

Investigating the Effects of Traffic Calming on Near-Road Air Quality Using Traffic, Emissions, and Air Dispersion Modelling

by

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ABSTRACT

This thesis focuses on the development of a microscopic traffic simulation, emission and dispersion modeling system which aims at quantifying the effects of different types of traffic calming measures on vehicle emissions both at a link-level and at a network-level and on air quality at a corridor level using a scenario analysis. The study area is set in Montréal, Canada where a traffic simulation model for a dense urban neighborhood is extended with capabilities for microscopic emission estimation and dispersion modeling.

The results indicate that on average, isolated calming measures increase carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxide (NO_x) emissions by 1.50%, 0.33% and 1.45%, respectively across the entire network. Area-wide schemes result in a percentage increase of 3.84% for CO_2 , 1.22% for CO, and 2.18% for NO_x . Along specific corridors where traffic calming measures were simulated, increases in CO_2 emissions of up to 83% are observed. These increases are mainly associated with a change in vehicle drive-cycles through increased accelerations and decelerations. The results for air quality modeling suggest on average NO_2 levels increase between 0.1% and 10% with respect to the base case. A high positive correlation of 0.7 between segment emissions of NO_x and concentrations of NO_2 is observed. Also, the effects of wind speed and direction are investigated in this thesis. The results show that higher wind speeds decrease NO_2 concentrations on both sides of the roadway while winds orthogonal to the road increase the difference between concentrations on the leeward and windward sides with the leeward side experiencing higher levels. The effect of different

measures on traffic volumes is also investigated and moderate decreases in areas that have undergone traffic calming are observed. Finally, the results show that speed bumps result in higher emission levels and poorer near-roadway air quality than speed humps.

RESUMÉ

Cette thèse porte sur le développement d'une simulation microscopique de la circulation et des émissions de véhicules ainsi qu'une modélisation de la dispersion atmosphérique qui vise à quantifier les effets de différents types de mesures d'apaisement de la circulation sur les émissions et la qualité de l'air. Cette analyse est conduite à la fois au niveau de liens spécifiques et au niveau du réseau à travers plusieurs scénarios de modélisation. La zone d'étude se situe à Montréal, Canada, où un modèle de simulation de trafic pour un quartier urbain dense est étendu avec des capacités d'estimation des émissions de véhicules et modélisation de la dispersion des polluants de l'air.

Les résultats indiquent que, en moyenne, les mesures d'apaisement isolées augmentent les émissions de dioxyde de carbone (CO_2), monoxyde de carbone (CO) et oxydes d'azote (NO_x) de 1.50%, 0.33% et 1.45%, respectivement sur l'ensemble du réseau. Les mesures étendues sur plusieurs corridors augmentent de 3.84% les émissions de CO_2 , 1.22% de CO, et 2.18% de NO_x . Le long des corridors spécifiques où des mesures de modération de la circulation ont été simulées, des augmentations d'émissions de CO_2 allant jusqu'à 83% sont observées. Ces augmentations sont principalement associées à des changements de cycles d'accélération et de décélération. Les résultats de la modélisation de la qualité de l'air, suggèrent en moyenne que les niveaux de NO_2 augmentent entre 0.1% et 10% par rapport au scénario de référence. Une corrélation positive de 0.7 entre les émissions de NO_x et de concentrations de NO_2 est observée. En outre, les effets de la vitesse et direction du vent sont étudiés. Les résultats démontrent que

des vitesses du vent plus élevées réduisent les concentrations de NO₂ des deux côtés de la chaussée alors que des vents perpendiculaires à la route d'augmentent la différence entre les concentrations des deux côtés de la route avec des niveaux plus élevés pour le côté situé en amont du vent. L'effet de l'apaisement de la circulation est également étudié sur les volumes de trafic et des diminutions modérées dans les zones qui ont subi l'apaisement sont observées. Enfin, les résultats démontrent que différents types de mesures d'apaisement ont des effets différents sur les émissions et la qualité de l'air.

To
my husband, Ahmadreza
and
my parents, Shahin and Ali

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LIST OF ABBREVIATIONS

CDF	Computational Fluid Dynamics
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
DTA	Dynamic Traffic Assignment
GHG	Greenhouse Gas
GPS	Global Positioning System
HC	Hydrocarbon
HGV	Heavy Vehicles
MOVES	Motor Vehicle Emissions Simulator
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen Oxide
O ₃	Ozone
OD	Origin-Destination
<i>opmode</i>	Operating Mode
OSPM	Operational Street Pollution Model
USEPA	United States Environmental Protection Agency
VKT	Vehicle Kilometer Travelled
VSP	Vehicle Specific Power

CHAPTER 1

INTRODUCTION

1.1 Background

Traffic calming refers to a combination of physical changes in road design and speed management aiming at improving road safety especially for users of non-motorized transportation sharing the road with drivers (Lockwood 1997). Traffic calming strategies are based on either one of two approaches: 1) black-spot approach or 2) area-wide approach. In the black-spot approach, isolated measures are planned and designed to be implemented on a particular segment of a road network, while in the area-wide approach measures are planned systematically and installed on the entire network (Elvik and Vaa 2004).

Various traffic calming measures with the means of improving road safety have been implemented all over the world for decades. Traffic calming goals include reducing conflicting movements, pedestrian exposure to traffic, and vehicle speeds, as well as improving visibility, and sharpening drivers' attention. Speed reduction caused by the implementation of traffic calming measures may lead to fewer fatal or serious injury accidents (Ewing 1999). It has been recognized that on average, a 1 mph reduction in mean vehicle speed results in an average accident reduction of 5 percent (Taylor *et al.* 2000).

Relatively few studies have been conducted to capture the environmental impact of traffic calming. Some studies only focused on the effects on emissions using

real traffic data and on-road emission measurements or employing different modeling methods to estimate them (for example, see Ahn and Rakha 2009 and Daham *et al.* 2005). Results for most of the studies showed a substantial increase in emissions while results of the studies conducted to quantify the effects on air quality demonstrated that calming measures did not significantly affect air quality and even in some cases they improved air quality because of traffic rerouting (Owen 2005 and Elsom 1997).

1.2 Problem Statement

Despite the beneficial effects of traffic calming on road safety, it has been associated with impacts on air quality. In fact, varying speed frequently and slowing down while driving on a calmed street, produces more air emissions due to increased accelerations and decelerations. While the safety impact of traffic calming has been studied in depth (for example, see Grundy *et al.* 2009, Mountain *et al.* 2005, Tester *et al.* 2004, Retting *et al.* 2001, Hyden and Várhelyi 2000 and Huang and Cynecki 2000), relatively few studies have been conducted to capture the environmental impact of traffic calming. Most of the literature presented many advantages such as the use of real drive-cycles, traffic volumes, and air pollution measurements to quantify the effects of traffic calming on air quality. However, they lack the capability of evaluating the effects of instantaneous speed changes and traffic volumes simultaneously and in isolation.

1.3 Research Objective

1.3.1 Overall Goal

The overall goal of this research is to develop a microscopic traffic, emission and dispersion modeling system which aims to capture the effects of traffic calming schemes on vehicle-induced emissions and air quality.

1.3.2 Research Tasks

Two tasks were identified to address the main goal of this research:

Task 1

This task quantifies the effects of different types of traffic calming measures on vehicle-induced emissions. Using a scenario analysis, the effects of traffic calming schemes both at a link-level and at a network-level are captured. This exercise also investigates the effects of isolated traffic calming measures at a corridor level and area-wide calming.

Task 2

This task tries to capture the effects of a range of traffic calming schemes on ambient air quality. Again, by using a scenario based analysis, ambient air quality is modelled at a corridor level.

1.4 Research Significance

This research designs and implements an integrated modelling system which includes a combination of a microscopic traffic simulation, emission and dispersion modeling and aims at quantifying the effects of different types of traffic calming measures on vehicle emissions and air quality. The developed

model is capable of evaluating the effects of instantaneous speed changes and traffic volumes simultaneously and in isolation, an aspect that most previous literature omits. We expect this research to have strong policy-relevance as it will assist policy makers in decisions on the types and locations of traffic calming measures to be deployed.

1.5 Organization of the Thesis

This thesis is presented in six chapters as follows. Chapter 1 defines the problem and presents the objectives of the research and structure of the thesis. Chapter 2 contains a review of literature on traffic calming, its effects on traffic emissions and near-road air quality. Chapter 3 presents the methodology employed to quantify the effects of calming schemes on emissions and air quality as well as the validation of employed models. Chapter 4 presents the results for Task 1. This chapter demonstrates the detailed findings of the research regarding the effects on traffic emissions. In Chapter 5 the results for Task 2 of the research is presented. In this chapter the findings regarding ambient air quality changes resulting from implementation of traffic calming are discussed. Chapter 6 presents the conclusions and limitations of the thesis and makes recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section reviews the literature pertinent to the research questions articulated in the introduction and which form the back-bone of this thesis. As mentioned previously, two main aspects of environmental effects of traffic calming are explored in this thesis: 1) effect on traffic emissions, and 2) effect on near-road air quality. As such, this section presents the main findings associated with both research dimensions.

2.2 Background and Definition of Traffic Calming

Traffic calming has a broad definition. For instance, Pharoah and Russel (1989) defined traffic calming as “the attempt to achieve calm, safe and environmentally improved conditions on streets”. Carmen Hass-Klau (1990), described traffic calming as “the combination of policies intended to alleviate the adverse environmental, safety and severance effects motor vehicles continue to impose on both the individual and society at large”. One of the most commonly used definition of traffic calming is provided by the Institute of Transportation Engineers (ITE): “the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users” (Lockwood 1997).

Various traffic calming measures with the means of improving road safety have been implemented all over the world for decades. Traffic calming goals include reducing conflicting movements, pedestrian exposure to traffic, and vehicle speeds, as well as improving visibility, and sharpening drivers' attention. These may result in fewer collisions and/or less serious ones (Ewing 1999). Speed humps, speed bumps, speed tables, raised intersection, curb extension, chicanes and bollards are commonly used traffic calming measures. A brief history of traffic calming applied in different contexts is discussed in the following paragraphs.

The concept of traffic calming originated from an incident in Delft, The Netherlands in 1970. A difference in elevation of eight centimeters, like a bump, built at the end of an alley followed several complaints about it of the neighborhood. This was a break-through in traffic engineering. In mid-1976, for the first time in Europe, design standards for residential areas to lower the traffic speeds, 'woonerf', were published in The Netherlands. Since then, traffic calming became a popular element in road design and planning for improving safety specifically in residential areas (Klaus 1997).

Influenced by the 'woonerf', several designs were applied in the seventies such as wooden plant pots, soft lighting and ornamental paving in various colours, materials, and shapes. Generally these former designs required constant maintenance which resulted in an increase in costs. Consequently, due to the economic recession later in the eighties, simpler speed inhibiting measures like

speed humps were designed. When the economy recuperated in the nineties, the designs became a little more excessive again. For instance, streets in the Netherlands were modified by adding hump-like measures at the start and end of roads to outline residential areas while speed limits of 50 km/h were applied. Moreover, intersections were transformed into roundabouts or raised intersections while for long road sections, road narrowing, tapering, tagging shifts, and speed humps were applied; separated cycle tracks were used to improve bicyclists safety (Wit and Talens 1998).

A new code was appended to the Danish Road Traffic Act in the late seventies. The code entailed a change in speed limits; in most cases streets experienced a transformation to 30 km/h speed limits and in few cases to 15 km/h. In addition to the changes in speed limits, speed inhibiting measures such as speed humps, lateral dislocation and narrowing of carriageway were installed on calmed streets (Engel and Thomson 1992). The new code introduced a speed classification system to help address the “through” traffic problems in Denmark’s highway and road network systems. Although a bypass road could have been the solution, construction of bypasses were too expensive. Also, since bypass roads do not solve local traffic issues and it was unrealistic to imagine commercial traffic accepting 30 km/h through all Danish villages, a speed classification system was introduced.

