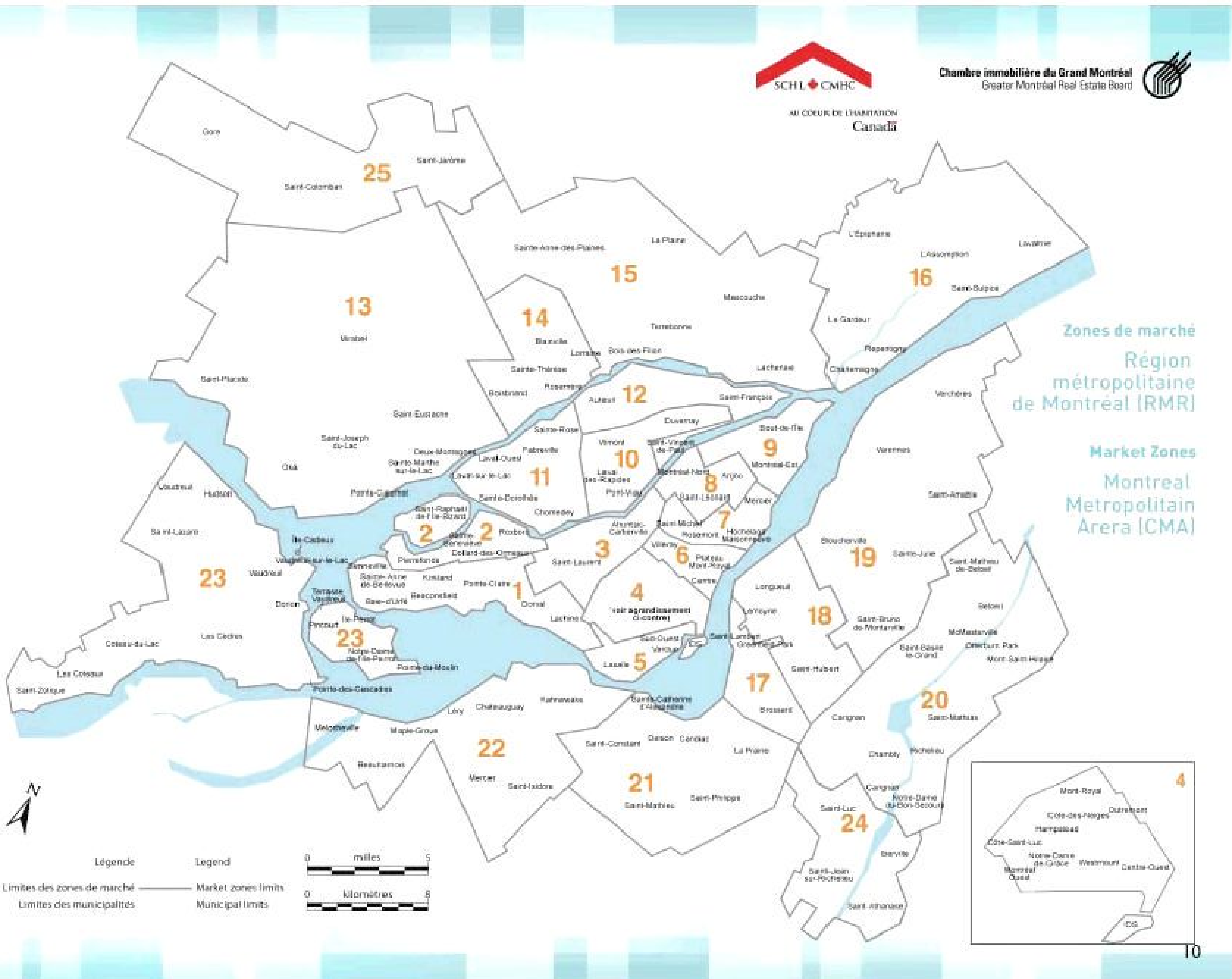
	Market Zones	MLS® SALES 3rd Qtr 2008 units	Change 12 months	JAN to SEPT 2008 units	Change 12 months	ACTIVE MLS® LISTINGS 3rd Qtr 2008 units	Change 12 months	AVERAGE MLS® PRICE 3rd Qtr 2008 $	Change 12 months	JAN to SEPT 2008 $	Change 12 months	AVERAGE LISTING PERIOD 3rd Qtr 2008 Days	LISTINGS / SALE * 3rd Qtr 2008	MARKET CLASSIFICATION
Single Family House	MONTREAL ISLAND													
	zone 1	259	-1%	918	-10%	464	15%	402,396	12%	365,289	11%	52	4	Seller
	zone 2	208	-14%	904	-12%	504	16%	327,676	14%	306,170	10%	55	5	Seller
	zone 3	89	-28%	399	-12%	221	15%	390,313	11%	363,709	3%	55	5	Seller
	zone 4	157	-6%	632	-12%	446	27%	740,262	19%	728,477	7%	67	5	Seller
	zone 5	40	8%	177	-10%	106	26%	300,350	3%	285,420	4%	60	4	Seller
	zone 6	23	-32%	101	-11%	47	15%	431,239	15%	384,460	4%	45	4	Seller
	zone 7	62	-17%	262	-5%	122	5%	252,085	8%	251,526	6%	76	4	Seller
	zone 8	56	-23%	251	-6%	166	19%	288,628	2%	273,533	0%	80	6	Seller
	zone 9	117	-9%	518	-8%	374	20%	242,840	7%	235,844	6%	74	6	Seller
	total	1,011	-11%	4,162	-10%	2,450	18%	401,024	14%	375,789	7%	61	5	Seller
Condo	MONTRÉAL ISLAND													
	zone 1	64	-6%	240	1%	148	-14%	235,668	15%	225,137	6%	69	6	Seller
	zone 2	82	-14%	336	-5%	181	-19%	178,707	4%	183,073	7%	105	5	Seller
	zone 3	167	10%	644	0%	442	-12%	225,095	5%	223,837	6%	92	6	Seller
	zone 4	308	3%	1,145	-1%	981	9%	341,949	-4%	335,101	-1%	93	6	Seller
	zone 5	158	3%	689	4%	385	4%	219,739	-6%	218,486	3%	73	5	Seller
	zone 6	383	13%	1,391	-2%	878	3%	288,472	12%	278,965	10%	78	5	Seller
	zone 7	221	25%	981	25%	542	-4%	202,217	4%	198,144	2%	82	5	Seller
	zone 8	60	11%	228	16%	191	-8%	210,774	7%	200,411	5%	84	9	Balanced
	zone 9	85	23%	416	18%	271	22%	158,947	2%	155,704	4%	95	6	Seller
	total	1,528	8%	6,050	5%	4,019	0%	254,281	3%	245,056	3%	85	6	Seller
Plex	MONTRÉAL ISLAND													
	zone 3	81	14%	298	3%	203	19%	412,651	5%	403,427	4%	81	6	Seller
	zone 4	61	2%	225	4%	145	-12%	512,787	19%	491,901	12%	72	6	Seller
	zone 5	121	3%	457	-6%	324	11%	332,036	14%	327,831	11%	65	6	Seller
	zone 6	105	14%	358	3%	236	19%	369,261	1%	375,542	-1%	57	6	Seller
	zone 7	215	-7%	843	-10%	565	20%	343,513	4%	344,160	7%	62	5	Seller
	zone 8	75	-1%	311	3%	271	45%	374,710	0%	394,989	6%	82	8	Balanced
	other zones	58	35%	189	-12%	190	17%	298,256	-1%	303,765	3%	100	9	Balanced
	total	716	4%	2,681	-4%	1,934	17%	367,119	6%	367,595	7%	70	6	Seller

