Natural Resources Canada / GIMVEC

TRAFFIC CONGESTION IMPACT ON CO_2 EMISSIONS IN CANADA

Final Report

March 1999

DELCAN CORPORATION
2001 Thurston Drive
P.O. Box 8004
Ottawa, ON K1G 3H6
Telephone: (613) 738-4160
Fax: (613) 739-7105

in association with

A.K. SOCIO-TECHNICAL CONSULTANTS (OTTAWA) INCORPORATED
145 Owl Drive
Ottawa, ON K1V 9J5
Telephone: (613) 738-1575
Fax: (613) 738-1575

Executive Summary

ES.1 Purpose

This document constitutes the Final Report of the study of *Traffic Congestion Impact on CO_2 Emissions in Canada*. The study had three main objectives:

1. Define the impact of traffic congestion on CO_2 emissions, and its associated characteristics, through a literature review.

2. Review current transportation models in Canada's three largest urban areas (Montréal, Toronto and Vancouver), as well as Edmonton.

3. Recommend approaches and methods to build upon these models (which forecast travel and congestion in each urban area) in order to forecast CO_2 emissions as a function of congestion.

Delcan Corporation, in association with A.K. Socio-Technical Consultants, prepared this study for Natural Resources Canada (NRCan), as well as for the Government Industry Motor Vehicle Energy Committee (GIMVEC). This committee is composed of representatives from the vehicle manufacturing industry as well as Federal Government officials from NRCan, Transport Canada, Industry Canada and Environment Canada.

Government and industry in Canada are committed to a balanced national approach for reducing GHG emissions. CO_2 is the main GHG generated by the transportation sector, including road transport. It is recognized that fuel consumption and CO_2 emissions are influenced by traffic congestion levels. In turn, NRCan and GIMVEC identified a need to better understand both the linkages among congestion, fuel consumption and CO_2, and the tools that are available to forecast these relationships in Canada's three largest urban areas – Montréal, Toronto and Vancouver.

It is noted that the study's objectives were largely definitional and prescriptive and, therefore, the study was not intended to quantify actual fuel consumption or CO_2 emissions in the three urban areas. In this regard, the study does not distinguish among vehicle types (e.g., light-duty versus heavy-duty vehicles), nor does it distinguish between CO_2 and CO_2 -equivalent gases.

The report is divided into three distinct parts. Each addresses one of the study objectives. Part I reports the literature review. Part II describes the current modelling capabilities in the three urban areas and the City of Edmonton. Part III proposes an analytical benchmarking framework for quantifying and forecasting congestion, fuel consumption and CO_2 emissions for urban areas in Canada. The main points of each part are summarized below.

ES.2 Part I: Literature Review

Part I of the study focussed upon defining traffic congestion, and its impact upon fuel consumption and CO_2 emissions. This was achieved primarily via a review of the literature, the aim of which was to define the relationship and describe the techniques and models that are used to characterize it.

To start, what is meant by the term "traffic congestion?" Traffic congestion usually results when:

- the road system is unable to accommodate traffic at an adequate speed,
- there are conflicts among the different types of traffic (cars, trucks, buses, cyclists or pedestrians), and
- traffic controls are used improperly or are not co-ordinated to optimize throughput along a corridor.

Although congestion is normally associated with morning and evening weekday peak periods, it may also occur during weekends, holiday periods, before or after athletic or cultural events or during road construction and maintenance.

Congestion has both a spatial and temporal component. In terms of space, it may occur along both short and long sections of roadway, while temporally, it may occur for a few minutes, a few hours, or the entire day.

A workable definition of traffic congestion is provided by the *NCHRP Report Quantifying Congestion* (National Co-operative Highway Research Program, 1997). It defined two terms:

- **Congestion** is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.

- **Unacceptable congestion** is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day.

The NCHRP reports also defined four components that quantify the scope of roadway congestion. These are **duration**, **extent**, **intensity**, and **reliability**.

In a 1996 report by the Transportation Association of Canada, a congestion indicator was derived for five Canadian urban areas. This measure is defined by the average trip distance, multiplied by the number of vehicle trips and divided by the number of arterial and expressway lane-kilometres. These data demonstrate a considerable difference among several major Canadian urban centres, and that the index for Montreal, Ottawa, Toronto and Vancouver is many times higher than for other urban areas in Canada (TAC 1996).

The Texas Transportation Institute (TTI) prepared an *Urban Mobility Study* for 50 urban areas in the United States. The study was based on transportation data collected between 1982 and 1994. The centres were ranked according to a number of criteria, including congestion roadway index, delay, area-wide speed ratio, wasted fuel, and cost.