Speed classification alone could not solve the “through” traffic problem in Denmark. In 1981, the Danish Road Directorate presented a new method called

“environmentally adapted through roads” to address “through” traffic issues. These introduced changes in road design such as traffic islands and bicycle tracks, staggering, narrowing and raising levels of carriageways and changed road surfaces as well as planting and lighting. Moreover, it illustrated that the individual elements could be combined such as pre-warnings, gates, track crossings, intersections, and speed reducing measures to form new design solutions. The Danish Road Directorate undertook a test on traffic calming measures applied to highways through the towns of Vinderup, Skrerbaek, and Ugerlose. A number of individual measures were combined and implemented in these three towns to reduce the overall speed in their highway network (Herrstedt 1992).

In the 1980s in Germany, the state of Nordrein Westfalen conducted an experiment on twenty-eight villages by adopting the Danish method. These villages were traffic calmed with narrowings, roundabouts, textured surfaces and redesigned street spaces. In the 1980’s, the effects of traffic calming measures were investigated in six German towns including different residential areas of Berlin-Moabit, Borgentreich, Buxtehude, Esslingen, Ingolstadt and Mainz-Bretzenheim where several calming measures were implemented, including 30 km/h speed limits, speed tables, chicanes, pinch points in local streets and collectors, roundabouts, textured surfaces and redesigned street spaces, and narrowing ring roads and arterials (Brilon and Blankeb 1993 and Ewing 1999).

A 1963 British government document, *Traffic in Towns by Colin Buchanan*, is often credited with initiating the modern traffic calming movement. This document was inspired by a traffic calming plan launched in 1982 in Britain to decrease collision rates. The plan had a quite less effect on accident rates compared to German, Dutch, and Danish calming strategies. Therefore, changes in law and regulation and a new edition of the street design manual were applied to bring Britain to the same level with the rest of Europe. For instance, older regulations only allowed 3.5 meters humps for the use of vertical measures while new regulations included almost any reasonable vertical or horizontal features (Ewing 1999).

The United States experience with traffic calming measures started in the 1940's and 1950's with the installation of street closures and traffic diverters in Montclair, NJ and Grand Rapids, MI focusing on improving specific road networks. In the 1970s, a complete citywide traffic management plan was implemented in Berkeley, CA and area-wide traffic calming measures were established in Seattle, WA. These experiences are probably the first of their kind in the US (Ewing 1999). Currently, the focus of current traffic calming practice is on neighborhood-wide improvements rather than improving single locations. New methods have expanded the variety of implemented traffic calming measures including speed humps and bumps, traffic circles, chicanes, pedestrian streets, traffic diverters and signing techniques.

In Canada, increasing “through” traffic volumes became major cities’ concern like Toronto and Vancouver since the 1970’s. Therefore, traffic calming measures have been implemented in residential neighbourhoods to prevent “through” traffic. Typically, these implemented measures included physical changes such as closing access points and creating maze-like streets. The *Canadian Guide to Neighbourhood Traffic Calming* was published in 1998 and since then, dozens of Canadian cities have applied sufficient traffic calming measures (TAC 1998).

2.3 Traffic Calming and Its Effects on Traffic Emissions

While little research has been carried out to date to explore the effects of traffic calming on vehicle emissions, a few studies have focused on this issue along two different dimensions: 1) assessing the effects of isolated traffic calming measures at a corridor level, and 2) evaluating area-wide calming schemes.

Crabbe and Elsom (1996) outlined examples of several assessments of air quality impacts of specific traffic management measures including traffic calming in the United Kingdom. The article demonstrated the results from a Transport Research Laboratory study (1995) in which driving patterns have been simulated (taking into consideration vehicles travelling at speeds of 23 to 30 km/h for simulating calmed areas and vehicles travelling at a constant speed of 40 km/h for non-calmed roads) suggesting a 25-50% increase in CO, HC and CO₂ emissions and 50% decrease in NO₂ emissions. Also, results for another study summarized in Crabbe and Elsom s’ article showed that two traffic calming strategies, including a route network for pedestrians and cyclists and imposing speed limits of 30 km/h

instead of 50 km/h in Buxtehude, Germany, resulted in CO, HC, and NO_x emissions reductions.

The report prepared by Cloke *et al.* (1999) for the Transport Research Laboratory highlighted the evaluation of the environmental impact of area-wide traffic calming measures installed in the Leigh Park area of Havant, England. In total, 20 cars were driven through the calmed zone while their speeds were recorded. Driving cycles were established using recorded speed variations. Results from calculated air pollutant emissions by a computer model, considering a reduction in traffic volumes, indicated a decrease in CO, HC, and NO_x emissions. However, without considering traffic volume changes, CO and HC emissions were increased while NO_x emissions were decreased.

In 2001, Boulter *et al.* studied the impact of nine different traffic calming schemes on air pollutant emissions and air quality. These schemes included flat-top road hump, round-top road hump, two types of speed cushions, combined pinch point and speed cushion, raised junction, chicane, curb extension and mini-roundabout. For deriving driving cycles, actual driving speeds were measured before and after the implementation of calming measures. Exhaust emission measurements were conducted using the derived driving cycles. The results indicated that installed traffic calming measures increase the mean emission rates of CO, HC, and CO₂ by up to 60 percent for the three types of cars (petrol non-catalyst, petrol catalyst and diesel cars). NO_x and particulate matter emissions were increased substantially for

diesel cars. Further estimations using a dispersion model showed that the increased emission rates slightly worsen the local air quality.

Várhelyi (2001) conducted a before/after study in Växjö, Sweden to evaluate the effects of the implementation of 21 mini-roundabouts, replacing signalized and yield regulated junctions, on air pollutant emissions. Driving cycles were derived from recorded distance travelled by an equipped car. Emissions were calculated using a model which considered volume change at intersections. Results of this article showed that at a roundabout replacing a signalized intersection, CO and NO_x emissions decrease following a decrease in speed variations, while at a roundabout replacing a yield regulated junction, CO and NO_x emissions increase as a result of the slowing down of traffic.

Daham *et al.* (2005) conducted a study to determine the effect of speed humps on air pollutant emissions. In their study, a car equipped with an on-road emission measurement device with a very heavy load was driven at a constant speed of 50 km/h to simulate a normal road with seven speed cushions. To simulate a calmed road with round-top speed humps, the car was slowed down to 16 km/h to go over installed speed cushions on the same road and accelerated up to 32-48 km/h. The results of the calmed road compared to the normal one showed substantial increase in CO₂, CO, NO_x and HC emissions by 90%, 117%, 195%, and 148%.

Ahn and Rakha (2009) estimated air pollutant emissions for three roads before and after installation of various types of calming measures, using a combination

of global positioning system data from floating-cars and microscopic emission models. Results for the first road with a speed limit of 40 km/h showed that the installation of five speed cushions increased emissions of various air pollutants significantly. Also, for the second road with speed limit of 25 km/h where two speed bumps were installed, results indicated a significant increase in emission rates. The third study corridor included three uncontrolled intersections, one four-way stop controlled intersection, four traffic circles and three intersections with three speed humps. Intersections with calming measures resulted in significantly higher emission rates than intersections without calming measures or stop signs.

2.4 Traffic Calming and Its Effects on Near-Road Air Quality

2.4.1 Characterization of Near-Road Air Quality

There is a recognizable amount of literature that focus on measuring and modeling near-road air quality. Several studies measured real-world air pollutant concentrations with different sampling methods.

Beckerman *et al.* (2007) measured different pollutant concentrations near a major expressway in Toronto including fine particulate matter, ultrafine particulate matter, black carbon, NO₂, NO_x and O₃. Their measurements showed that NO₂ levels are correlated with other traffic-related pollutants and decline with increasing distance from the expressway.

Two studies investigated the relationship between NO₂ concentrations and distance from the roadway. The first study, in 2003, installed several Ogawa

passive samplers at different distances from a major highway in Montreal, Canada. One year later, in 2004, a second study was conducted to sample NO₂ concentrations near a highway in South-west Sweden. Both studies supported the idea that NO₂ levels decrease as the distance from the roadway increases and they have a logarithmic relationship (Gilbert *et al.* 2003 and Pleijel *et al.* 2004).

Moodley *et al.* 2011 collected NO₂ concentrations at five intersections in Durban metropolis, South Africa. They used Ogawa passive samplers and an active sampler (chemiluminescence detector) and compared the samples measured from the two methods. Based on their analysis, no statistically significant difference between the two sampling methods was found.

A commonly used dispersion model which has been validated in various studies is The Operational Street Pollution Model (OSPM), developed by Hertel and Berkowicz (1989). In 2006, Berkowicz *et al.* modeled NO_x and CO concentrations along a road in Copenhagen, Denmark using OSPM. In their modeling process they calculated the emission factors using the European COPERT methodology. The modeled concentrations were significantly lower than measured concentrations. They suggested that a more accurate estimation for the emission factors may result in closer results of the modeled and measured concentrations. In contrast, a study conducted in three street canyons of Nantes, France found a good agreement between NO_x levels measured and modeled with OSPM (Gokhale *et al.* 2005). The good agreement between modeled and

measured concentrations was also concluded in several other studies (Kukkonen *et al.* 2001, Berkowicz 2000 and Raducan 2008).

Also, the comparison between NO_x levels measurements and modeled concentrations with OSPM showed that the leeward concentrations are higher than the windward concentrations in a street canyon (Berkowitz *et al.* 1996). Nevertheless, the assessment of air pollution for 2008 Beijing Olympic Games indicated that the street configuration and the wind speed and direction may impact the windward and leeward concentrations in a way such that the windward levels may be higher than the leeward concentrations (Wang and Xie 2009).

2.4.2 Traffic Calming and Air Quality

Oduyemi and Davidson in 1998 investigated the effects of several traffic management measures including the traffic restrictions in Dundee city centre, UK on ambient air quality. Diffusion tubes, measuring NO₂ at each site, were used in order to investigate the difference between the air quality within and outside traffic restricted areas. Results of this study showed that the annual mean NO₂ concentration at two of the study sites was close to 40 µg/m³, indicating the effectiveness of traffic management measures in protecting air quality.

The report by Cloke *et al.* (1999) evaluating the environmental impact of area-wide traffic calming measures installed in the Leigh Park area of Havant, England where NO₂ and benzene levels were measured using diffusion tubes at 6 different

sites, demonstrated that the implemented traffic calming scheme in the area did not have a significant effect on air quality.

Boulter *et al.* (2001) studied the impact of different traffic calming schemes such as flat-top road hump, round-top road hump, curb extension and mini-roundabout on air quality using a dispersion model. Although their results showed substantial increases in emission rates, dispersion modeling showed that the increased emission rates worsened local air quality by a maximum percentage change of 5% in NO₂ levels.

In 2005, Owen published an article evaluating the effects of traffic calming measures, such as speed humps and traffic lights, on vehicle emissions and ambient air quality of six 32 km/h zones (approximately 0.5 km x 0.5 km) in North West England before and after the installation. Ambient concentrations of NO₂ and benzene were measured using diffusion tubes and thermal desorption tubes. The results of these measurements showed that the installation of calming measures did not significantly affect air quality in the six zones.

2.5 Gaps in Available Literature

Despite the beneficial effects of traffic calming on improving road safety, it has been associated with impacts on air quality. In fact, varying speed frequently and slowing down while driving on a calmed street, may tend to produce more air emissions due to increased accelerations and decelerations. While the safety impact of traffic calming has been studied in depth for several years, relatively

few studies have been conducted to capture the environmental impact of traffic calming. The studies mentioned so far present many advantages such as the use of real drive-cycles, traffic volumes, and air pollution measurements to quantify the effects of traffic calming on air quality. However, they lack the capability of evaluating the effects of instantaneous speed changes and traffic volumes simultaneously and in isolation. This thesis focuses on the development of a microscopic traffic, emission and dispersion modeling system which aims to capture the effects of a range of traffic calming schemes on traffic volumes, speeds, emissions and air quality both at a link-level and at a network-level using a scenario analysis. It also investigates the effects of isolated traffic calming measures and area-wide calming schemes at a corridor level on air quality.