* : 4-quarter moving average

Zone 1	Baie d'Urfé, Beaconsfield, Dorval, Kirkland, Lachine, Pointe-Claire, Sainte-Anne-de-Bellevue, Senneville
Zone 2	Dollard-des-Ormeaux, Pierrefonds, Roxboro, Sainte-Geneviève, Saint-Raphaël-de-l'Île-Bizard
Zone 3	Ahuntsic*, Saint-Laurent
Zone 4	Centre-Ouest, Côte-des-Neiges, Côte Saint-Luc, Hampstead, Île-des-Soeurs, Montréal-Ouest, Mont-Royal, Notre-Dame-de-Grâce, Outremont, Westmount
Zone 5	LaSalle, Sud-Ouest, Verdun (excluding Île-des-Soeurs)
Zone 6	Centre**, Plateau Mont-Royal, Villeray*
Zone 7	Hochelaga-Maisonneuve**, Mercier, Rosemont-Petite-Patrie*, Saint-Michel
Zone 8	Anjou, Montréal-Nord, Saint-Léonard
Zone 9	Montréal-Est, Pointe-aux-Trembles, Rivière-des-Prairies
Zone 10	Duvernay, Laval-des-Rapides, Pont-Viau, Vimont
Zone 11	Chomedey, Fabreville, Laval-Ouest, Laval-sur-le-Lac, Sainte-Dorothée, Sainte-Rose
Zone 12	Auteuil, Saint-François, Saint-Vincent-de-Paul
Zone 13	Deux-Montagnes, Mirabel, Oka, Pointe-Calumet, Saint-Eustache, Saint-Joseph-du-Lac, Sainte-Marthe-sur-le-Lac, Saint-Placide