Research studies around the world demonstrate that congestion is expected to continue to escalate at a significant rate in major urban centres as well as in medium and small urban areas (Birk and Bleviss 1991, Birk and Zegras 1993; ECMT 1985, 1998, Khan 1993).

Causes of congestion. The literature review identified several causes. A primary cause is the imbalance between transportation demand and available capacity of the transportation system to accommodate traffic. Other important causes are defined by an urban area's

- land use and socio-economic characteristics (i.e., the distribution of urban activities, the extent of sprawl, etc.);
- traffic peaking characteristics (i.e., the time of day, mode, and route-specific peaking of traffic and the inability of the transportation system to adapt to such peaks are major causes of congestion);
- treatment of incident and accidents (including road maintenance, the weather, etc.); and
- the information that is available to travellers (for example, real-time travel information systems allow drivers to react quickly in order to avoid accident sites, bottlenecks, etc., and thus maximize the use of available capacity and improve traffic flow).

Several **highly adverse impacts** are attributed to traffic congestion. These include: increased vehicle operating costs, including increased fuel consumption; costs related to time and loss of productivity; increased costs of congestion-related accidents; and higher emissions attributable to congestion.

At the same time, several measures are available to mitigate congestion. These can be grouped into three categories:

- **Demand management** refers to a wide range of actions and policies that attempt to influence the travel behaviour of individuals in order to reduce congestion, most notably, that is associated with the use of single-occupant vehicles during peak hours. Demand management measures, such as ride-sharing programs and High-Occupancy Vehicle (HOV) lanes, are commonly aimed at reducing "single-occupant vehicles" as their main object.
- **Traffic management** refers to strategies, other than the construction of major transportation infrastructure, which have the potential to influence the supply of transportation capacity (the optimization of existing facilities).
- **Capacity and level of service improvements** can be achieved by building new roadways and by widening existing roadways. The capacity of a facility is defined as the maximum hourly rate at which vehicles can traverse a uniform section of roadway during a given time period under prevailing roadway, traffic, and control conditions.

The literature review further examined four fundamental aspects of congestion, outlined below:

- **Relationship between traffic volume, speed and congestion.** Classical traffic flow theory suggests that as traffic volumes increase, speeds tend to drop. The parameters defining this relationship dictate the rate at which the reduction occurs. For example, modern theory suggests that the speed reduction may be quite negligible until the volume approaches the capacity of the road section, at which point the speed reduction is quite severe and breakdown, or congestion, occurs. Following a review of traffic flow theory, the literature review described how different models quantified the relationship.

- **Techniques used to characterize congestion.** Several techniques are available to analyze individual facilities as well as entire regional networks. A facility can comprise a single intersection or interchange, or arterials and freeways of varying lengths. Frequently, travel corridors and entire road networks are also the subject of study from the perspective of enhancing their traffic-carrying capability. Characterizing congestion is an essential task, regardless of the size of the facility or the network. The literature review examined the current “industry standards,” and compared analytical techniques. Emerging techniques also were examined.

- **Relationship between vehicle fuel consumption, CO_2 emissions and vehicle speed profiles**. The relationship between fuel consumption and instantaneous speed is relatively well defined. However, vehicle-specific fuel consumption ratings are based on defined driving cycles that exhibit average speeds. The issues and factors relating to vehicle speed, fuel consumption, and CO_2 emissions were reviewed in this section. Relevant factors included vehicle maintenance, the operating environment and driver behaviour. The literature review also examined existing and emerging vehicle design technologies that could affect fuel consumption and CO_2 emissions.

- **Fuel consumption models**. These relate fuel consumption to a variety of road network attributes, such as: the number of vehicle kilometres travelled, the number of stops per unit of time, the total vehicle delay per unit of time, and the vehicle's average speed. The literature review identified several models, including drive mode elemental models, instantaneous speed models and average speed models. Each model has characteristics that apply to specific situations, depending on the level of accuracy that is desired and the amount of traffic information that is available.

ES.3 Part II: Current Modelling Capabilities

Part II examined the current modelling capabilities of the three urban areas. Each of the three has developed a sophisticated travel demand forecasting model, using the EMME/2 software. These models simulate travel by all urban modes (auto, transit, etc.) throughout the urban area. They are used commonly in transport plans to identify future needs for infrastructure according to forecasted travel and congestion. They also are used to assess the impacts of alternate policies, such as the location of future development, or the impact of road pricing policies or demand management techniques, etc.