CHAPTER 3 METHODOLOGY

3.1 Introduction

In this thesis, the effects of traffic calming measures on air pollutant emissions and air quality in a Montréal neighborhood are examined by employing a combination of mesoscopic and microscopic traffic models, the USEPA's Motor Vehicle Emissions Simulator (MOVES) and Danish Operational Street Pollution Model (OSPM). First, a regional traffic assignment model is used to allocate trips on the metropolitan road network. Second, Origin-Destination (OD) matrices for all trips generated from, destined to, or passing through the study neighborhood are input into a traffic simulation model operated in Dynamic Traffic Assignment (DTA) mode. Traffic simulation is then run for a range of traffic calming measures and under each scenario, second-by-second speed profiles for each link in the neighborhood are extracted. Using these instantaneous link speeds, air pollutant emissions are modeled using a version of MOVES fitted with input data describing the Montréal vehicle fleet. Later, concentration levels of air pollutants are modeled in OSPM at the corridor level.

3.2 Study Area

The study area includes the Plateau-Mont-Royal borough, more often referred to as "The Plateau", within the Montréal Metropolitan Region (FIGURE 3.1). The Plateau is a dense and lively neighborhood which recorded a population of 101,054 individuals in an area of only 8.1 km², according to the most recent

Canadian census report. Its residents are currently experiencing large volumes of “through” traffic due to the borough’s proximity to the Montréal central business district leading to the generation of significant amounts of traffic emissions as well as safety risks. The local council of the neighborhood is actively pursuing the goal of managing increasing traffic volumes especially on local streets and improving pedestrians’ and cyclists’ safety.

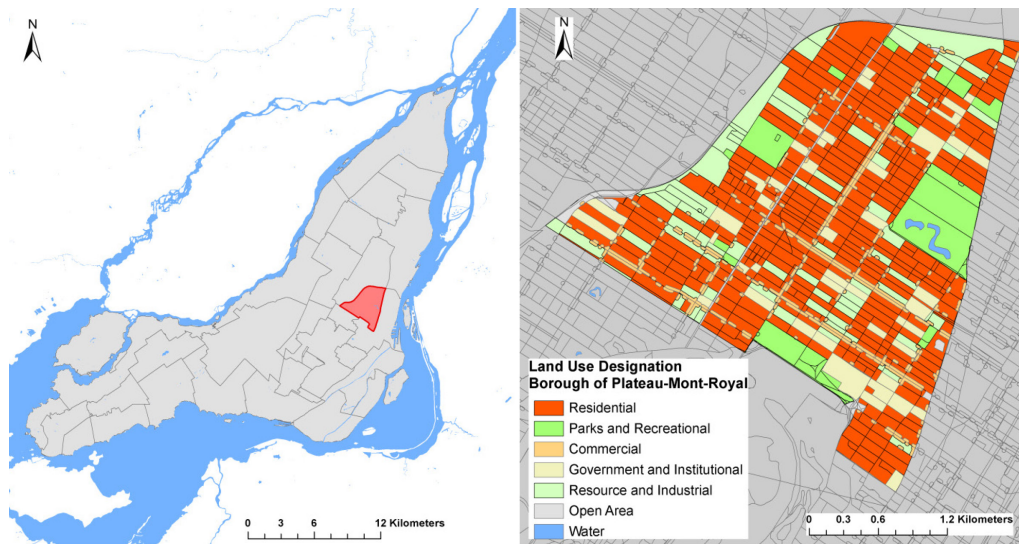


FIGURE 3. 1 The Plateau borough in the context of the Montréal region.

Within the Plateau, this thesis focuses on a small sub-area that has recently been the subject of much debate due to the increasing traffic volumes and speeds witnessed along several residential streets with a large number of daycares, schools, churches, and community centers. This area is bound by four main arterial roads: Rue St Gregoire to the North, Rue Rachel to the South, Rue St. Denis to the West, and Avenue Papineau to the East (FIGURE 3.2). It is important to note that while the traffic simulation model will be run at the level of the entire Plateau borough, our main focus will be on the traffic calming measures and link-

evaluation in this sub-area, in particular, the four residential and school corridors (Marquette, Chambord, Garnier, and Fabre) highlighted in FIGURE 3.2.

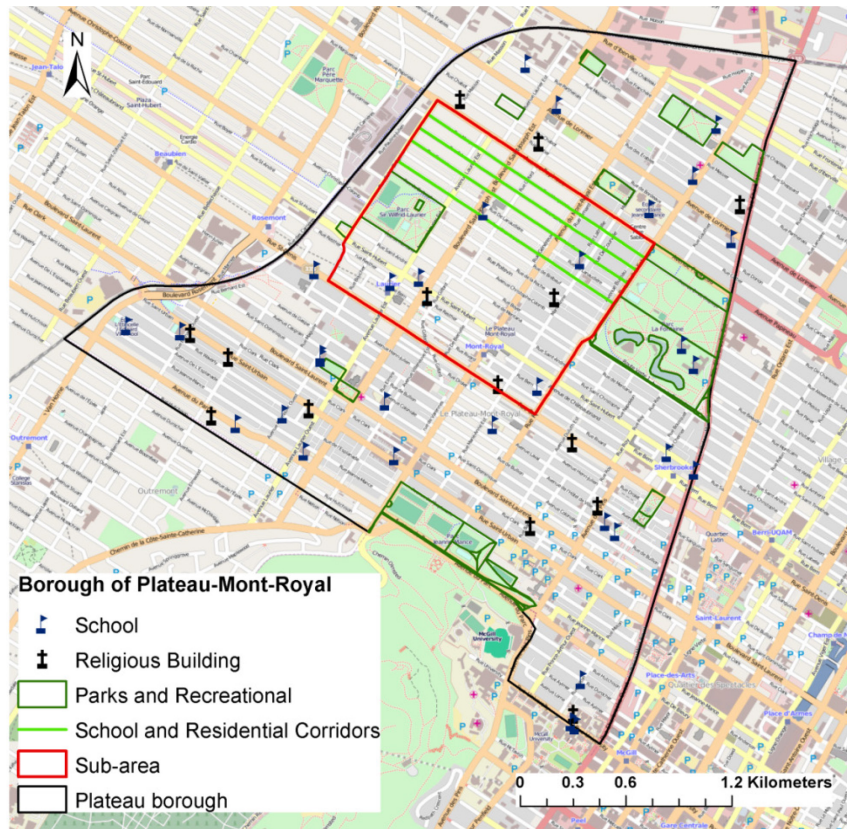


FIGURE 3. 2 Sub-area featuring highlighted residential and school corridors.

3.3 Traffic Simulation

In order to estimate emission levels one must consider the accelerations and instantaneous speeds for individual vehicles; therefore, for this study a microsimulation model of the road network in The Plateau is developed to achieve the sensitivity necessary to analyze the effects of different policy interventions. A model at the meso scale cannot capture such effects.

In order to do this, first a regional traffic assignment model is developed for the Montréal Metropolitan Area using the PTV VISUM platform. This model takes the 2008 OD trip data for the Montréal region provided by the Agence Métropolitaine de Transport. The regional network consists of 127,217 links. VISUM runs under a stochastic user equilibrium traffic assignment for the 6-7AM period and for the 7-8AM period. The regional traffic model generates a trip demand matrix that is in-turn used as input into the traffic simulation model for the Plateau. The matrix contains the numbers of trips, traffic analysis zones, and boundary links associated with each trip for the following: (1) trips generated outside the Plateau and destined to the borough, (2) trips generated in the borough and destined to an outside zone, (3) trips generated and destined within the Plateau, and (4) “through” traffic.

For the development of the micro-simulation in VISSIM, a database of all intersections in the study area is created. For every intersection, traffic light signal phases, turning restrictions, and traffic counts are input. Traffic counts are obtained from the City of Montréal automatic counters and through manual counts. The VISSIM network is developed using a combination of orthophotos, topographic maps, cartographic maps, and field visits. All stop signs, traffic lights, and the changes in speed limit between arteries, local roads and school zones are included. The VISSIM network has 8,656 links and connectors and 576 intersections. The matrix of the number of trips from VISUM is used and VISSIM runs under dynamic traffic assignment to assign vehicles on a very detailed road network within The Plateau. On the boundaries, each link acted as an abstract

parking lot to remove vehicles from or generate vehicles onto the network. Also, an origin link and a destination link for each zone centroid within the borough are added to include vehicles that originated from or were destined to the Plateau. In multi-run mode with the volume initially set at 10% of the total, increasing by 10% for the next nine iterations, the convergence reached its criterion after 39 iterations in the base case. In order to generate the instantaneous link speeds and volumes, one final iteration after convergence is run and data for every second between 7-8AM is recorded. It must be noted that link speeds and volumes are extracted only for the sub-area in The Plateau where traffic calming measures will be tested, while the VISSIM is run for the entire borough.

3.4 Emission Modeling

The Motor Vehicle Emission Simulator (MOVES) was developed by the U.S. Environmental Protection Agency (EPA) in order to estimate link-based emissions from mobile sources under a variety of user-defined conditions. MOVES requires information about the link length, road grade, traffic volume, traffic composition, and vehicle speed. Speed is input as second-by-second speed that captures acceleration, deceleration, cruising, and idling, commonly referred to as the drive-cycle to represent actual driving conditions (see EPA 2012 for a full description). Instantaneous speeds and hourly drive-cycles (full 3600 seconds) for each link in the sub-area are extracted from VISSIM.

Other required information for emission modeling, including meteorological data, fleet composition, fleet age distribution, and fuel quality for Montréal, were input

to reflect local conditions. Meteorological data were input for October 2011, which corresponds with the period for traffic counts. Vehicle type and model year information were obtained from the Société de l'assurance automobile du Québec (SAAQ). MOVES was used to calculate hourly CO₂, CO, and NO_x emissions per link.

3.5 Dispersion Modeling

The Danish Operational Street Pollution Model (OSPM) is used for dispersion modelling. OSPM has been previously used in a number of studies showing good agreement between modelled and measured pollutant concentrations (Raducan 2008, Berkowicz *et al.* 2006, Gokhale *et al.* 2005, Kukkonen *et al.* 2001 and Berkowicz 2000). OSPM calculates the concentrations of exhaust gases from road traffic using a combination of a plume model to reflect the direct contribution and a box model to reflect the recirculating part of pollutants along the street. When computing concentrations, the leeward side of the street experiences both the direct contribution and the recirculation part while the windward side experiences the recirculation component. The model also considers both ambient and traffic-induced turbulence. In OSPM, the three following reactions are considered for modeling NO₂ concentrations:



Required inputs in OSPM include: street configuration, meteorological data, background concentrations, emission factors, and traffic data (Berkowicz *et al.*

2003, Hertel and Berkowicz 1991 and Hertel and Berkowicz 1989). The required data for street configuration including average height of buildings, width, and orientation of the street were gathered through field visits. The link emissions generated from MOVES divided by the total number of vehicles and the length of each link are input into the model. Traffic volumes and vehicle speeds extracted from VISSIM are used to calculate total link emissions as well as simulate vehicle-induced turbulence. Hourly meteorological data such as wind speed, wind direction, and temperature are collected for October 2011 from Environment Canada (14). A total of 31 days of meteorological data are used for dispersion modelling. Wind speed and wind direction are the two most critical variables for dispersion, they are presented in FIGURE 3.3. This figure illustrates a windrose which includes all wind speed and direction conditions for the month of October 2011 which are used in OSPM to compute a monthly average NO₂ along selected segments. Hourly urban background concentrations of NO₂, NO_x, and O₃, global radiation, and the percentage of NO₂ directly emitted by vehicles were also input for October 2011. The NO₂ concentrations for three study corridors (Marquette, Chambord and Garnier) are modeled for different wind speeds and directions using OSPM and the results are presented for every segment of the study corridors in Chapter 5. The summary of corridor specifications and meteorological data are shown in Table 3.1.