* One section of Villeray (zone 6) now forms part of Ahuntsic (zone 3) and another forms part of Rosemont–La Petite Patrie (zone 7).
** A section of Hochelaga-Maisonneuve (zone 7) now forms part of the Centre (zone 6).

Zone 14	Blainville, Boisbriand, Lorraine, Rosemère, Sainte-Thérèse
Zone 15	Bois-des-Filion, Lachenaie, La Plaine, Mascouche, Sainte-Anne-des-Plaines, Terrebonne
Zone 16	Charlemagne, L'Assomption, Lavaltrie, Le Gardeur, Repentigny, Saint-Gérard-Majella, Saint-Sulpice, L'Épiphanie
Zone 17	Brossard, Greenfield Park, Saint-Lambert
Zone 18	Lemoyne, Longueuil, Saint-Hubert
Zone 19	Boucherville, Saint-Amable, Saint-Bruno-de-Montarville, Sainte-Julie, Varennes, Verchères
Zone 20	Beloeil, Carignan, Chambly, McMasterville, Mont-Saint-Hilaire, Notre-Dame-de-Bon-Secours, Otterburn Park, Richelieu, Saint-Basile-Le-Grand, Saint-Mathias-sur-Richelieu, Saint-Mathieu-de-Beloeil
Zone 21	Candiac, Delson, La Prairie, Sainte-Catherine-d'Alexandrie, Saint-Constant, Saint-Mathieu, Saint-Philippe
Zone 22	Beauharnois, Châteauguay, Léry, Maple Grove, Melocheville, Mercier, Saint-Isidore
Zone 23	Hudson, Île-Cadieux, Île-Perrot, Notre-Dame-de-l'Île-Perrot, Pincourt, Pointe-des-Cascades, Pointe-du-Moulin, Saint-Lazare, Terrasse-Vaudreuil, Vaudreuil-Dorion, Vaudreuil-sur-le-Lac, Les Cèdres, Saint-Zothique, Coteau-du-Lac, Les Coteaux
Zone 24	Iberville, Saint-Athanase, Saint-Jean, Saint-Luc
Zone 25	Bellefeuille, Gore, Lafontaine, Saint-Antoine, Saint-Colomban, Saint-Jérôme


Chambre immobilière du Grand Montréal
Greater Montréal Real Estate Board
SCHL CMHC
AU COEUR DE L'HABITATION
Canada
Zones de marché
Région métropolitaine de Montréal (RMR)
Market Zones
Montreal Metropolitain Arera (CMA)
Légende
Legend
Limites des zones de marché
Market zones limits
Limites des municipalités
Municipal limits
milles
kilomètres
Gore
Saint-Jérôme
Saint-Colomban
Mirabel
Saint-Placide
Saint-Eustache
Oka
Hudson
Vaudreuil
Dorion
Les Cèdres
Coteau-du-Lac
Les Coteaux
Saint-Zotique
Sainte-Anne-des-Plaines
La Plaine
Mascouche
Terrebonne
Blainville
Lorraine
Bois-des-Filion
Sainte-Thérèse
Boisbriand
Rosemère
L'Épiphanie
L'Assomption
Lavaltrie
Saint-Sulpice
Le Gardeur
Repentigny
Charlemagne
Lachenaie
Verchères
Varennes
Sainte-Julie
Boucherville
Longueuil
Saint-Hubert
Brossard
La Prairie
Candiac
Saint-Constant
Saint-Philippe
Saint-Mathieu
Châteauguay
Léry
Kahnawake
Mercier
Saint-Isidore
Maple Grove
Beauharnois
Chambly
Richelieu
Carignan
Saint-Luc
Iberville
Saint-Athanase
Saint-Mathias
Beloeil
McMasterville
Mont-Saint-Hilaire
Mont-Royal
Outremont
Hampstead
Côte-Saint-Luc
Westmount
Centre-Ouest
IDS
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