Transport Canada Transports Canada

THE COST OF URBAN CONGESTION IN CANADA

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EXECUTIVE SUMMARY

The Cost of Urban Congestion in Canada study developed congestion indicators for the nine largest urban areas in Canada. The research required the development of common means to measure congestion and extract the requisite data for the indicators from each urban area's travel demand forecasting models. Although the models all produce the same outputs (i.e. simulations of vehicle trips), there were structural and methodological differences among them. Some of the differences are obvious - such as the definition of expressways and arterials – while others are subtle, such as the methods used to calibrate the urban models. Consequently, the differences are significant enough not to allow a simple comparison of congestion across all nine urban areas. However, such congestion indicators, if collected over time, could be particularly useful in tracking trends.

An engineering approach was used in the aforementioned study to define and to develop the congestion indicators and to estimate the social costs of congestion associated with extra time wasted due to congestion and the cost associated with greenhouse gas (GHG) emissions. The engineering approach focuses on the direct and physical characteristics of congestion based on engineering principles that link vehicle flow/traffic speed to road capacity (measured as vehicles per hour). This approach differs from estimating the cost of congestion as the "deadweight loss" or loss to society associated with excessive road use – due to the absence of proper pricing of the road infrastructure use that reflects the social cost of congestion, including the environmental and external costs of congestion. The economic approach recognizes that there is an "optimal" amount of delay (i.e. economically efficient level of congestion) caused by impeding users, and that some congestion is already internalized for some users.

The study estimates that the total annual cost of congestion (in 2002 dollars) ranges from $2.3 billion to $3.7 billion for the major urban areas in Canada. More than 90 percent of this cost represents the value of the time lost to auto travellers (drivers and their passengers) in congestion. The remainder represents the value of fuel consumed (around 7 percent) and GHG's emitted under congestion conditions (around 3 percent). The study estimates an increase of 1.2 to 1.4 megatonnes of GHG due to congestion every year.

It is important to note that these estimates of congestion costs are conservative, because data availability precluded the inclusion of cost associated with non-recurrent congestion (i.e. congestion caused by random events, such as bad weather, accidents, stalled vehicles and other incidents), freight transportation, off-peak congestion and other congestion-related costs such as noise and stress. More data is required to better understand their costs.

In the past, some Canadian transport authorities have attempted to measure and quantify the cost of congestion for specific urban areas. However, methods and data have varied. The recently completed Transport Canada study on congestion provides the first systematic analysis of urban congestion in Canada. In this respect, it represents a major contribution to our understanding of urban congestion in Canada.[1]

[1] The study was carried out by a team of consultants composed of Delcan (prime consultant), iTRANS and ADEC Consultants.

THE COST OF URBAN CONGESTION IN CANADA

1. Introduction

"Congestion" is commonly cited as a major and growing urban ill. Many Canadian drivers encounter congestion and traffic jams every day, although their severity and frequency vary from area to area. Urban, regional and provincial transportation authorities aim to manage the problem through a variety of measures.

But what exactly is meant by congestion? How can it be quantified? What does it cost individuals, firms and society as a whole? Individual drivers do not have a common view and understanding of what congestion means. For some, it could mean a situation such as traffic jams with complete stops and long delays. For others, it could mean stop-start driving, moving slowly or, more broadly, the condition of traveling at less than the speed limit. Technically, congestion is in fact the saturation of road network capacity due to regular or irregular reductions in service quality, exemplified by increased travel times, variation in travel times and interrupted travel.

The research asks two questions that are important to the ways in which urban transportation authorities and decision-makers can address congestion:

- Why is it important to understand congestion?
    - Research in the United States (U.S.) and Europe has demonstrated that an understanding of congestion (what it means, how it can be measured) is fundamental to being able to allow urban authorities to develop solutions to congestion. Thus, this study represents only a first step, albeit an important one on this subject, by suggesting a methodology that Canadian municipalities could use to develop their own congestion estimates. This could, if data is collected on a regular basis, be useful in tracking congestion trends.
    - It follows that an understanding of the costs of congestion – that is, the manifestation of congestion's impacts on travelers and on society at large – allows potential solutions to be developed in the full context of urban goals, such as improved quality of life, increased productivity, etc.
    - The interest in measuring congestion and its costs does not imply that the only 'solution' is for urban authorities to build more roads and highways: rather, this measurement may provide a basis for understanding how congestion can be incorporated explicitly into urban authorities' assessments of their own transportation plans (whether these involve roads, or whether they are transit, transportation demand management schemes or other alternatives to driving).
- How to comprehensively measure congestion?
    - The development of indicators of congestion could significantly improve decision-making and could contribute to the development of a more sustainable transportation system, particularly in the urban sector. A key product of this study is the development of a methodology that transportation authorities could use to consistently assess the congestion reduction benefits of alternative transportation proposals, including proposals for public transit, transportation demand management and other ways to reduce the demand for

auto travel, as well as ways to better manage traffic (such as Information Transportation Systems). The promotion of better ways to meet and manage transportation demand (as opposed to continued expansion of the road and highway network) has been a common theme of the transportation plans of most Canadian urban areas for several years. The end result could be a transportation system that operates efficiently and that meets mobility needs without jeopardizing quality of life.

The rest of this paper summarizes the main findings and conclusions of the study. Section 2 is a short overview of past efforts made by individual cities to measure the cost of urban congestion within their own jurisdiction. In section 3, the main two generic causes of traffic congestion – recurrent and non-recurrent congestion are described. Section 4 explains the definitions of congestion from two main perspectives – the definition based on engineering principles that link traffic flow to road capacity, and the economic interpretation of congestion as an externality and its implications for evaluating congestion costs. Section 5 focuses on the sources of data used by the study and coverage. In section 6, the three main components of the costs of congestion included by the study – time loss, fuel wasted and air pollution – are described. Section 7 presents the various indicators developed for traffic congestion. In section 8, the estimates of various components of the costs of congestion covered by the study are presented. Section 9 focuses on the expected growth of traffic congestion in Canada based on major economic drivers. Section 10 summarizes the main recommendations made by the study in terms of congestion-related data and modeling needs. Lastly, section 11 presents conclusions and final observations.