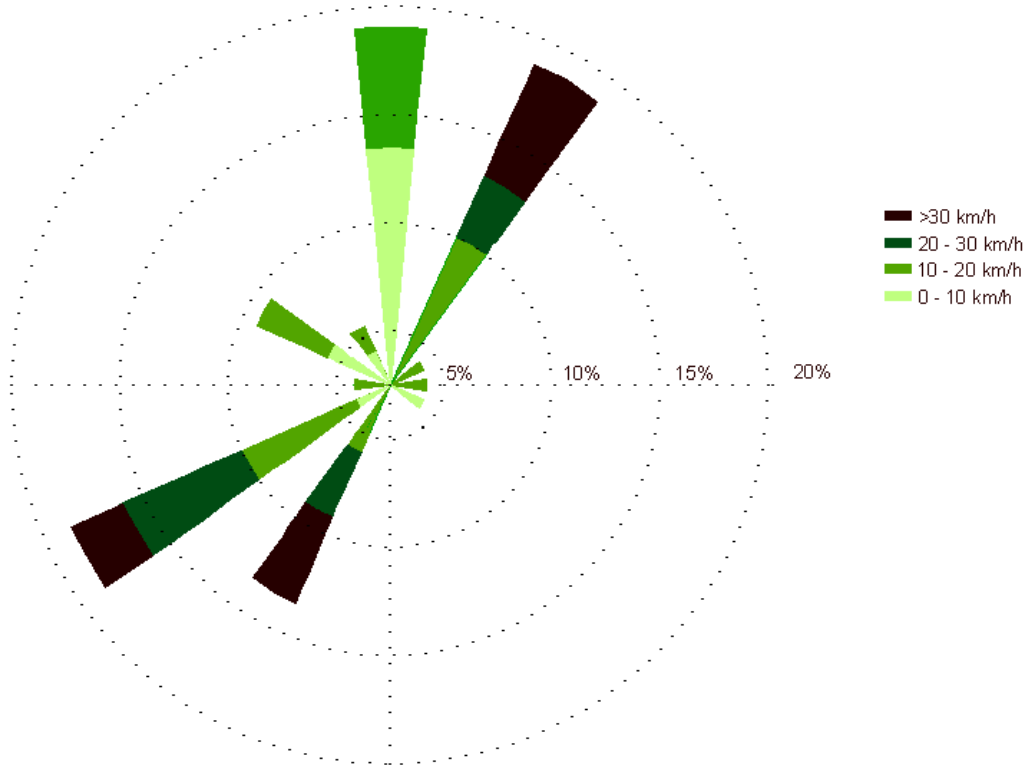


FIGURE 3. 3 Wind speeds and directions for October 2011.

Table 3. 1 Corridor Specifications and Meteorological Data

		Chambord	Garnier	Marquette
Background Levels	Average Width (m)	11	10	11
	Direction	130°	130°	130°
	Average Building Height (m)	11	12	10
	Average Temperature (°C)	10		
	Global Radiation (W/m2)	140		
	NO _x (ppb)	18		
	NO ₂ (ppb)	10		
	O ₃ (ppb)	17		

3.6 Traffic Calming Scenarios

A total of eight different traffic calming scenarios including single, isolated, and network-wide measures have been identified and simulated within the traffic simulator, microscopic emissions model and dispersion model. Besides the base-case scenario which has a network-wide speed limit of 50 km/h, the eight simulated scenarios are identified and described in Table 3.2. In general the identified measures include speed humps, speed bumps, and speed limits:

- Speed bumps are defined as raised areas in the roadway pavement surface that are less than 0.3 m in width and are crossed at very low speeds: 5-10 km/h. Within VISSIM, we simulated them by defining an area of 0.3 m in width with a speed of 5 km/h.
- Speed humps are also similar to speed bumps, but are broader, typically 3 to 4 m in width, and are crossed at higher speeds (25- 30 km/h). Within VISSIM, we simulated them by defining an area of 3 m in width with the speed of 25 km/h.
- A network-wide speed limit of 30Km/h was implemented in VISSIM by defining the desired speed of every residential street as 30 km/h. This includes most streets in the study area except for the major arteries.

All the scenarios summarized in Table 3.2 are analysed for the estimation of emissions of Greenhouse Gases (GHGs) and air pollutants and the results are presented in Chapter 4. For studying the effects of traffic calming on air quality, scenario 4 is not included in the modeling process and scenarios 1, 2 and 3 are

presented in one scenario called speed bumps on roads. Chapter 5 presents the results of the air quality analysis.

Table 3. 2 Description of Scenarios

Scenarios	Descriptions
Scenario 1	Entails the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Marquette, a major residential street in the neighborhood
Scenario 2	Entails the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Chambord, a major residential street in the neighborhood
Scenario 3	Entails the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Garnier, a major residential street in the neighborhood
Scenario 4	Entails a network-wide speed limit of 30 km/h
Scenario 5	Entails the implementation of 17 speed bumps along each of the following streets: Marquette, Chambord, Garnier, and Fabre. This scenario essentially captures the simultaneous effects of scenarios 1-3, including an additional street.
Scenario 6	Entails the implementation of 17 speed humps along each of the following streets: Marquette, Chambord, Garnier, and Fabre. This scenario essentially replaces speed bumps in scenario 5 with speed humps
Scenario 7	Entails the implementation of 17 speed humps along each of the following streets: Marquette, Chambord, Garnier, and Fabre including a network-wide speed limit of 30 km/h. This scenario essentially merges scenarios 4 and 6.
Scenario 8	Entails the implementation of 17 speed bumps along each of the following streets: Marquette, Chambord, Garnier, and Fabre including a network-wide speed limit of 30 km/h. This scenario essentially merges scenarios 4 and 5

3.7 Model Validation

Validation of observed and simulated traffic counts in the entire network as well as of drive-cycles for selected corridors (of importance to the study) was conducted. Traffic counts simulated by the VISSIM model for the entire Plateau neighborhood were compared with traffic counts conducted at 329 intersections during the same time period represented by the model (Fall 2011, AM peak period). Counts at the 329 intersections include a combination of automated and manual efforts. The R^2 value for these observations is 0.71 for the 7-8AM period

indicating a reasonable correlation between simulated and measured traffic volumes.

In order to validate drive-cycles generated from traffic microsimulation, we used global positioning system (GPS) data from three floating cars for several trajectories within our study area (the sub-area within the Plateau neighborhood). Of most interest to our study is the correspondence between simulated and observed data along the segments undergoing traffic calming measures. Instead of comparing instantaneous speeds, we opted for comparing the operating mode (*opmode*) distributions at the selected segments. The main reason for choosing this comparison method is that MOVES estimates second-by-second emissions based on the *opmode* of each second. In MOVES, an *opmode* corresponds to a combination of speed and vehicle specific power (VSP). The VSP is a function of instantaneous speed, acceleration, vehicle weight, and road grade as shown in equation (4) (EPA 2012). An emission factor is defined for each *opmode* for different conditions such as vehicle type, model year, meteorology, fuel type, etc.

$$VSP = \left(\frac{A}{M}\right) * v + \left(\frac{B}{M}\right) * v^2 + \left(\frac{C}{M}\right) * v^3 + (a + \text{Sin}\theta) * v \quad (4)$$

where A, B, and C are the road load coefficients in units of (kiloWatt second)/(meter), (kilowatt second²)/(meter²), and (kiloWatt second³)/(meter³), respectively. The denominator term, M, is the fixed mass factor (for passenger car is M= 1.48 metric tons), g is the acceleration due to gravity (9.8 meter/ second²), v

is the vehicle speed in meter/second, a is the vehicle acceleration in meter/second², and $\sin\theta$ is the (fractional) road grade.

The decision to focus on comparing *opmode* distributions for validation purposes rather than comparing second by second drive-cycles is due to the fact that drive-cycles that are not exactly identical, may lead to the same amount of emissions if they have similar *opmode* distributions. This no longer imposes on the traffic simulation model to exactly mimic sec-by-sec conditions but rather to follow similar operating modes.

The VSP and associated *opmode* were calculated for data collected using each on-board GPS outside of MOVES. Then, the cumulative *opmode* distribution was developed for every road segment. Similarly, segment-level drive-cycles were extracted from VISSIM and the *opmode* distribution for simulated data was also derived while running VISSIM under three different random seeds. The cumulative distributions of *opmode* for on-board GPS and simulated data were compared.

FIGURE 3.4 illustrates the operating mode distributions for six selected road segments in our study area. In each case, *opmodes* derived from three GPS trajectories and derived from VISSIM under three random seeds are presented. Results show a reasonable agreement between simulated and observed data with lower agreement on two segments where VISSIM simulated higher traffic speeds than observed. Note however that when we calculated segment-level emissions

based on observed and simulated data, we clearly see a non-significant difference between mean CO₂ emissions under both cases (at 5% significance level). The results of CO₂ emissions for the same six road segments are presented in Table 3.3. We observe that in only one case, the mean CO₂ emissions based on observed vs. simulated data are different (at 5% significance level).

In addition to comparing observed and simulated data based on *opmode* distributions and resulting emissions, we investigated the effect of varying the random seed within VISSIM on the resulting emissions before and after a traffic calming measure is implemented. The motivation for this analysis is to ensure that a traffic calming measure would have a similar effect on emissions under various random seeds. For this purpose, we simulated the base case scenario under three different random seeds. Similarly, we simulated scenario 6 (network-wide speed humps) under the same three random seeds. We then estimated CO₂ emissions along an entire corridor (the Chambord corridor, composed of six links) which experienced a total of 17 humps (Table 3.3). Results show that even under different random seeds, the hump introduces a significant change (at a 5% significance level) in average emissions except for one segment.

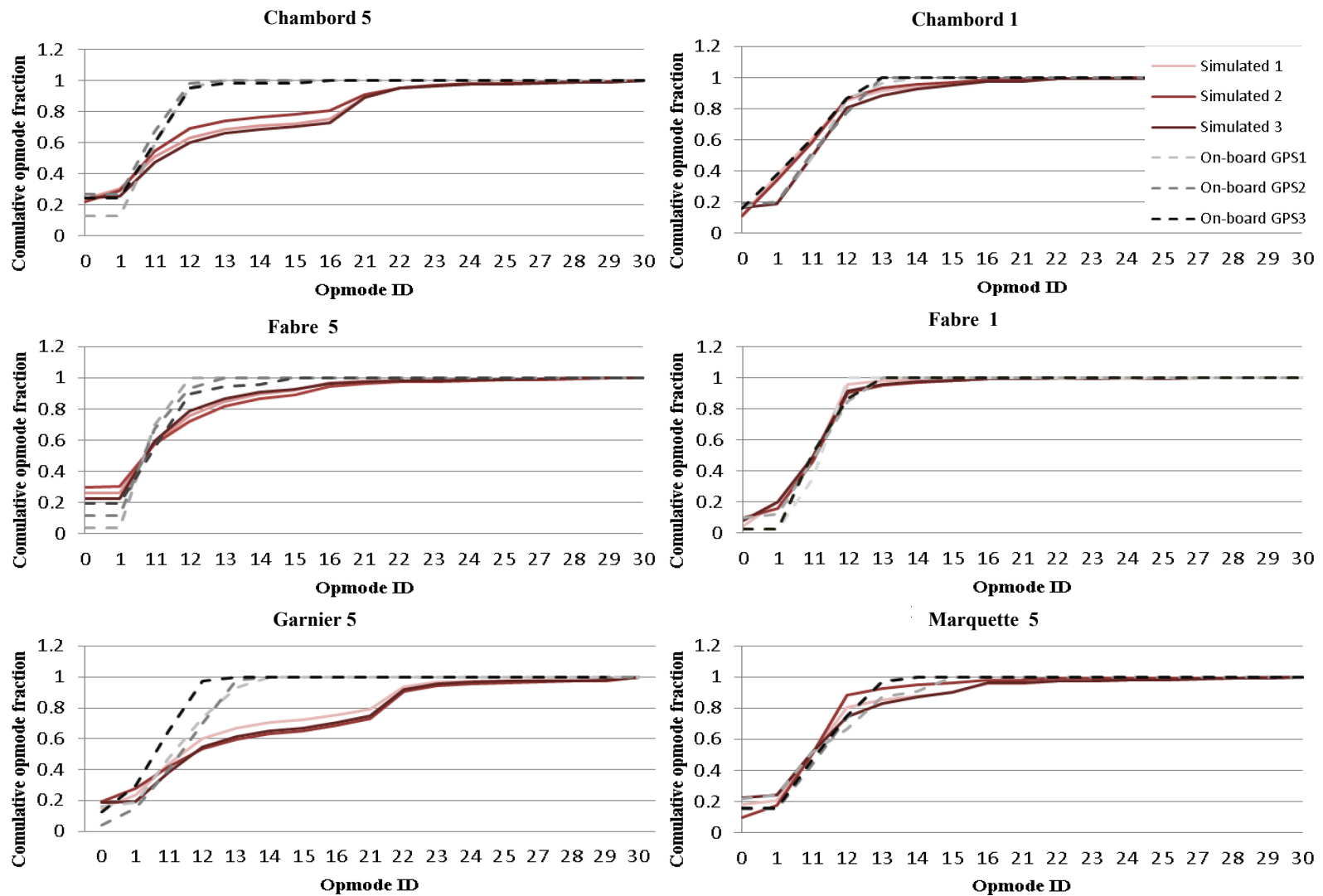


FIGURE 3. 4 Operating mode distributions for six selected road segments in our study area.