Because of this comprehensive coverage of urban travel, and because they can forecast travel under a variety of conditions, travel demand models provide an appropriate basis for forecasting fuel consumption and CO_2 emissions. In fact, the three urban areas have used their models to consider GHG, albeit to different degrees.

Accordingly, the consultant assessed the travel demand, fuel consumption and CO_2 modelling capabilities of Montréal, Toronto and Vancouver. The basis of the assessment was a detailed interview survey, as well as the consultant's knowledge of the three models and urban areas. At the client's request, the consultant also examined Edmonton's EMME/2 model, which includes a comprehensive treatment of fuel consumption and CO_2 and has addressed some of the limitations that are inherent to urban travel demand modelling.

In addition, the consultant compared these forecasting capabilities with those of the NRCan Interfuel Supply and Demand (IFSD) model, which is a fuel and emissions forecasting model. This model provides econometric forecasts for Canada as a whole, and for regions (individual provinces / territories or groups). It forecasts demand for all transportation sectors, passenger and freight, urban and inter-city. However, because it is based on economic considerations, it cannot account explicitly for the impacts of (for example) road pricing, demand management or land-use policies. It can be described as a top-down approach; in comparison, the urban EMME/2 models might be described as bottom-up.

Overall, the following was found:

- A four-step land-use – travel demand – traffic operations – air quality hierarchy is defined. The hierarchy recognizes that long-term decisions regarding land-use (where to live, where to work, etc.) can impact the short-term dynamics of vehicle emissions. Efforts to model this hierarchy are underway in the United States, driven partly by legal air quality requirements. However, fully working models that completely cover the hierarchy are several years away from operational use.

- A similar hierarchy generally does not exist in Canada (neither legally nor model-wise). However, each of the four urban areas has a sophisticated travel demand forecasting model. These use the EMME/2 software.

- Each model is based upon comprehensive data bases; notably, origin-destination surveys, land-use (demographic / socio-economic) data and traffic counts.

- These models and data bases provide a sufficient and comprehensive base upon which to model fuel consumption and CO_2 emissions.

- Among the three large urban areas, only Montréal models fuel consumption as a function of its EMME/2-model output. Only Vancouver models CO_2 as a function of its EMME/2 model. Edmonton does both.

- No specific legal requirements exist to model fuel consumption or CO_2. However, there is a strong policy interest in all three areas. Greater Vancouver's Air Quality Management Plan effectively requires modelling capabilities, which are exemplified by the Regional Transportation Energy and Emission Model (RTEEM). Among the three urban areas, RTEEM can be said to be the most comprehensive model of CO_2. Among the three urban areas, MTQ's fuel consumption model (Montréal) can be said to be the most comprehensive, although reference data are lacking.

In sum, we can suggest that an appropriate basis exists for modelling fuel consumption and CO_2 in these urban areas. The basis is each urban area's travel demand forecasting model. However, several needs were identified:

- Improved reference data.

- Factoring from a.m. to daily and annual conditions. This is a critical issue, since the models in the three large urban areas (and most other cities) focus upon the peak travel conditions associated with the AM peak. Edmonton has addressed this by simulating different time "slices" for other parts of the day, recognizing that a traveller's choice of mode and route for a particular trip is linked to his/her activity during the rest of the day. As well, in terms of volume most travel occurs outside the AM (and PM) peak periods – for example, in Edmonton two-thirds of all weekday trips (measured in the number of trips) are made outside the two peak periods.

- Need to replicate fuel consumption and CO_2 modelling capabilities (i.e., bring the three urban areas to a common basis). Again, Edmonton provides an example, as do Montréal and Vancouver (to different degrees).

- Need to replicate demand management and road pricing capabilities (again, to bring the three urban areas to a common basis). In this regard, Vancouver's model is most advanced, having explicitly developed capabilities to examine road pricing and demand management measures. (All models use land-use forecasts as input.)

Two related issues also should be recognized when considering current capabilities for modelling fuel consumption and CO_2 emissions:

- The development of the full "decision-making" (modelling) hierarch*y* would allow the development of the full range of urban policies and plans that is required to support fuel consumption and CO_2 targets. The aforementioned needs to focus upon the link between travel demand forecasting models and "air quality." However, this both bypasses traffic operational models, and ignores land-use models (respectively, steps 3 and 1 in the hierarchy). To some extent, development of the hierarchy must await the outcome of the aforementioned US initiatives. However, Canadian urban areas could advance considerably, using existing models and techniques, through the development of land-use models and traffic operational models.