2. Past Efforts to Measure the Costs of Congestion in Canada

Governments at all levels recognize that addressing congestion is an important part of implementing urban transportation plans and meeting national, provincial and local transportation sustainability goals. However, the ability to measure congestion – that is, to quantify – and value it is a fundamental first step in being able to address it.

In the past, there have only been some isolated attempts in Canada to measure the cost of congestion in specific urban areas, but there is no routine measurement, or national estimate.

By far the most comprehensive estimate of the cost of congestion has been prepared for the Montréal region. The Ministère des Transports du Québec (MTQ) conducted two studies to calculate the costs of congestion in that region. The first estimated the economic cost of traffic congestion at around $502 million per year in 1997 dollars (based on 1993 traffic data). The cost of congestion included three main components: delay costs (time wasted under congested conditions), vehicle operational cost (fuel wasted) and an imputed cost for excessive pollution cost due to traffic congestion for passenger vehicles, trucks and city buses. In 2000, MTQ updated its estimates, generally applying the same methodological approach to new data from a 1998 regional origin-destination survey, and estimated the annual costs of congestion for Montréal at around $600 million (in 2000 dollars).

In 2001, MTQ recalibrated its travel demand forecast model (based on the 1998 data). Using the new tool, a MTQ report estimated in 2004 that the total cost of congestion for the Montréal region was about $779 million per year (in 1998 dollars). The most recent

MTQ study reports that congestion in Montréal, measured in term of vehicle-hour delay, increased by 54 percent between 1993 and 1998 due to the saturation of some parts of the network. This affects the performance of the overall network. According to the report, the cost of congestion in the Montréal region has increased from $498 million to $779 million (in 1998 dollars).

The cost of congestion in Toronto was estimated around $1.8 billion (in 1997 dollars) per year according to the "1988 Goods Movement Study for Metropolitan Toronto" for the freight sector. The report does not give many details on the methodology used to estimate the cost.

The Regional Office of Transport Canada in British Columbia estimated that the cost of congestion for commuters in the Lower Mainland/Vancouver was approximately $680 million (in 2001 dollars). Transport Canada (the Regional Office) derived its estimates from the Translink travel demand forecast model. In 1998, the British Columbia Trucking Association (BCTA) estimated that congestion imposed a cost of $519 million on commercial vehicle operators, not including social costs, such as air pollution (in 1999 dollars). If these costs were additive, the total cost of congestion in Vancouver would therefore be, including both truck and general traffic, approximately $1.2 billion (in 1999 dollars).

The studies showed that the cost of congestion is substantial, and can be measured in billions of dollars, and is possibly increasing significantly. However, there are inconsistencies in the methods and data upon which these studies were based.

3. Nature and Causes of Urban Road Congestion

When measuring congestion, it is important to distinguish between two types of congestion, according to their generic causes: recurrent congestion and non-recurrent (incident) congestion. The study entitled *The Cost of Urban Congestion in Canada* focuses on the former. An understanding of recurrent congestion is required before non-recurrent congestion can be analyzed.

Recurrent congestion occurs mainly when there are too many vehicles using the limited space on the road network at the same time, consequently reducing traffic speed and increasing personal commuting time. Typically, it occurs during weekday morning and afternoon peak periods, when most people go to work and return home at around the same time, since the common work schedule has a narrow window of flexibility. This reflects the fact that much of the demand for travel peaks at a precise time of day, and peak demand also appears in the consumption of energy and water, etc. Consequently, in larger urban areas, the peak periods can range from 6:00 to 9:30 a.m. and from 3:30 to 7:00 p.m. In smaller urban areas, the peaks may have a shorter duration (one or two hours).

Of interest is the growing recurrent congestion that occurs during off-peak periods (i.e. at other weekday hours and even on weekends). This reflects, in part, a rapid growth in off-peak travel (often growing faster than peak-period travel). One manifestation of this is the fact that certain sections of expressways in Toronto and Montréal are regularly congested between the peak periods, essentially operating under all-day-peak period conditions.

The underlying factors generating recurrent road congestion hinge on rapid growth in population, urbanization and related growth in car ownership and use. In the decade from 1993 to 2003, Canada's population grew by 2.7 million, or 9.3 percent, spurred notably by immigration of nearly 2.2 million. The urbanized proportion of the population grew from 77 percent to 80 percent, and growth was faster in the larger metropolitan areas, with those of over 100,000 population experiencing growth of nearly 16 percent during the decade.

In 2003, around 65 percent of Canada's population, or about 20 million people, lived in the nation's 27 census metropolitan areas, up slightly from 61.8 percent in 1993. Growth was concentrated in four large urban regions: the extended Golden Horseshoe,[2] Montréal and adjacent region, the Lower Mainland and southern Vancouver Island and the Calgary-Edmonton corridor.

During the period, growth was particularly rapid in the metropolitan areas of Vancouver, at 23 percent, and Calgary, at 27 percent. By far the largest absolute increase in population took place in the metropolitan area of Toronto, where population grew by over 900,000, or 21.5 percent, in the past decade.[3]

Motor vehicles in use have also continued to increase faster than the total population; the fleet of cars and trucks combined rose by 13 percent during the past decade up to 2003. Statistics reporting trends for total national vehicle use suggest that total vehicle-kilometres grew at least as fast as the vehicle fleet. Truck traffic has grown even faster than private vehicle traffic during the last decade and a half, under the unprecedented stimuli of deregulation, North American Free Trade and continued innovations in logistics management (e.g. "just-in-time" delivery).

The other main source of traffic congestion is what is called ***non-recurrent congestion*** associated with random conditions or special and unique events. The four main causes of non-recurrent congestion are: traffic incidents (ranging from disabled vehicles to major crashes), work zones (which slow traffic), weather and special events. Because of the random character of this type of congestion, non-recurrent congestion is more difficult to predict and to address. The impact of non-recurrent congestion on predictable and reliable travel time could be important. The reliability and predictability of travel time is of utmost importance to the public, the shipping industry and the economy in general. Variability of travel time leads to costly uncertainty for commuters and, in particular, for goods transporters who must meet fixed delivery schedules. Less variability in travel times can be even more important for the public that length of travel time.