Table 3. 3 CO₂ Emissions along an Entire Corridor for the Base Case Scenario and Scenario 6 under Three Different Random Seeds

Link Name	Base-case			Mean CO ₂ Emissions Base-case	Scenario 6			Mean CO ₂ Emissions Scen6	p-value for difference between means
	Run 1	Run 2	Run 3		Run 1	Run 2	Run 3		
Chambord 1	17,788	19,327	18,784	18,633	20,175	21,288	21,463	20,975	<0.01
Chambord 2	9,150	9,307	9,910	9,456	9,399	10,673	10,413	10,162	0.17
Chambord 3	18,640	20,319	21,444	20,134	20,788	22,471	24,615	22,625	0.02
Chambord 4	11,591	10,971	12,782	11,781	14,279	12,767	14,285	13,777	0.03
Chambord 5	27,348	29,803	28,922	28,691	28,514	32,298	31,236	30,683	0.04
Chambord 6	5,007	5,934	5,339	5,427	5,786	6,661	6,228	6,225	<0.01

CHAPTER 4

RESULTS FOR THE EFFECTS OF TRAFFIC CALMING ON EMISSIONS OF GREENHOUSE GASES

4.1 Introduction

In order to evaluate the effects of the different traffic calming measures, two categories of measures are proposed and presented in this chapter: (1) *network level measures*: the total Vehicle Kilometers Traveled (VKT) within the network, total vehicle emissions on the network, and total emissions per VKT (2) *link level measures*: the total emission percentage change on each link with respect to the base case scenario. The network level measures provide a sense of the overall performance within our sub- area. The link level measures allow us to investigate the effects of different measures in the immediate vicinity of the change.

4.2 Network Level Evaluation

The network-level emissions computed for all the scenarios are presented in Table 4.1. As expected, because traffic flows are reduced, the imposed traffic calming measures decrease the total VKT in the area under all of the scenarios compared to the base case except for scenario 5 (which introduces speed bumps along four different roads). In scenario 5, total volumes on the network are lower, although the total VKT is higher. This might be due to the fact that a significant number of vehicles avoided the calmed corridors which resulted in traveling longer distances. Indeed, Scenario 5 makes calmed corridors most unattractive compared to neighboring corridors thus inducing the search for alternative paths.

In terms of emissions, in general, total emissions are higher under all scenarios with respect to the base case. More important, however, are emission rates (in gr/VKT) which also increase thus indicating that vehicles on the network are generating higher emissions due to the resulting changes in drive-cycles. Scenarios 1, 2, and 3 which introduce calming measures along individual corridors generate smaller increases in emission rates than Scenarios 7 and 8 which combine lower speed limits and traffic calming along four different streets at the same time. Scenario 8 yields the highest increase in emissions of CO₂ by 7.60 %, CO by 4.54%, and NO_x by 4.62%, this is because speed bumps (which necessitate a slowing down to 5 km/h) lead to higher emissions than speed humps (which only necessitate a reduction to 25 km/h). Both speed humps and bumps lead to higher emissions when combined with lower speed limits. This could be the effect of lowering network-wide average speeds.

For comparative purposes, the average speed of each link on the network is calculated and MOVES in average-speed emission estimation mode is used in order to estimate the average-speed emissions and compare them to the second by second emissions presented in Table 4.1. Table 4.2 presents the results of this comparison. It is observed that average-speed emissions are systematically higher than instantaneous speed emissions. This is due to the fact that the average speeds on the network, even in the base-case scenario, are already fairly low (10-40 km/h). Indeed, when MOVES is operated with average speeds, it tends to overestimate emissions when speeds are low due to the embedded drive cycles

that do not necessarily represent local driving conditions. Using instantaneous speeds derived for the entire hour of simulation (3,600s) ensures that a more reasonable treatment of emissions is obtained. It is also observed that the difference between emissions estimated using average vs. instantaneous speeds is higher along links with lower average speeds.

While the network-wide evaluation shows small to moderate changes in emissions (up to 7.6%), it is important to recognize that our sub-area comprises 352 links of which only 30 will undergo traffic calming. It is important to investigate link-level effects in order to identify whether certain links will undergo significant changes in drive-cycles and emissions.

Table 4. 1 Effects of Traffic Calming on Total Air Pollutant Emissions and Total VKT

Scenarios	CO₂ (ton)	CO (kg)	NO_x (kg)	VKT	CO₂ (gr/VKT)	CO (gr/VKT)	NO_x (gr/VKT)
Base case	2.80	50.35	3.57	9751	287.41	5.16	0.366
Sc 1: Bumps on Marquette	2.83	50.45	3.61	9690	291.51	5.21	0.372
Sc 2: Bumps on Chambord	2.84	50.51	3.62	9744	291.33	5.18	0.372
Sc 3: Bumps on Garnier	2.85	50.16	3.61	9739	292.36	5.15	0.371
Sc 4: Speed limit	2.84	50.66	3.53	9738	291.45	5.2	0.362
Sc 5: Network-wide speed bumps	2.98	51.15	3.78	9775	305.14	5.23	0.387
Sc 6: Network-wide speed humps	2.83	49.51	3.62	9733	291.04	5.09	0.372
Sc 7: Network-wide speed humps and speed limit	2.84	50.13	3.53	9683	293.39	5.18	0.364
Sc 8: Network-wide speed bumps and speed limit	3.02	52.63	3.74	9691	311.18	5.43	0.386

Table 4. 2 Comparison between Network-Wide Emissions Derived

Scenarios	Second by second emissions			Average speed emissions		
	CO ₂ (ton)	CO (kg)	NO _x (kg)	CO ₂ (ton)	CO (kg)	NO _x (kg)
Base case	2.80	50.35	3.57	3.40	51.72	4.11
Sc 1: Bumps on Marquette	2.83	50.45	3.61	3.40	51.70	4.09
Sc 2: Bumps on Chambord	2.84	50.51	3.62	3.41	51.83	4.11
Sc 3: Bumps on Garnier	2.85	50.16	3.61	3.44	52.18	4.13
Sc 4: Speed limit	2.84	50.66	3.53	3.44	52.42	4.13
Sc 5: Network-wide speed bumps	2.98	51.15	3.78	3.51	52.90	4.16
Sc 6: Network-wide speed humps	2.83	49.51	3.62	3.41	51.89	4.11
Sc 7: Network-wide speed humps and speed limit	2.84	50.13	3.53	3.43	52.19	4.11
Sc 8: Network-wide speed bumps and speed limit	3.02	52.63	3.74	3.57	53.67	4.16

4.3 Link Level Evaluation

The base case scenario has a network-wide speed limit of 50 km/h. FIGURE 4.1 shows the spatial distribution of generated CO₂ emissions per kilometer of roadway in the sub-area. Of the 16.147 tons of CO₂ generated in the Plateau borough over the 7-8 AM period, 2.803 tons occur in the study area. As shown in FIGURE 4.1, arterial roads have the highest CO₂ emissions especially boulevard Saint-Joseph, going across the study area and avenue Papineau, on the Northeast side of the network. Other residential and school corridors are experiencing CO₂ emissions of less than 100 kg/km.

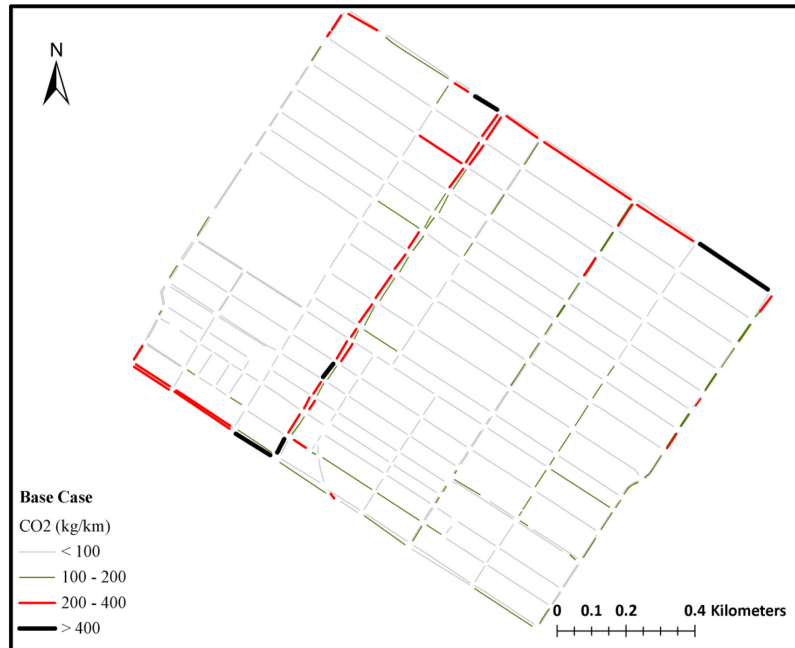


FIGURE 4. 1 CO₂ emissions in the study area under the Base Case scenario.

The link level evaluations for isolated measures (Scenarios 1, 2, and 3) are presented in FIGURE 4.2. We observe that implementing speed bumps along isolated corridors (Marquette, Chambord, and Garnier) increases total CO₂ emissions along the corridor itself by 15-81% compared to the base case. The rest of the network does not experience a significant change in emissions. Note that the VKT on these links decrease but they still experience a rise in CO₂ emission rates (in g/VKT) by 35-74% therefore indicating that the increase in emissions is associated with changes in drive-cycles.

Generally, area-wide calming measures introduced in scenarios 5 and 6, including humps and bumps along four different streets at the same time, not only increase emissions along calmed roads but also worsen emissions across the network (FIGURE 4.3). We observe that calmed streets shift some of the traffic to

alternative routes thus worsening their emissions. Comparing the results of scenarios 5 and 6, it is observed that speed bumps generate more acute increases in emissions (10% to 83%) than speed humps (1% to 38%).

Also, in FIGURE 4.3 the results for network-wide speed limits (Scenario 4) combined with speed humps (Scenario 7) or bumps (Scenario 8) are shown. It is observed that CO₂ emissions increase along most of the roads in the network. The results for scenario 4 (speed limits) and scenario 7 (speed limit and speed humps) follow almost the same trend, with scenario 7 additionally increasing emissions along the calmed roads (1-23% change in CO₂ g/VKT). In scenario 8 (speed limit and speed bumps), we note a substantial increase in CO₂ emission rates with respect to the base case scenario, mostly along roads on which bumps were simulated (37-96% change in CO₂ g/VKT). Clearly, lowering network-wide speed has led to a deterioration of emissions as vehicles move at lower average speeds. Again by comparing the results of scenarios 7 and 8 for calmed roads, the difference between emissions induced by bumps and humps becomes more apparent.