- *Additional benefits*. Many of the technical needs and approaches identified in this study address other issues, beyond the modelling of fuel consumption and CO_2 emissions. These include, for example, urban planning for "healthy/livable communities" and improved means of forecasting the toll revenue streams for privatized roads (which in turn is a significant issue for private investors). The benefits of more explicit modelling capabilities for fuel consumption and CO_2 emissions would extend far beyond the immediate needs of energy and environmental policy.

ES.4 Part III: Benchmarking Framework

On the basis of the preceding analyses, in Part III the consultant proposed an analytical framework to benchmark the impact of congestion on total fuel consumed, and subsequently CO_2 emissions, in Montréal, Toronto and Vancouver. The framework describes alternative approaches and methods, and assesses their suitability, for analyzing the impacts of traffic congestion on fuel consumption and CO_2 emissions over a range of time horizons.

The framework is derived from the description of current modelling capabilities in the three large urban areas, plus Edmonton. However, it could be applied to other cities across Canada.

The proposed framework is a "menu" of available approaches and methods to benchmark the impact of traffic congestion on fuel consumption and CO_2 emissions. Most important to note is that all the methods were chosen with a view to practicality and feasibility, and that the most appropriate choice may well consist of a combination of methods. Several of the options may be quickly eliminated by known constraints in the available time horizon for assessment, while others may not be pursued unless additional resources are willing to be directed toward the proposed method. The proposed framework is presented as Table ES-1.

The proposed framework consists of three levels of analysis, as described below.

- **Policy-level** refers to methods that address the change in region-wide CO_2 emissions due to various policy initiatives that target congestion relief. Examples include the imposition of a fuel tax or increased vehicle registration fees.

- **Strategic-level** refers to methods that address changes in CO_2 emissions due to the application of demand or supply management measures that target congestion relief. Examples include the introduction of high occupancy vehicle (HOV) lanes and public transit improvements.

- **Tactical-level** refers to methods that address changes in CO_2 emissions due to the introduction of various traffic management and/or operational strategies. Examples include Advanced Traffic Management Systems (ATMS) for traffic signals, Freeway Traffic Management Systems (FTMS), and local intersection or freeway interchange optimization measures.

The proposed framework is also defined temporally by three periods:

- Immediate refers to a time period of 3–6 months.
- Short refers to time periods of 6–12 months.
- Long refers to time periods of 1–5 years.

Table ES-1: Proposed Framework for Assessing the Impact of Traffic Congestion on CO_2 Emissions

		Time Horizon		
		Immediate (3–6 months)	**Short-term (6–12 months)**	**Long-term (1–5 years)**
Approach	**Policy Level**	Employ aggregate fuel consumption indices that are sensitive to traffic congestion. Consider modified econometric models (i.e., NRCan's IFSD model) and/or area-wide indices (i.e., TTI wasted fuel index).	Same as immediate, but incorporate improved model input parameters and forecasts.	Same as short, but incorporate further enhancements to model input parameters and forecasts.
	Strategic Level	Employ existing EMME/2 models in combination with post-processors that compute fuel consumption and CO_2 emissions.	Employ existing EMME/2 models with updated fuel consumption / CO_2 emission modules.	Apply integrated land use – transportation models to model the full range of decisions that impact urban travel.
	Tactical Level	Apply simulation models, such as INTEGRATION, to small, simplistic networks. CO_2 emissions may be estimated from fuel consumption using factors.	Same as immediate, but with an expanded study area (i.e., detailed corridor) and improved model input parameters. CO_2 emissions will be explicitly estimated by the model.	Same as short, but with an expanded study area (i.e., regional level sub-network) and improved model input parameters.

During the immediate time horizon, it would not be feasible to develop completely new evaluation tools. Therefore, existing methods must be adopted. Alternatively, given an infinite time horizon, the 'menu' of possible approaches may be constrained if resources are not made available to collect the required data for implementing an existing tool or to further develop such tools. The menu is elaborated below, for the three approaches.

- **Policy level**. At the policy level, any evaluation of traffic congestion impacts on CO_2 emissions would involve the application of existing "broad-brush" methods. NRCan's IFSD model is one such technique (assuming that the model can be modified to reflect the impact of traffic congestion). This econometric model was used to produce the forecasts presented within NRCan's Energy Outlook projection.