The ability to identify and to measure different types of congestion, including the non-recurrent type, is key to developing appropriate mitigation solutions and policy responses. In the U.S., a preliminary assessment by the Federal Highway Administration

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[2] This region consists of the urban centres of Oshawa, Toronto, Hamilton and St. Catharines-Niagara, plus Kitchener, Guelph and Barrie. It accounted for 59 percent of Ontario's population and 22 percent of the nation's population in 2001. Almost one-half of Canada's total population growth occurred there.

[3] Annual Demographic Statistics, Statistics Canada 91-213-XIB2004000. Information on census is also available at Statistics Canada website.

estimates that roughly half of the congestion experienced by Americans is due to non-recurrent congestion caused by temporary disruptions. The lack of data on incidents, in combination with the scarcity of travel time data, forces some agencies to find proxy solutions to measure non-recurrent congestion. For example, the Washington State Department of Transport estimates that non-recurrent delay generally comprises between 30 and 50 percent of all peak-period delay. This estimate assumes that “incident-related trips” are any trips that take twice as long as a free-flow trip.

The lack of coherent incident sets that could be correlated to travel time makes the estimation of non-recurrent congestion somewhat cumbersome. In some areas, where data is readily available, the challenge lies in linking the data together while selectively filling gaps. Annual traffic count programs, traffic studies and police accident reports often contain a plethora of traffic information that can be readily available for use. However, this data typically is not compiled in a format that is usable for congestion analysis; nor are the different data sets necessarily consistent with each other. An inventory of available data and its sources should be developed to identify any gaps or limitations. Once these gaps and limitations have been identified, a plan can be coordinated that would fill in the missing information and develop estimates for non-recurrent congestion. The study recognizes the importance of measuring non-recurrent congestion to fully reflect the cost of all types of congestion. However, given the above challenges in terms of data availability, non-recurrent congestion was not the subject of the study. In this regard, Transport Canada has recently completed research that examines different methods that could be used to estimate non-recurrent congestion using existing data.[4]

4. Definition of Congestion

In assessing the cost of congestion and measurement approaches, a distinction should be drawn between private and social costs. Individually, people define congestion differently depending on their own experience or situation. However, time delays and fuel wasted generally constitute key impacts as far as individual drivers are concerned. Other private costs, such as increased stress level or noise, could also be important to some individuals. The notion of social costs indicates that congestion caused by the volume and density of traffic that reduces speeds, and consequently imposes delays on all drivers, imposes an economic cost on society as a whole – in terms of productive time lost and increased fuel consumption, vehicle operating and related costs incident risk, air pollution and GHG emissions. This study is an attempt to assess the social cost of congestion.

Technically, there is no consensus on a specific definition of congestion. Transport Canada recognizes that there are alternatives. The consultant study adopted the following definition, in consultation with urban and provincial transportation experts:

> *“Congestion is the inconvenience and increased costs that travellers impose on each other while using their vehicles, attempting to use the road network at the same time, because of the relationship that exists between traffic density and speed (with due consideration of capacity).”*

[4] See Krigger, D. 2005.

This definition is consistent with theoretical engineering principles that link *vehicle flow* (actual throughput, measured as vehicles per hour) to *road capacity* (available capacity for throughput, measured as vehicles per hour). This provides the basic reference for the engineering analysis of congestion; that is, explaining congestion according to the physical characteristics of the road. Traffic streams are described by three variables: density k (vehicles per lane per kilometre), speed v (km/h) and flow q (vehicles per lane per hour). Traffic flow is the product of traffic density (vehicles/km) and speed (km/h), so these three variables are related by the equation $q = kv$. All things being equal, as more vehicles enter the same road, traffic density increases, travel speed falls and travel time increase. This is the fundamental traffic flow principle on which the *engineering approach* bases its definition of congestion.

From an economic point of view, traffic congestion occurs when the cost of travel is increased by the presence of other vehicles. The congestion externality arises because additional road users increase travel times for other vehicles. Travel time increases because increased traffic density forces drivers to go slower due to the reduced gap between vehicles, because greater attention is required to drive safely, or because queuing might occur at junctions or bottlenecks. The externality of congestion differs in some respects from most other examples of externalities. By definition, externalities refer to costs (or benefits) that are not market-priced and accrue to third parties as a result of actions taken by individuals. In contrast to environmental and noise externalities, congestion externality costs are internal to the transport sector as a whole, so they are considered an *intra-sectoral* externality. In their decision-making process, motorists recognize the higher time costs they face during road congestion, but they do not recognize that they impose delay costs on other motorists on the road. Motorists do not perceive themselves as a cause but rather as a victim of congestion. In a sense, the externality is internalized in the aggregate, a form of collective internalization unlike most other externalities.

Economically efficient pricing requires that market prices appropriately reflect social costs, not solely private costs. Any implementation of measures attempting efficient pricing must rely on estimates for all elements of social marginal cost, including external costs. Congestion costs are a crucial component of the social cost. From an economic efficiency perspective, the crucial issue is to distinguish between the external element of the cost of congestion and the total or average cost of congestion. The total cost of congestion is borne by the sum of users themselves. However, under congestion conditions, each additional user inflicts costs on other users. The external element, the costs inflicted on others, is the relevant part for pricing purposes. Additional users of transport infrastructure impose costs on other transport users as well as on themselves through congestion.

In terms of measurement, from an economic standpoint, the cost of congestion has a precise meaning only if it refers to an optimal situation based on a determined level-of-service objective accompanied by the full economic price of this level of service. In other words, the congestion that is observed is compared to an optimal traffic level. Therefore, an alternative method to consider is to measure the congestion that would be eliminated by efficient congestion pricing, where such efficient pricing included the marginal external costs associated with congestion, including the costs of delays, wasted fuel, additional costs due to additional use of vehicles, accidents and environmental damage imposed by users on others. Remaining congestion, as well as remaining accidental and environmental damage and other costs, would be “efficient” in the sense of being internalized and accepted by users. In choosing instruments for congestion reduction, it is useful to differentiate between this “external” congestion and “internal” or “potentially-internalized” congestion.