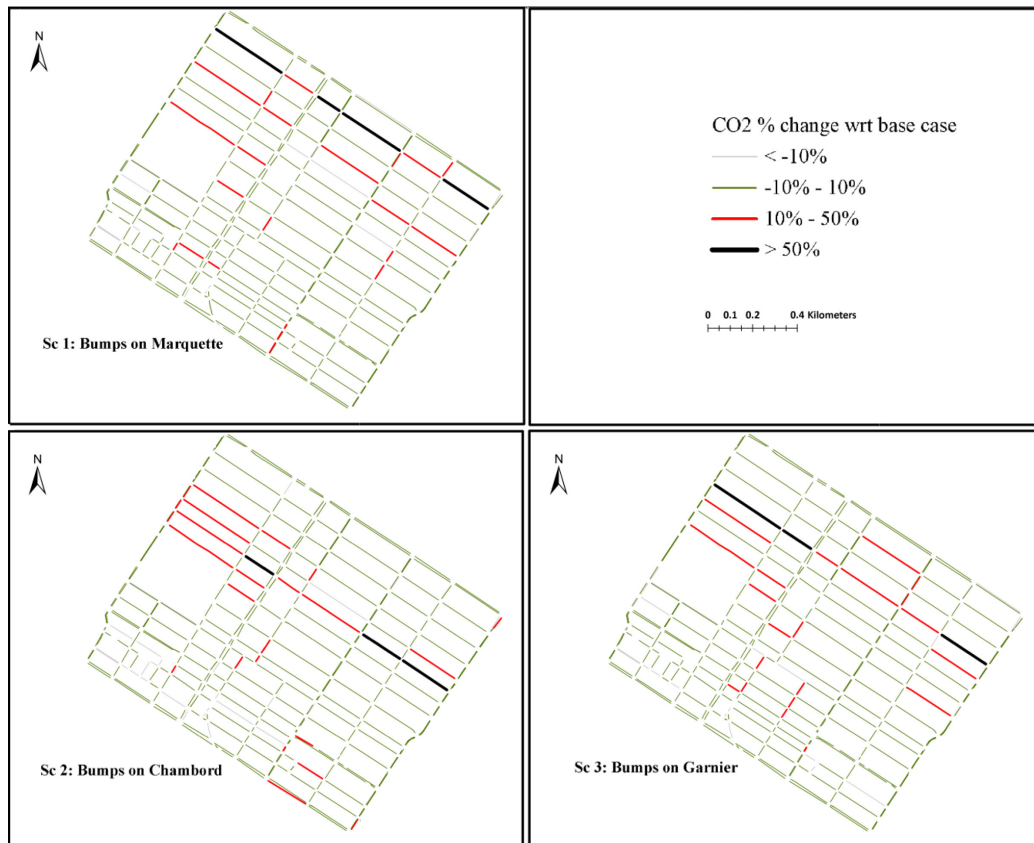


FIGURE 4. 2 Link level emissions for isolated calming measures.

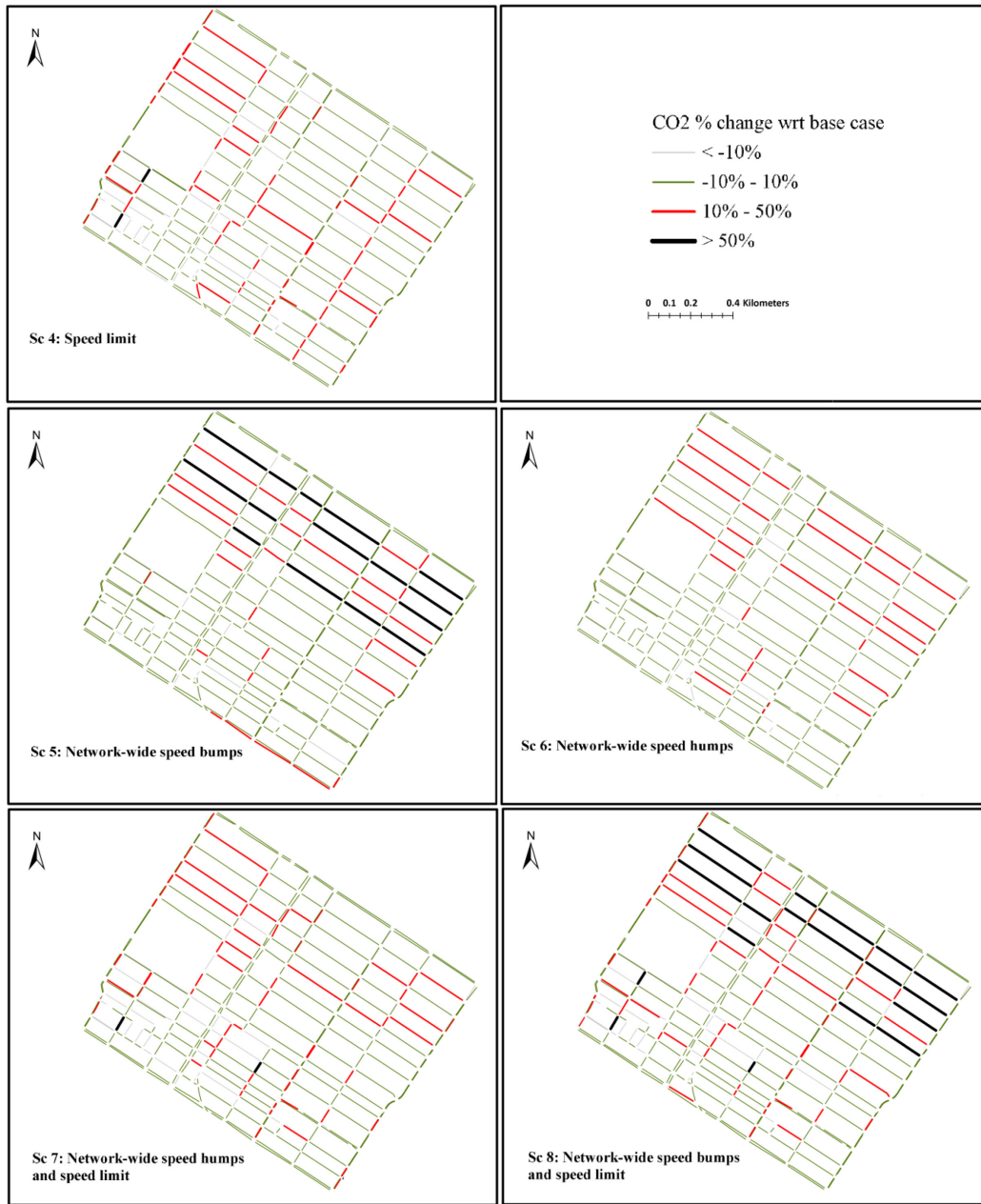


FIGURE 4. 3 Link level emissions for area-wide calming measures.

4.4 Conclusion

In this chapter, results for estimating the effects of isolated traffic calming measures at a corridor level and area-wide calming schemes on vehicle induced emissions are presented. In general, the results show that total VKT on the

network are slightly lower due to the implementation of traffic calming. In spite of this decrease, network emissions are higher. While both isolated and area-wide measures lead to modest increases in network-wide emissions (on average, 1.50% in CO₂, 0.33% in CO, and 1.45% in NO_x under isolated measure and 3.84% in CO₂, 1.22% in CO, and 2.18% in NO_x under area-wide measures) compared to the base case, link-level emissions along roads that have experienced traffic calming and proximate alternative routes increase by up to 83% in CO₂ indicating that localized air quality impacts are inevitable especially in the Plateau which is characterized by dense urban canyons. Under both isolated and area-wide calming measures, speed bumps result in higher increases in emissions than speed humps.

CHAPTER 5

RESULTS FOR THE EFFECTS OF TRAFFIC CALMING ON AIR QUALITY

5.1 Introduction

Near-road air quality results from a range of factors including traffic volumes, wind and temperature, as well as dispersion characteristics of the road (e.g. urban canyon effects). In this chapter, first the results for validation of a dispersion model using a case study are presented. Next, an evaluation of traffic calming measures on NO₂ levels along selected roadways is presented. The analysis presented in this section mostly follows the same scenarios as those used for emissions evaluation.

5.2 Case Study and Validation of Dispersion Model

The case study presented in this section is used to test the agreement between estimated and measured NO₂ concentrations. This case study is set along the Papineau corridor located within The Plateau. The NO₂ levels are estimated using a combination of traffic simulation, emission and dispersion modeling. Details of the modeling process are presented in the following sections in this chapter. The estimated NO₂ concentrations are compared with data for NO₂ levels measured using passive diffusion samplers at different locations close to the study corridor (Crouse *et al.* 2009).

5.2.1 Study Corridor and Field Data Collection

The case study is set along the Papineau corridor. Avenue Papineau is a major road experiencing high traffic volumes every day. The study corridor is a two way street bound by Avenue Mont-royal and Boulevard Saint Joseph with approximately 500 meters length and 17 meters width. Traffic volumes including volumes of passenger cars, vans, SUVs, trucks and buses on the corridor were manually counted for three days in November 2012 during the 8-9AM and 4-5PM peak and 10-11AM off-peak period. The manual counts were then used as input for the traffic simulation in VISSIM.

Concentrations of NO₂ obtained from Crouse *et al.* (2009) are used for validating the modelled NO₂ levels along the Papineau corridor. Crouse *et al.* (2009) measured NO₂ concentrations using two-sided Ogawa passive samplers (Ogawa and Co., USA) for two weeks in November/December 2005. The samplers were installed at 133 locations in Montréal. Of these 133 locations, three samplers were installed less than 150 m from our study corridor and their measured concentrations are used for our model validation.

5.2.2 Traffic Simulation

In order to analyze NO₂ levels properly considering the accelerations and instantaneous speeds of individual vehicles; a microscopic traffic model of the Papineau corridor is developed. The corridor platform is modeled in VISSIM using a combination of orthophotos, topographic maps, cartographic maps and field visits. Traffic lights and signal timings are included. Vehicles are assigned to

the network using the static routing decision which allocates vehicles on routes from a defined point to a defined destination relying on static percentages for each destination calculated from the manually counted traffic volumes. The model includes three types of vehicles: cars/vans/SUVs, heavy vehicles (HGV) (trucks) and buses. Traffic volumes are modeled for the 8-9AM and 4-5PM peak hours and 10-11AM off peak hour. Results for the validation of the traffic simulation are presented in Table 5.1. Although there are some underestimations in terms of heavy vehicles and overestimations in terms of buses, the overall simulated traffic volumes are acceptable. A correlation of 0.8 between observed and simulated total traffic volumes shows a reasonable agreement. Based on VISSIM output, the instantaneous link speeds and volumes are generated for emission and dispersion modeling.

Table 5. 1 Results for Validation of The Traffic Simulation

	Street	Cross 1	Cross 2		Car\Van\ SUV	HGV	BUS
AM	Papineau	Mont-royal	Gilford	Simulated	1,533	51	20
				Traffic counts	1,538	60	22
				Percentage difference	-0.3	-14.8	-11.3
	Papineau	St. Joseph	Gilford	Simulated	1,554	48	26
				Traffic counts	1,482	132	30
				Percentage difference	4.9	-63.8	-12.9
OP	Papineau	Mont-royal	Gilford	Simulated	1,262	91.7	12
				Traffic counts	935	79	11
				Percentage difference	35.0	16.1	9.1
	Papineau	St. Joseph	Gilford	Simulated	1,241	92	12.8
				Traffic counts	1,290	158	12
				Percentage difference	-3.8	-41.8	6.7
PM	Papineau	Mont-royal	Gilford	Simulated	1,175	54	23
				Traffic counts	1,015	51	14
				Percentage difference	15.8	5.9	64.3
	Papineau	St. Joseph	Gilford	Simulated	1,186	56	26
				Traffic counts	1,431	49	25
				Percentage difference	-17.9	14.3	4.0

5.2.3 Emission Modeling

The Motor Vehicle Emission Simulator (MOVES) is employed to model the NO_x emissions along the Papineau corridor. A more detailed model description is presented in section 3.4. The instantaneous link speeds and volumes extracted from VISSIM are input for estimation. Other required input data include link length, link grade, meteorological data, fleet composition, and fleet age distribution for Montréal, which are input to reflect local conditions. Links lengths are extracted from AutoCAD maps of the corridor. The meteorological data are collected for November 2012. The vehicle type and model year information are obtained from the Société de l'assurance automobile du Québec (SAAQ) and Statistics Canada, also for November 2012. MOVES is used to calculate NO_x emission factors for all vehicle types (cars, heavy vehicles and buses) for each segment of the study corridor. The results for emission modeling are presented in Table 5.2. The results for emission factors are consistent with the results from the earlier literature (see for example John *et al.* 1999 and Wang *et al.* 2010).