  A second technique available is that of an area-wide Wasted Fuel Index, which estimates the amount of wasted fuel due to traffic congestion. The TTI index, developed as part of their Urban Mobility Study, provides an appropriate method (see summary of Part I, above).

  In the immediate, short and longer terms, either of these techniques would be applicable at the policy level. Extension of the time horizon would permit improvements to the input parameters and data forecasts.

- **Strategic level.** The strategic-level approaches represent a shift away from the macroscopic, region- (province-) wide models used at the policy level. The strategic-level evaluation uses urban travel demand forecasting models to estimate "vehicle activity." As noted, the urban models differ from NRCan's IFSD model in several fundamental ways: focus (urban area versus the province as a whole), approach (microeconomic versus macroeconomic), and method (a holistic portrayal of activities by all travellers versus activities of vehicles). Equally important, these urban models also explicitly model congestion and can consider the impacts on traveller behaviour of road pricing, TDM, etc. The existing EMME/2 models in each of the three urban areas provide a sound analytical basis for future work. However, and again as noted (see summary of Part II), the actual abilities to model fuel consumption and CO_2 emissions vary among the three urban areas. Here, Edmonton's EMME/2-based modelling capabilities may provide guidance.

  In the immediate time horizon, both the NRCan IFSD model and the individual urban models could be used. Although considerable judgement would be required, sufficient information and indicators could be derived from both models to allow one to validate the other. The result is a blend of the two types of models. However, the time frame precludes the development of a common baseline forecast (i.e., containing common assumptions regarding TDM, road pricing, etc.) for the three urban areas.

  The short-term goal is to upgrade the capabilities of the urban models for modelling fuel consumption and CO_2 emissions. The upgrade would take into account more recent (and local) inputs: emission rates, vehicle mixes, etc. Extension of the time-horizon further affords an opportunity for developing compatible baseline and forecast scenarios among the three regional planning authorities.

  The long-term goal is to expand the modelling capabilities to better reflect the traveller's decision-making "chain:" specifically, the addition of a front-end land-use modelling capability. Further refinement to the CO_2 emission estimates could be introduced by developing and applying appropriate integrated land use-transportation models. Such a model is the current focus of the US *Travel Model Improvement Program*. However, the availability of a working prototype is some years away, although Edmonton's models provide some practical direction for this approach.

- ***Tactical-level***. This level increases modelling capabilities, through the development of micro-simulation tools. These represent a further transition from travel demand forecasting models to a more detailed and dynamic representation of traffic operations, which in turn is required for a full analysis of fuel consumption and CO_2 emissions. As with the strategic-level travel demand models, the road networks of the three urban areas are represented. However, at the tactical level, these networks are considerably more detailed. Furthermore, traffic is modelled at the individual vehicle level as opposed to total hourly or daily volumes. Since network modelling at this "microscopic" level requires considerably more input data, and individual vehicle dynamics are represented, simulation approaches require considerable computing power. These constraints may limit the simulation study area, but the payoff is improved representation of traffic congestion, and hence improved representation of fuel consumption and CO_2 emissions. One candidate micro-simulation model that can evaluate the impacts of traffic congestion on CO_2 emissions is INTEGRATION.

  In the immediate time horizon, INTEGRATION could be applied to simplistic or hypothetical networks. The study area is limited to small or skeleton networks because microscopic modelling techniques are not widely used, nor currently applicable, at the regional level. Micro-simulation could be used in the immediate-term to provide general insights into the impact of traffic congestion on estimates of fuel consumption and CO_2 emissions, but not to provide region-wide estimates. It should be noted that INTEGRATION presently computes fuel consumption as an output measure, from which CO_2 can be derived using published factors.

  The additional time and resources available in the short-term time horizon could broaden the application of tactical-level approaches to an expanded study area, perhaps a detailed corridor in which traffic congestion is prevalent – for example, a problematic section of an urban freeway. During this period, there would also be an opportunity for improvements to be made to INTEGRATION's capabilities, for example, the representation of multiple vehicle types (rather than the current single composite vehicle representation) and/or explicit modelling of CO_2 estimates. (INTEGRATION's developer currently is developing such features for inclusion in future releases of the model.)

  In the long term, the applicability of micro-simulation models to the regional level, or sub-networks thereof, is expected to become more practical. Advancement in computing capabilities should allow larger (or even region-wide) networks to be considered. In the long-term, further INTEGRATION improvements may allow the representation of, for example, alternative fuel technologies.

For further details, contact:

Patrick Gosselin
Office of Energy Efficiency,
Natural Resources Canada
(613) 992-9254