With respect to recurrent congestion measurement, among practical measurement systems around the world, the most common measurement of congestion includes all traffic delay beyond “free-flow”[5] or unimpeded conditions. This is the approach used by the Texas Transportation Institute (TTI) in their “Urban Mobility Report ”,[6] which provides annual congestion statistics for major cities in the U.S. Some other studies estimate actual network speeds and travel times over the course of a day using technology generated data such as Global Positioning System (GPS), speed cameras and floating cars, and compare them to speeds and travel times when volumes are lowest. However, the more common method relies on traffic volume data on specific road sections (that are usually more readily available and are expanded statistically to represent other roads), and estimates speeds and travel times for each section and each time period based on standard speed-flow relationships with geometric characteristics then compares them to free-flow times. That is the TTI approach, using data for sections of highways and arterials in U.S. urban areas that is recorded in the Federal Highway Administration’s Highway Performance Monitoring System.[7]

The most frequently expressed challenge to this common method is that free-flow speed is not the most environmentally sustainable or economically efficient target for network capacity provision, and therefore not a reasonable policy objective, since:

a) Maximum flow occurs only at speeds lower than free-flow (as shown in standard speed-flow relationships);
b) Capacity expansion is “lumpy” and expensive, so the life cycle of an investment typically involves an initial period with excess capacity, and free-flow speeds, followed by growing congestion with traffic growth, up to the point at which additional expansion is warranted, so the average condition will involve some congestion;
c) Economically efficient congestion pricing would leave a substantial amount of congestion, eliminating only the external part of the congestion costs; and
d) Drivers expect a certain degree of quality service from the road network, but this degree depends upon the real and perceived cost of road use in congested conditions. The bottom line is that most drivers may accept a certain level of congestion as long as any given trip could be completed safely, within a reasonable and predictable time and with minimum interruption.

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[5] Free-flow is the condition of traffic when there is no interference from other vehicles on the road; consequently there is only one vehicle on the road or other vehicles are far enough away so as not to be a constraint for the driver. Drivers can travel freely at the speed they wish.

[6] The complete Urban Mobility Report can be found on-line at http://mobility.tamu.edu/ums/.

[7] The Federal Highway Administration’s Highway Performance Monitoring System (HPMS) is a database of operational performance measurements for the transportation system in the US. The HPMS is a comprehensive database built from annual reports submitted by State departments of Transportation to the Federal Highway Administration as a minimum requirement to apply for federal funding.

Practical alternatives are not easy to suggest, which explains why delay from free-flow continues to be used in the U.S. An alternative has been proposed by the MTQ in its Montréal studies, in an attempt to measure the social cost of recurring congestion for the Montréal region. This suggests that users expect and accept congestion in peak hours on their normal routes, but that a threshold exists beyond which it becomes "unacceptable". For practical estimation purposes, the study chooses a threshold of 60 percent of the posted speed limit – i.e. 60 km/h for highways or expressways with posted limits of 100km/h and 30 km/h for urban arterials with posted limits of 50 km/h. Then the study estimates congestion delays and costs by comparing speeds on the Montréal network with these thresholds.

The choice of threshold is somewhat subjective, because it must take into account local perceptions of congestion, but it is believed to give a more sustainable target for congestion reduction than free-flow.

Building from the aforementioned recent work by the MTQ in Montréal, the study estimates congestion based on the threshold approach and uses data output from travel demand forecasting models (generally, the so-called EMME/2 models), in most cases conventional four-stage models developed and used by most large Canadian cities (or derivatives of them, such as the "MOTREM" model used in Montréal). The urban models used by the cities allow speeds and travel times to be synthesized on the urban networks from traffic volume and origin-destination data, and compared to free-flow, or any chosen threshold speeds. The main limitation of these models is that they only model a single peak-hour activity (Edmonton and Calgary are exceptions), although they are still useful for estimating the total additional delays caused by traffic congestion and could permit comparisons over time.

Because of the sensitivity of the estimates to the pre-determined threshold, the study examines three threshold values: 50 percent, 60 percent and 70 percent of free-flow speeds for both expressways and arterials. The study recognizes that although free-flow conditions can be fixed, the percentage of free-flow speed that represents the threshold varies according to local conditions (quantitatively) and local perceptions (qualitatively). There is no single 'acceptable threshold' for all municipalities and for a given network.

5. Data Sources and Coverage

Outputs from the travel demand forecasting models in each urban area were used as a key source of data. Because the data originates in these urban models, a consultative approach was developed to collect the data and agree on measurements and indicators. As part of this effort, seven technical meetings were held with the municipalities involved. This consultative work permitted the definition of expressways and arterials, and identified differences in data definition, modeling methods and gaps in the available data. With the cooperation of the urban authorities, it was possible to collect the relevant data and to develop a consistent set of measurements for this research. The research applied the resultant congestion measurements and indices to Canada's nine largest urban areas (from east to west, these are Québec City, Montréal, Ottawa-Gatineau, Toronto, Hamilton, Winnipeg, Calgary, Edmonton and Vancouver). The nine urban areas represented just over half (51 percent) of Canada's population in 2003.[8]

[8] *Annual Demographic Statistics*, Statistics Canada, 91-213-XPB.

In terms of coverage, the study estimates traffic congestion for freeways and arterials and delays for passenger vehicles only. Collectors and local streets, by definition, are assumed not to have pervasive congestion[9] and they are often not depicted in model networks at all. They are treated in the abstract (e.g. one link can represent several parallel local streets) or lack any reference traffic counts.

> An expressway is a facility that serves only through traffic, with no access to abutting properties. Access is controlled and, generally, limited to ramp locations. Expressways feature uninterrupted traffic flow, i.e. there are no signalized or stop-controlled at-grade intersections. Such facilities typically have two or more lanes for the exclusive use of traffic in each direction and a divided cross section, and generally have posted speed limits of 90 km/h or higher.[10] On-street parking or stopping is prohibited at all times.
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> An arterial[11] is a signalized facility that primarily serves through traffic and provides access to abutting properties as a secondary function (although intense roadside development can generate friction to traffic, thus impeding speeds along the arterial). Arterials have interrupted traffic flow, with signalized intersections spaced at distances of up to 3 kilometres or less. Arterials can have multiple lanes and can have a divided or undivided cross section. Posted speed limits typically range between 50 km/h and 90 km/h.

Because the urban models only model peak-hour travel, the congestion indicators developed in the study and the costs of congestion include only peak-hour congestion.