Table 5. 2 Emission Modeling Results

Vehicle type	Distance Traveled (VKT)			Total NO _x (gr)			Emission Factor (gr/VKT)		
	AM	OP	PM	AM	OP	PM	AM	OP	PM
Car/Van/SUV	633.9	517.9	485.4	234.5	191.9	176.2	0.37	0.37	0.36
HGV	20.7	30.5	22.5	374.3	556.5	387.7	18.09	18.23	17.25
Bus	8.8	5.0	9.8	63.2	34.9	65.1	7.16	6.95	6.64

5.2.4 Dispersion Modeling

The Danish Operational Street Pollution Model (OSPM) is used for modeling the concentrations of NO₂ along the Papineau corridor. The description of the model is presented in section 3.5. The vehicle volumes and speeds extracted from the VISSIM model and emission factors derived from MOVES are used as input in OSPM. It should be mentioned that for dispersion modeling heavy vehicles and buses are combined into one group of heavy vehicles. Other required data include street configuration (average height of buildings and width and orientation of the street) gathered through site visits, meteorological data (wind speed, wind direction, global radiation and temperature) collected for the month of November 2012, background concentrations of NO₂, NO_x and O₃ and the percentage of NO₂ emitted directly by vehicles. Table 5.3 and Table 5.4 present the summary of street configuration and meteorological data, respectively. FIGURE 5.1 illustrates street configuration for one segment along Papineau as it is expressed in OSPM.

Table 5. 3 Papineau Corridor Configurations

	Papineau Gilford&Mont-Royal	Papineau St.Joseph&Gilford
Length (m)	300	110
Width (m)	17	17
Direction	130°	130°
Building height (m)	11	11

Table 5. 4 Meteorological Data

		AM	OP	PM
Global Radiation (W/m2)		140	140	140
Temperature (°C)		-1	4.4	10.9
Background levels	NO _x (ppb)	10	10	8
	NO ₂ (ppb)	8	8	7
	O ₃ (ppb)	19	19	25

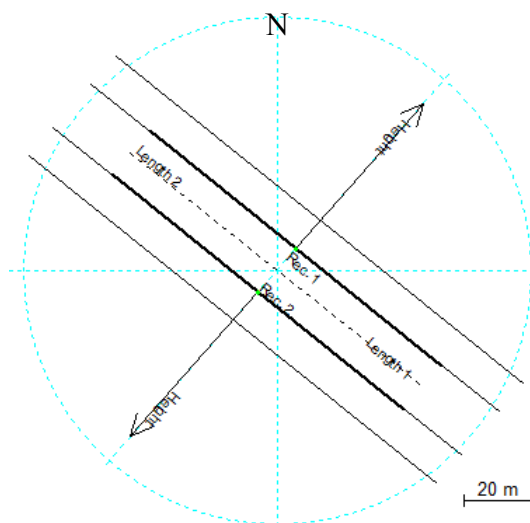


FIGURE 5. 1 Link level emissions for area-wide calming measures.

5.2.5 Comparison of the Dispersion Model Results with Data Measured Using Passive Diffusion Samplers

The results of dispersion modeling and its comparison with measured levels are presented in this section. Table 5.5 illustrates estimated NO₂ concentrations along the Papineau corridor using OSPM for three time periods. Each estimate represents the mean NO₂ over the entire month of November for the respective time period. The monthly average NO₂ level of the three time periods is 16.8 parts per billion (ppb). The results show that the average concentration is highest during

the morning rush hour. TABLE 5.5 also illustrates the maximum and minimum simulated levels during the month of November. We observe maxima reaching 40 ppb occurring in the afternoon rush hour.

Table 5. 5 Estimated NO₂ Concentrations (in ppb) along the Papineau Corridor (without background concentrations)

	AM	PM	OP
Mean	17.8	15.3	17.3
Median	17.5	14.2	16.7
Standard Deviation	5.6	6.7	6.3
Minimum	9.5	7.6	8.6
Maximum	35.7	40.1	35.8

The average NO₂ level based on three samplers installed on three different roads located in proximity to the Papineau corridor is 14.6 ppb while the estimated average concentration (for the three periods) with OSPM is 16.8 ppb. It should be noted that the samplers were installed along residential roads with lower traffic volumes compared to the Papineau corridor and therefore a slightly lower concentration is expected compared to the dispersion model output. In addition, the NO₂ data we have is for the year 2005 while our model (traffic counts and meteorology) is for 2012. Thus it is not unreasonable to expect increased traffic volumes along such a major corridor over time and as a result, higher near-road air pollutant levels. Looking at the monthly average NO₂ levels for November/December 2005 to 2011 obtained from a permanent monitoring station in Montréal close to study area shows a low variation over time with standard

deviation of 1.65 (Table 5.6). Note however that this station is not located near-road and therefore levels are expected to be higher closer to the roadway.

Table 5. 6 Monthly Average NO₂ Levels for November/December 2005 to 2011 for a Permanent Monitoring Station in Montréal

Year	Avg. NO ₂ (ppb)
2005	24.38
2006	21.91
2007	23.4
2008	21.4
2009	21.13
2010	21.44
2011	19.26
Standard Deviation	1.65

5.3 Analysis of Near-Road Air Quality under Traffic Calming

This section presents the results of evaluation of traffic calming measures on NO₂ levels along the roadways. The analysis presented in this section follows the same scenarios as those used for emissions evaluation except for the scenario with the imposed speed limit (scenario 4). Also, scenarios 1, 2 and 3 with Scenario 1 entailing the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Marquette, Scenario 2 entailing the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Chambord and Scenario 3 entailing the implementation of 17 speed bumps (necessitating a speed reduction to 5 km/h) along Rue Garnier are presented under one scenario entitled speed bumps on the roads. Concentrations of NO₂ are estimated for different combinations of wind speeds and directions representing the month of

October 2012 conditions for each segment of the study corridors in the sub-area highlighted in FIGURE 3.2 (Chambord, Marquette, Garnier).

5.3.1 Base-Case Conditions

Three corridors are selected for air quality analysis; these include Chambord, Garnier, and Marquette. The three selected corridors are residential roads with a speed limit of 50 km/h in the base-case for which the effects of wind speed and wind direction on NO₂ levels are investigated and concentrations are modelled along both sides of each road segment.

FIGURE 5.2 illustrates the average, maximum, and minimum NO₂ concentrations and total NO_x emissions for the base-case. The average NO₂ levels range between 11.4 and 13.0 ppb. The maximum NO₂ concentrations, exceeding 26.2 ppb, are recorded on a segment along the Chambord corridor. This segment is characterized by the highest traffic volumes which illustrates the association between traffic flow and near-road air quality. In the base-case, the correlation between average NO₂ levels and average traffic volumes is 0.9.

In addition, FIGURE 5.2 illustrates that while the averages on all segments are close in magnitude and closer to the minimum than the maximum, the maxima have a much higher variability. The minima do not fall below 11 ppb indicating the effect of traffic under the most dispersive wind conditions due to the meteorological conditions of the month of October with relatively strong winds that favor mixing. In fact, the simulated minimum NO₂ levels occur much more

often than the maximum levels and as a result push the average closer to the minimum. Moreover, we observe a very high variability in NO_x emissions which vary between less than 5 grams to more than 35 grams per segment while average NO_2 levels are less disperse. The correlation for total NO_x emissions and average NO_2 levels is 0.7. This illustrates the importance of different variables affecting dispersion such as segment orientation with respect to wind, height of buildings and width of roadway.

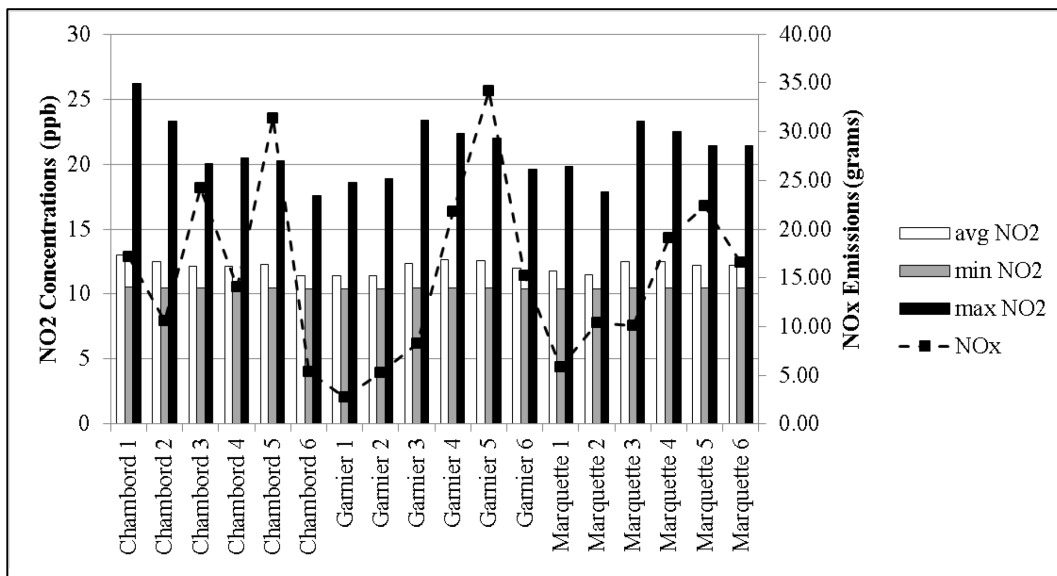


FIGURE 5. 2 Average, maximum and minimum NO_2 concentrations (ppb) and NO_x emissions (grams) for the base case along the study corridors.

In order to investigate the effects of wind speed and wind direction on NO_2 levels, for various wind speeds and directions, concentrations were modelled along both sides of each road segment. FIGURE 5.3 illustrates the effects of wind speed on the NO_2 concentrations along a road segment pertaining to the Chambord corridor (the busiest corridor in terms of traffic flow). In this figure, we clearly observe a negative association between wind speed and NO_2 levels: as the wind speed

increases, the NO₂ concentrations decrease. The largest effect of increasing wind speed is seen when transitioning between a speed of 6 km/h to a speed of 9 km/h. Beyond 20 km/h, the decrease in NO₂ levels is maintained but becomes less drastic.

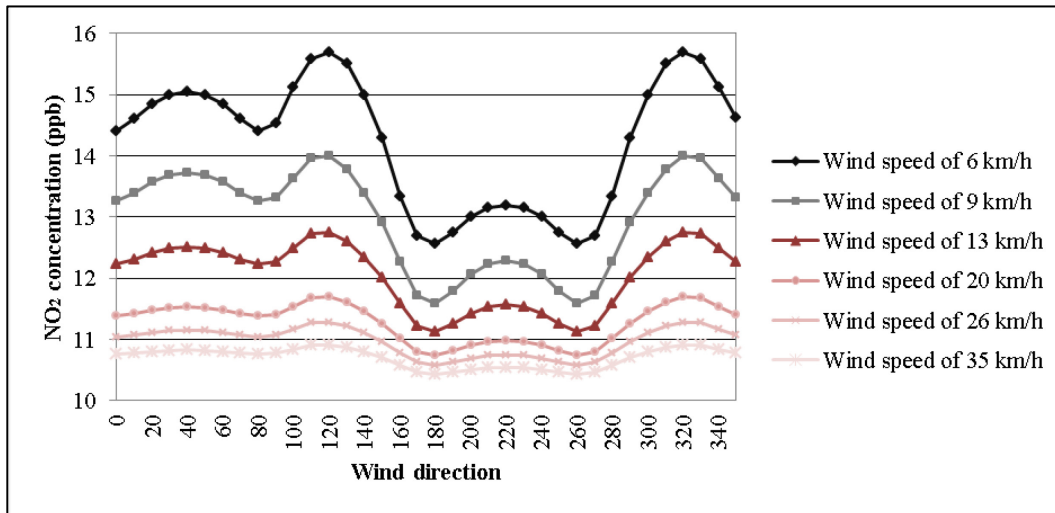


FIGURE 5.3 The effects of wind speed on NO₂ concentrations for a road segment of Chambord corridor (wind direction is expressed as degrees from the true North).