Truck traffic data is only available for a small number of urban areas. None of the models accounts for other vehicles in the traffic mix such as taxis, emergency vehicles, and light-duty vehicles used for commercial activity. Consequently, these vehicles are excluded from the scope of the study.

6. Components of the Costs of Congestion

The potential effects of traffic congestion are many: time loss, productivity loss, change in accident frequency and characteristics, increase in air pollutants and GHG emissions, increased vehicle operating costs and increased noise nuisance. These consequences represent a loss of scarce resources, which can amount to a significant value. At a certain level of severity, these consequences could explain the location and relocation of land-based activities (i.e., industries, businesses, retail establishments, etc.) as well as the choices of individuals to relocate their homes or even to change jobs or schools. Most of these effects are externalities, meaning that they are not integrated in the travel market; there is no direct market price attached to them and they are not the object of a conscious exchange between parties.

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[9] MTQ's costs of congestion research in Montréal found that 95 percent of the region's congestion occurred on expressways and arterials.

[10] The majority of expressway links in the (urban) centre of the Island of Montréal have posted speed limits of 70 km/h. Technically, they cannot be classified as expressways; however, in fact, under free-flow conditions, vehicles tend to travel at 'expressway' speeds (i.e., well above the posted limit).

[11] These definitions were drawn from the *Highway Capacity Manual* (2000).

The costs evaluated in this research only cover three of the main components of costs of congestion: delay costs (time wasted in congested periods), fuel costs (fuel wasted due to congested conditions), and an imputed cost for GHG emissions due to traffic congestion for passenger vehicles.

A review of the literature done by this study found that the relation of congestion to accidents and noise is not clear in theory and cannot be appraised empirically either. So this possible impact of congestion could not be estimated empirically in this research.

6.1 Time Loss

A unit price value for each of the three main components of congestion was used. The most important of these was the cost associated with time loss. To assess the costs of delay, Transport Canada's 1993 approach to travel time valuation was used.[12] This approach was adopted in the early 1990s, and because Transport Canada has been involved mostly in interurban travel issues, the methodological choices reflect this field of transport analysis (i.e., interurban rather than urban). The 1993 approach develops time values according to *business* and *non-business* trip purposes. Based on a review of the literature, the values were updated to reflect the base year for each urban area's travel demand forecasting model (i.e., the source of the congestion measurement data), and in turn updated to a common year (2002). The updated time values are summarized in Table 1 for business and non-business travel respectively.

It is important to note that the categorization of work and non-work trips is not consistent among the urban areas: this is evident from the range in the percentage breakdowns among the nine urban areas. In particular, the treatment of work-related trips varied (e.g., these appear not to have been included in Winnipeg, while an estimate was made for the Ottawa-Gatineau trips based on existing information). Also, breakdowns were not always available for peak-period travel (sometimes for the peak hour only or for the 24-hour period; this is important because work / work-related purposes could be over- or under-estimated respectively); and some estimates were available only for all modes (rather than just the automobile alone, although the automobile-based trips accounted for auto-persons [driver and passenger]). Finally, as noted, the Montréal and Québec City data are drawn from the actual link assignment, whereas the breakdowns from the other urban areas reflect survey or modelled trip matrices.

6.2 Fuel Wasted

For the purposes of this research, the consultants applied a simplified fuel and GHG emission calculation *without distinction* by vehicle type; i.e. taking all motor vehicles in the model assignment as a single class of light-duty vehicles. However, fuel consumption and GHG emission rates continue to vary by link speed. The method is described below. It is based on one that is employed in the Virginia Tech microscopic energy and emission model (VT-Micro, a microscopic fuel consumption and emission model under development by researchers at Virginia Polytechnical Institute) and the

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[12] Transport Canada. 1993. *Value of Passenger Time Savings*. Report TP11788.

Comprehensive Modal Emissions Model (CMEM). [13] The above models constitute the most recent and state-of-the-art energy and emission models and are categorized as either macroscopic or microscopic. Macroscopic models use average aggregate network parameters to estimate network-wide emission rates. Alternatively, microscopic models estimate instantaneous vehicle fuel consumption and emission rates, which are aggregated to estimate network-wide effectiveness measurement.

The study chose the CMEM model because of the network characteristics of the penalty function rather than the corridor-specific emissions ratings and speed relationships used by microscopic models. This method was used in lieu of the availability of network micro-simulation models, which estimate the dynamics of vehicle operations (i.e. acceleration, deceleration, cruise, etc.) and, in turn, fuel consumption and emissions, more precisely than travel demand models can. However, although the technology is evolving quickly, not all urban areas have network micro-simulation models, and those that exist address specific corridors only (these models are data- and computationally-intensive, precluding – for now – the ability to develop region-wide models).

Fuel consumption rates vary depending on the type of vehicle (i.e., gasoline-powered automobile versus diesel truck) and driving environment (i.e., urban versus freeway travel, un-congested versus congested travel).

The literature was referenced to determine appropriate fuel consumption and emission rates for air pollutants for various service levels as characterized by predefined Environmental Protection Agency (EPA) driving cycles.

These rates, derived from on-road vehicle testing of light duty gasoline-powered vehicles only, are summarized in Table 2.[14] The tables provide emission rates for various air pollutants (Criteria Air Contaminants) for both clean fleets (i.e., no high emitters) and a representative fleet in California (i.e. includes high emitters).

These data indicate that fuel consumption tends to increase with increased congestion (optimal fuel consumption is shown here to be achieved between 85 km/h and 105 km/h).

This research used the rates shown in Table 2, as being more closely representative of the Canadian vehicle fleet (i.e. including high emitters). Canadian data do not exist. The approximate average speeds represent the extremities of a speed range (e.g. the value for Arterial Level of Service (LoS) A represents 45 km/h or higher, for Freeway LoS D represents 85 km/h to 94 km/h, and for Arterial LoS E represents 20 km/h or less).

To estimate the cost of fuel wasted, unit prices (fuel prices) were used according to city, because fuel costs vary from one region to another in Canada. Unit prices vary according to fuel type (generally, diesel and gasoline). Since we are interested in the social costs of congestion, and not in private costs, taxes were excluded from the fuel prices. The total value of excessive fuel consumption is calculated by multiplying the total quantity of

[13] (a modal emission model and vehicle emission data set developed by researchers at University of California Riverside).

[14] See Hellinga, B and Chan, T. 2002.

estimated fuel consumption by its unit value, without taxes. Table 3 lists the values to use for gasoline for each urban area according to the base year of the traffic model. Not all the urban models distinguish between gasoline and diesel. This distinction is at least available for Montréal, Edmonton, Calgary and Vancouver, but not for the other five urban areas. Also, the study did not differentiate between gasoline prices by octane level (these are average prices for all unleaded fuels), given the lack of data that could break down the models' outputs in a manner that could use this information.

6.3 Greenhouse Gas Emissions

Environmental costs that are associated with congestion consist mainly of air pollutants and GHG emissions. Motor vehicle air pollutants are sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOCs), poly-aromatic hydrocarbons (PAH), hydrocarbons (HC), particulate matter (PM), methane (CH_4) and carbon monoxide (CO).

It is well established that the engine of a vehicle travelling at 20 km/h on a congested road operates at a less efficient level than at 60 km/h. Fuel combustion is then proportionally higher, and accordingly so are atmospheric pollutant emissions. For each congested road, the excess air pollution caused by congestion is equivalent to the difference between the estimation of air pollution during congested times (for example, the peak period, at 20 km/h) and the estimation of air pollution at the congestion threshold (for example 60km/h).[15]

In this research, only the costs of GHG emissions are estimated due to the fact that the estimation of other air pollutants requires a more precise analysis of the dynamics of vehicle operation than is available with travel demand forecasting models. GHG emissions are calculated as a function of fuel consumption (litres of diesel and gasoline fuel). Consequently, for all congested roadway links, additional GHG emissions are calculated directly with the additional diesel and gasoline consumed due to congestion.

To estimate the costs of congestion related to increased GHG emissions, CO_2 equivalent value was assumed based on a review of the literature. GHG emission values are quite difficult to assess in the absence of a market for CO_2 emission reduction. Some estimates, mainly those based on the potential impact of climate change and related environmental damage that are available in some studies, are too uncertain and insufficiently robust for broad application. Eventually, the Kyoto agreement and its implementation may facilitate the establishment of a real international market for those gases. The creation of a real market would set the true price for this damage to our climate's equilibrium, although the setting of this value will be strongly influenced by the technical feasibility of reducing emissions.

In the meantime, in order to cope with the range of air emission values, some authors propose to adopt a median value. The median, unlike the mean, is not affected by extreme values. Bell (1994)[16] compiled pollutant values from 37 different research studies and values proposed by governmental agencies in the United States. These

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[15] Environmental optimum is between speeds of 50 and 90 km/h, depending on which pollutant is being estimated.

[16] See Bell, Kevin. 1994.

values, summarized in Table 4, were used for congestion studies in Montréal in 2001, and are also used for benefit-cost analysis by MTQ. In this research, Bell's values were translated into Canadian dollars and updated to more recent years.

7. Congestion Indicators

The selection of relevant indicators is closely linked to the objective of the measurement exercise. The main objective of the congestion study was not to measure congestion in order to provide information to drivers about the day-to-day condition of the road network, but rather to provide policy makers with a rough order of magnitude of the (likely) annual impact and cost of congestion. After a review of the potential candidate indicators, the following four indicators were selected, based on relevance to the Canadian situation, data availability, data quality, practicality and replicability:

- Travel delay (extra time spent in congestion);
- Wasted fuel (due to slower speeds);
- Roadway congestion (relative importance of links with high volumes); and
- Travel rate (additional time required; related to travel delay but expressed as a ratio).

An additional indicator was developed for transit congestion (travel delay accrued by bus and rail transit that operates in mixed traffic). The need to develop an indicator for transit congestion was identified at the technical consultation meetings held with municipalities.

As mentioned earlier, the congestion indicators developed by this research reflect recurrent congestion. Non-recurrent congestion requires real-time speed-delay data. However, the concept of a dynamic 'traffic weather' map, such as that developed in Germany, may well represent the 'next generation' as described by Wachs (2003), but this also requires the availability of real-time data that covers a sufficiently representative number of roads, origins/destinations and time periods, and passenger vehicle fleets (i.e., taxis) that are equipped with GPS.

Congestion measurement is complex and multi-dimensional, so selection of multiple indicators was a meaningful way to provide a broad perspective on measuring and expressing congestion, one that could be applied immediately by transportation authorities in their analyses.

8. Main Findings on the Costs of Congestion in Urban Canada

Table 5 summarizes the total costs of congestion, combining the time value of delay, the costs of wasted fuel and the costs of the resultant GHG emissions. The total annual cost of congestion ranges from $2.3 billion (50 percent threshold) to about $3.7 billion (70 percent threshold).

There is little existing information against which these costs can be compared: only the methodological similarity with the MTQ work for Montréal allows an usable reference with that research. The combined total costs of $854 million (in 2002 dollars) for Montréal at this threshold are approximately 7 percent higher than the $779 million calculated by the MTQ study for 1998. These differences reflect the value of inflation, as well as the slightly different methodological application of the distinction between work and non-work trips, differences in the methods for calculating fuel consumption[17] and the fact that the MTQ study also accounted for vehicle operating costs and the costs of pollutant emissions. The costs of the time lost in delay - $795 million (2002 dollars) in the current research and $704 million (1998 dollars) in the MTQ's work - compare similarly well. The difference of 13 percent is largely attributable to time unit values. Consequently, the results of the current research appear reasonable.

The only other comparison is with the Vancouver studies, which estimated costs for auto travellers in the order of $0.7 billion. The $0.4 to $0.6 billion in costs estimated in this research are lower than the earlier Vancouver studies; however, the methodological bases differed (free-flow was used as a threshold in the BC study and unit time value was also different), thus limiting comparability with the earlier studies.

The total annual cost of delay due to congestion ranges from $2.0 billion (50 percent threshold) to $3.4 billion (70 percent threshold). Table 6 indicates that the time value of delay represents the greatest component of cost – in the order of 80 percent and upward, with an overall average of over 90 percent. These proportions are consistent with the findings of other studies that estimated congestion using different methods. Edmonton and Calgary were unable to provide specific figures regarding wasted fuel or emissions. Accordingly, costs of these components could not be calculated.

Table 7 expresses associated costs of wasted fuel due to congestion. For the seven urban areas for which data were available, the annual cost of wasted fuel ranges between $176 million (50 percent threshold) and $213 million (70 percent threshold).

Table 8 summarizes the costs of the annual GHG emissions that occur under congested conditions. The monetary values are shown in 2002 dollars. The values are based upon the estimated 1998 median rate of $29.97 per tonne of CO_2. To ensure consistency with other costs, the 1998 median rate was inflated to a 2002 value of $32.82 per tonne of CO_2 according to the Consumer Price Index.[18] For the seven urban areas for which wasted fuel estimates were available, the value of the GHG emissions ranges from $38 million at the 50 percent threshold to $46 million at the 70 percent threshold.

A comparison of the congestion estimates in this research with those of American urban areas was beyond the scope of this study. The ability to make such comparisons is limited, in part because the methodological approaches differ. However, by way of illustration, the aforementioned MTQ study did compare the results for Montréal with those of three similarly-sized urban areas in the U.S. (populations between 2 and 4 million). It found that Montréal's congestion levels were lower than those of its American counterparts (such as Boston, Dallas, St. Louis and Seattle), and cited reasons such as higher urban population densities, higher rates of public transit use and lower car ownership rates as explanatory factors.

[17] The study conducted by Transports Québec estimated 60.9 million litres of fuel at the 60% threshold – less than half the 135.3 M litres estimated in this research at the same threshold. This variation is due to methodological differences between the two studies mentioned above.

[18] This yielded an inflation rate of 9.5% over the four-year period. See Statistics Canada (2004). *Consumer Price Index, historical summary*.

9. Outlook for Congestion

Canada's population is expected to continue to grow at its recent pace, notably through continued immigration. Recent forecasts anticipate population growth of about 0.75 percent per annum to 2020. Greater urbanization is anticipated as well, as population expansion continues to be concentrated in urban areas, and is expected to rise over 80 percent as small cities continue to grow.

All underlying trends suggest that road traffic will continue to expand rapidly, in the absence of major economic shocks or policy changes. Gross Domestic Product (GDP) growth is anticipated to be greater than 2 percent p.a., and if recent trends continue, car ownership and use will rise by more than that, approaching 3 percent p.a.

10. Future Research

The consultant study makes a number of recommendations to improve and complement the current estimates of traffic congestion in Canada:

- Lack of data and common definitions and considerable variation among models, in terms of structure and coverage, are critical considerations in congestion estimation, and prevent a simple comparison of the nine urban areas:
    - There is a need for municipalities to develop common definitions for network link categorizations, to be able to model traffic beyond the peak period, and to incorporate freight and commercial vehicle traffic into the models.
    - In the short term, municipalities should be encouraged to conduct origin-destination surveys on a regular basis and to expand the surveys' vehicle coverage to freight and commercial vehicle traffic. In the longer term, municipalities would also benefit from collecting 'real-time' data on speed and volumes through the use of geographical positioning system technologies, and improving network micro-simulation models[19].
    - A better understanding of the magnitude and importance of non-recurrent congestion on costs, fuel consumption and emissions is also critical to a comprehensive picture of urban congestion in Canada. This would involve collecting more traffic data derived from major incidents.
- Complementing the *engineering* approach estimates with an *economic* definition of congestion and associated cost estimates is necessary to allow a full understanding of the topic and of the potential actions that could be taken to address traffic congestion.

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[19] Network micro-simulation models are computer models where the movements of individual vehicles travelling around road networks are represented. These models, presumably, provide a better, and 'purer', representation of actual driver behaviour and network performance. They are becoming increasingly popular for the evaluation and development of road traffic management and control systems.

11. Conclusions

The Cost of Urban Congestion in Canada study is an important first step in achieving a better understanding of the nature and extent of congestion in Canada, and in developing a consistent approach to estimating it.

The study found that urban recurrent congestion costs Canadians between $2.3 billion and $3.7 billion in 2002 dollar values. More than 90 percent of this cost is time lost in traffic by drivers and passengers; 7 percent is attributable to increased fuel consumption; and 3 percent is from increased GHG emissions.

This estimate of congestion costs is conservative, since it does not include the costs of non-recurrent congestion (i.e. congestion caused by random events, such as bad weather, accidents, stalled vehicles and other incidents). It also does not include costs to the freight transportation sector, vehicle operating costs (other than fuel) and the increase in noise nuisance. In addition, the estimates address only peak-period congestion, but not off-peak congestion, which is known to occur in many urban areas. More data is required to better understand their costs.

The study concludes that the lack of data and the considerable variation among models is a critical consideration in congestion estimation, and prevents a comprehensive estimation of congestion across the nine urban areas considered under the study. Therefore, encouraging municipalities to collect more and better congestion-related data and the development of common modelling approaches for implementing congestion measurements is very important to fully understand the congestion phenomena.

It is, therefore, difficult to draw accurate comparisons between each city, since data and how it is collected in each city are different, and each city has different perceptions of what congested road conditions are. However, such congestion indicators, if collected over time, could be particularly useful in tracking congestion trends.

This study represents only a first step, albeit an important one on this subject, by suggesting a methodology that Canadian municipalities could use to develop their own congestion estimates

Annex 1

Table 1. Factors Used to Calculate Costs of Delay (2002 $)

Urban Area	Year	% Work / Work-Related *	% Non-Work*	$/hr – Work / Work-Related	$/hr – Non-Work
Vancouver	2003	48%	52%	$29.72	$9.26
Edmonton	2000	31%	69%	$25.48	$7.84
Calgary	2001	37%	63%	$28.57	$8.79
Winnipeg	1992	88%	12%	$24.71	$7.63
Hamilton	2001	36%	64%	$29.64	$9.14
Toronto	2001	55%	45%	$30.86	$9.50
Ottawa-Gatineau	1995	43%	57%	$31.35	$9.67
Montréal	1998	70%	30%	$27.32	$8.48
Québec City	2001	58%	42%	$25.96	$8.15

*Trip purpose factors were provided by respective urban authorities (Edmonton, Calgary, Montréal, Québec City) or derived by the consultant from their model (Winnipeg) or travel survey (Vancouver, Toronto, Hamilton, Ottawa-Gatineau).

Table 2. Canadian Fleet Representative Penalty Function

Driving Cycle	Approximate Average Speed	AQ Emission (g/veh-km)			Fuel (ml/veh-km)
	(km/h)	CO	HC	NO_x	
Arterial LOS A-B	45	8.99	0.81	0.55	81.98
Arterial LOS C-D	30	10.70	1.01	0.60	95.92
Arterial LOS E-F	20	15.48	1.49	0.78	141.59
Freeway High-Speed	105	9.48	0.59	0.65	65.22
Freeway LOS A-C	95	9.29	0.55	0.61	63.79
Freeway LOS D	85	9.25	0.67	0.59	62.81
Freeway LOS E	50	8.63	0.82	0.52	71.84
Freeway LOS F	30	10.56	1.00	0.62	98.28
Freeway LOS G	20	11.28	1.09	0.54	113.13

Source: Simulation results using CMEM model coefficients

Table 3. Regular Unleaded Gasoline Prices for Each Urban Area

Urban area	Base year	Regular Unleaded Gasoline – excluding taxes	Regular Unleaded Gasoline – excluding taxes (2002 $)[20]
Vancouver	1996	30.41 ¢/l	38.65 ¢/l
Edmonton	2000	40.74 ¢/l	41.22 ¢/l
Calgary	2001	41.64 ¢/l	42.09 ¢/l
Winnipeg	1992	27.95 ¢/l	37.95 ¢/l
Toronto	2001	37.72 ¢/l	38.20 ¢/l
Hamilton	2001	36.33 ¢/l	36.30 ¢/l
Ottawa-Gatineau	1995	25.91 ¢/l	37.30 ¢/l
Montréal	1998	21.86 ¢/l	35.41 ¢/l
Québec City	1996	27.74 ¢/l	37.49 ¢/l

Source: M.J. Ervin & Associates

Table 4. Air Emission Median Values

	CO_2	CO	HC	NOx	SOx	PM
1990 US$/short ton	$20	$907	$3,300	$4,209	$1,793	$2,496
1990 C$/short ton	$23.34	$1,058.26	$3,850.35	$4,910.95	$2,092.03	$2,912.27
1998 C$/short ton	$27.19	$1,232.88	$4,485.66	$5,721.26	$2,437.21	$3,392.79
1998 C$/ton	$29.97	$1,359.00	$4,944.54	$6,306.54	$2,686.54	$3,739.87

Adapted from Convergence Research, 1994 in Litman, 1995. The U.S. dollar was worth C$1.16667 in 1990 and the 1990 Canadian dollar was worth C$1.165 in 1998. A metric tonne is equivalent to 1.1023 short tonnes.

[20] Most recent common year available.

Table 5. Total Costs of Congestion (2002 $)

Urban Area	Year	at 50% Threshold	at 60% Threshold	at 70% Threshold
Vancouver	2003	$402.8	$516.8	$628.7
Edmonton	2000	$49.4	$62.1	$74.1
Calgary	2001	$94.6	$112.4	$121.4
Winnipeg	1992	$48.4	$77.2	$104.0
Hamilton (all)	2001	$6.6	$11.3	$16.9
Toronto	2001	$889.6	$1,267.3	$1,631.7
Ottawa-Gatineau (all)	1995	$39.6	$61.5	$88.6
Montréal	1998	$701.9	$854.0	$986.9
Québec City	2001	$37.5	$52.3	$68.4
Total, all urban areas		$2,270.2	$3,015.0	$3,720.6

Table 6. Proportion of Congestion Costs Attributable to Delay (2002 $)

Urban Area	Year	at 50% Threshold	at 60% Threshold	at 70% Threshold
Vancouver	2003	92.4%	91.9%	92.7%
Edmonton & Calgary	2000/2001	--	--	--
Winnipeg	1992	88.1%	88.0%	90.2%
Hamilton (all)	2001	79.4%	85.4%	90.1%
Toronto	2001	87.4%	90.4%	92.4%
Ottawa-Gatineau (all)	1995	84.4%	87.0%	90.4%
Montréal	1998	92.3%	93.1%	93.9%
Québec City	2001	87.4%	87.0%	88.5%
Total, all urban areas		90.6%	91.8%	93.0%

Table 7. Annual Costs of Wasted Fuel (2002 $)

Urban Area)	at 50% Threshold		at 60% Threshold		at 70% Threshold	
	L, millions	$ millions	L, millions	$ millions	L, millions	$ millions
Vancouver	65.4	$25.3	89.0	$34.4	98.3	$38.0
Edmonton & Calgary	--	--	--	--	--	--
Winnipeg	12.6	$4.8	20.1	$7.6	22.2	$8.4
Hamilton (all)	3.0	$1.1	3.7	$1.4	3.8	$1.4
Toronto	241.3	$92.2	263.8	$100.8	267.8	$102.3
Ottawa-Gatineau (all)	13.5	$5.1	17.6	$6.6	18.7	$7.0
Montréal	124.0	$43.9	135.3	$47.9	138.7	$49.1
Québec City	10.4	$3.9	15.0	$5.6	17.3	$6.5
Total, all urban areas	470.2	$176.2	544.4	$204.2	566.8	$212.7

Table 8. Annual Costs of Greenhouse Gas Emissions from Delay (2002 $)

Urban Area	at 50% Threshold		at 60% Threshold		at 70% Threshold	
	Tonnes	$, millions	Tonnes	$, millions	Tonnes	$, millions
Vancouver	161,521	$5.3	219,713	$7.2	242,791	$8.0
Edmonton	--	--	--	--	--	--
Calgary	--	--	--	--	--	--
Winnipeg	31,003	$1.0	49,569	$1.6	54,686	$1.8
Hamilton (all)	7,512	$0.2	9,196	$0.3	9,271	$0.3
Toronto	595,709	$19.6	651,318	$21.4	661,226	$21.7
Ottawa-Gatineau (all)	33,447	$1.1	43,385	$1.4	46,107	$1.5
Montréal	306,100	$10.0	334,100	$11.0	342,500	$11.2
Québec City	25,600	$0.8	36,900	$1.2	42,700	$1.4
Total, all urban areas	1,160,800	$38.1	1,344,200	$44.1	1,399,300	$45.9

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