FIGURE 5.4 shows the NO₂ concentrations for both sides of one road segment along the Chambord corridor for the base case with the wind speed of 20 km/h. In FIGURE 5.4, receptors 1 and 2 are placed on both sides of the roadway. The segment orientation is 130 degrees from the true North and receptor 1 is located on the East side of the segment while receptor 2 is located on the West side. In this case, when the wind blows between 0 and 130 degrees and between 310 and 350 degrees from the true North, receptor 1 will be located on the leeward side of the road. We observe the windward side of the road experiences lower levels of NO₂ due to the urban canyon effect. This trend is observed for all other road segments. Berkowitz *et al.* (1996) and Wang and Xie (2009) also have the same

findings that the leeward concentrations are higher than the windward levels. When the wind is aligned with the roadway, both sides experience similar levels.

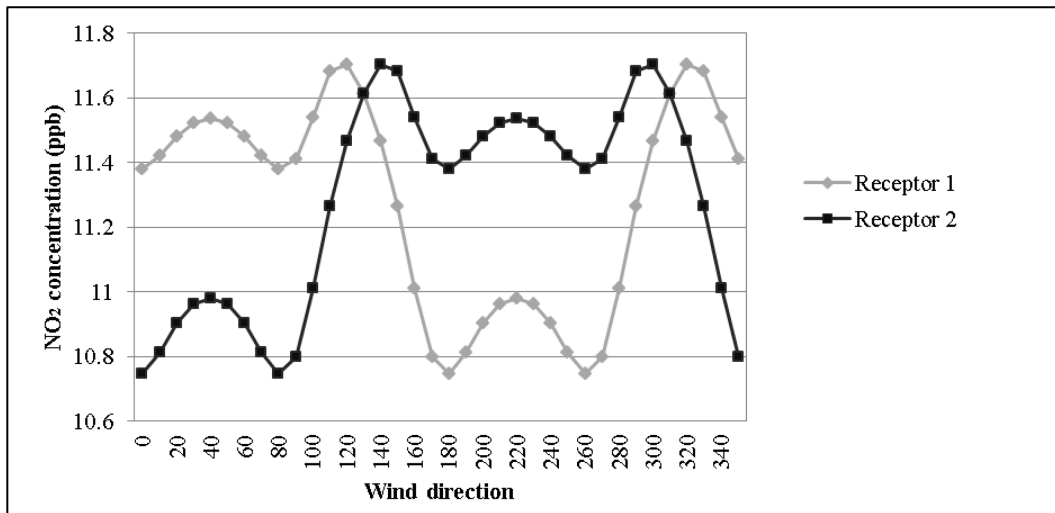


FIGURE 5. 4 The NO₂ concentrations for both sides of road segment of Chambord corridor for the base case (wind direction is expressed as degrees from the true North).

5.3.2 Scenario Analysis

TABLE 5.7 summarizes the percentage change in NO₂ levels and NO_x emissions compared to the base-case along selected corridors within the Plateau. In addition, paired-samples t-tests are performed on the resulting NO₂ concentrations under each scenario for every segment with respect to the base-case. The results of show that the differences between the NO₂ levels under each scenario and the base-case are significant for most of the segments at 95% confidence level, except for a few segments under scenario 6 and 7 which experience insignificant changes.

As shown in TABLE 5.7, traffic calming scenarios which include speed bumps (both isolated and area-wide) lead to higher air pollutant concentrations than speed humps. Moreover, the maximum percentage change in the NO₂ levels with

respect to the base-case is observed under scenario 8 which entails speed bumps on the four corridors and an area-wide speed limit of 30 km/h (reduced from 50 km/h). Increases of up to 9.9% compared to the base-case scenario are observed. While NO₂ levels increased significantly along most segments for all scenarios, under scenario 6 and scenario 7 where area-wide speed humps are simulated some segments experience a decrease in NO₂ levels by less than 2% with respect to the base-case. These decreases are associated with decreases or insignificant changes in NO_x emissions on those segments. We observe that all traffic calming measures cause a slight decrease in traffic volumes on the corridors which underwent the changes. In the case of speed bumps, the effect on drive-cycles is significant enough that it offsets any decrease in traffic volumes leading to an increase in NO_x emissions and NO₂ concentrations. In contrast, speed humps do not aggressively alter vehicle drive-cycles and therefore may lead to a reduction in emissions on the corridors experiencing the change while emissions are displaced onto alternative paths.

The results of emission and dispersion modeling illustrate that NO_x emissions and NO₂ levels follow the same trend under each scenario; when emissions increase, the concentrations also increase and vice versa. The high positive correlation of 0.8 between percentage changes in total NO_x emissions and average NO₂ concentrations is an indication of these similar trends. However, we do observe that the percent changes in emissions are much higher than the percent changes in concentrations with respect to the base-case. FIGURE 5.5 presents such trends in more details for four segments along the Chambord corridor confirming the

importance of conducting dispersion modelling rather than inferring potential air quality effects from changes in emissions solely.

Table 5. 7 Percentage Change in NO_x Emissions and NO₂ Concentrations under Each Scenario for Every Study Corridor

	Sc 1, 2, 3: Speed bumps on roads		Sc 5 : Network-wide speed bumps		Sc 6 : Network-wide speed humps		Sc 7 : Network-wide speed humps & speed limit		Sc 8 : Network-wide speed bumps & speed limit	
	%NO ₂ Conc.	%NO _x emission	% NO ₂ Conc.	% NO _x emission	% NO ₂ Conc.	% NO _x emission	% NO ₂ Conc.	% NO _x emission	% NO ₂ Conc.	% NO _x emission
Chambord 1	7.6	44.3	7.5	43.0	1.8	7.7	1.8	5.3	7.6	42.5
Chambord 2	6.6	46.1	7.3	55.0	1.7	9.2	0.1*	-5.0	7.1	51.7
Chambord 3	7.0	50.3	7.3	54.0	2.9	23.0	0.4*	-2.7	5.5	35.3
Chambord 4	8.7	75.9	8.0	68.0	2.4	24.0	0.7	5.8	8.0	68.3
Chambord 5	3.7	19.4	4.2	22.9	0.6	1.2	-1.9	-23.7	3.1	13.2
Chambord 6	7.3	135.8	7.9	161.2	2.3	47.0	1.1	17.5	7.0	132.4
Garnier 1	5.1	104.6	5.4	110.4	2.2	47.5	-0.1	-3.6	3.5	60.4
Garnier 2	5.2	112.1	5.3	116.5	2.7	58.8	1.5	27.9	4.6	95.8
Garnier 3	3.3	23.2	3.0	18.6	-1.1	-12.7	-2.0	-22.5	2.6	13.5
Garnier 4	5.6	29.3	6.3	35.8	1.3	6.1	-1.7	-16.8	4.6	20.4
Garnier 5	4.1	20.5	4.3	21.5	1.5	7.5	-1.8	-16.9	4.1	15.3
Garnier 6	9.7	92.4	9.3	82.8	3.0	27.9	1.3	5.6	9.1	81.1
Marquette 1	5.6	66.4	6.5	78.9	2.1	22.6	-0.8	-16.3	4.7	50.8
Marquette 2	7.0	104.9	6.6	98.2	3.4	58.8	1.1	11.9	5.2	72.2
Marquette 3	6.6	48.3	6.9	51.9	0.2*	-2.9	-0.2	-6.9	6.9	53.6
Marquette 4	6.5	41.8	6.8	45.6	2.7	19.0	-1.7	-15.7	5.1	28.4
Marquette 5	7.3	55.2	7.6	58.9	3.7	29.3	-0.9	-7.3	9.9	62.5
Marquette 6	9.3	81.8	8.8	77.6	3.3	30.1	0.8*	1.3	8.0	65.0

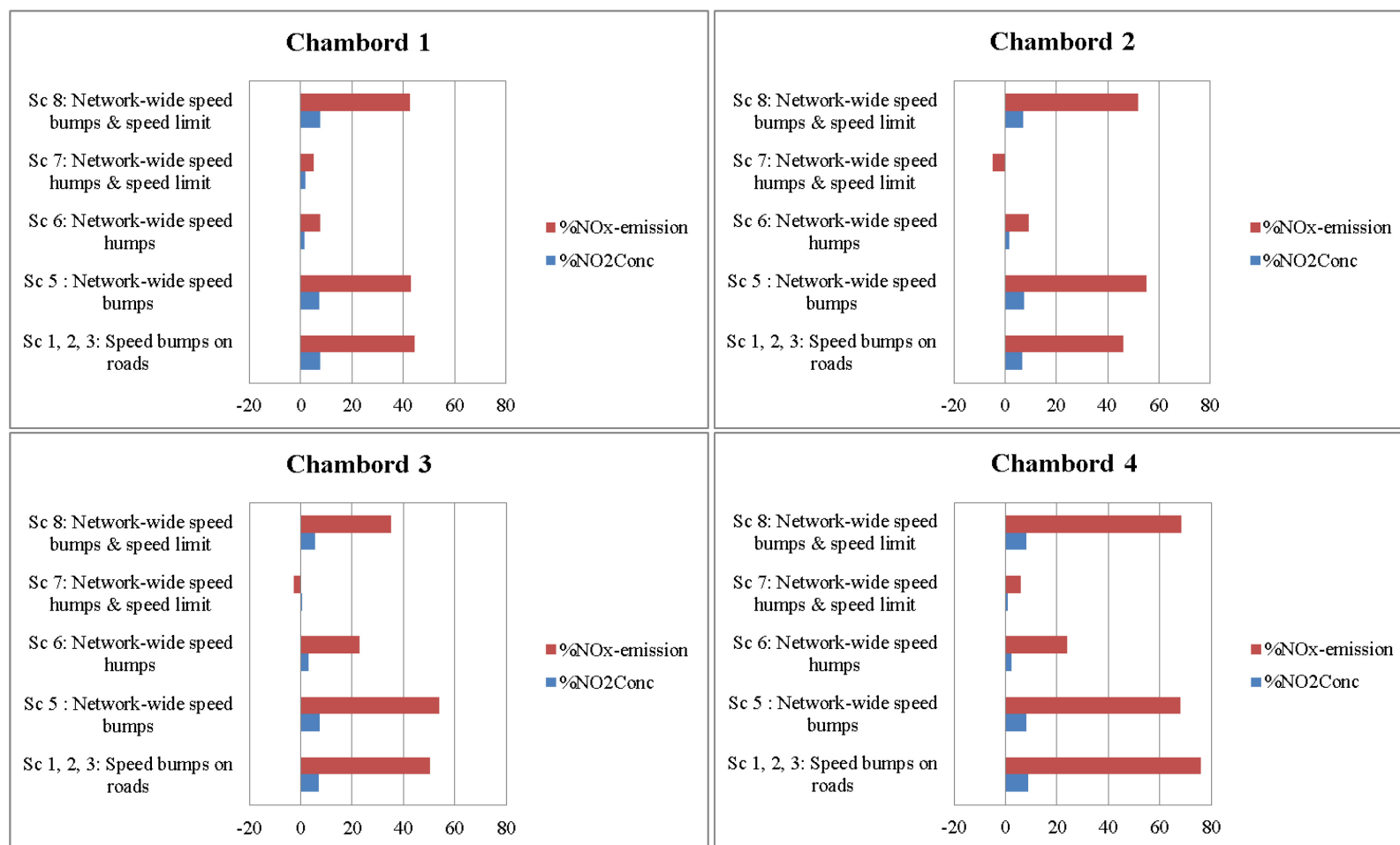


FIGURE 5. 5 Percentage changes in NO_x emissions and NO₂ concentrations for four segments of Chambord.

FIGURE 5.6 illustrates the daily NO_2 concentrations along one segment of the Chambord corridor under the base-case, scenario 5 (network-wide speed bumps) and scenario 6 (network-wide speed humps). We observe that changes in NO_2 levels compared to the base-case vary daily based on the meteorological conditions. On certain days, we observe large changes in NO_2 levels probably due to meteorological conditions which are unfavorable to atmospheric mixing while on days with stronger winds, we observe smaller changes in NO_2 compared to the base-case. Note that while meteorological conditions over 31 different days in October are considered for modeling NO_2 concentrations, the same NO_x emissions are used since they were not observed to change considerably with meteorological conditions. Although temperature and relative humidity affect NO_x emissions, their effects are only significant when comparing summer vs. winter conditions. Finally, we observe that speed bumps introduce higher increases in daily NO_2 levels than speed humps.

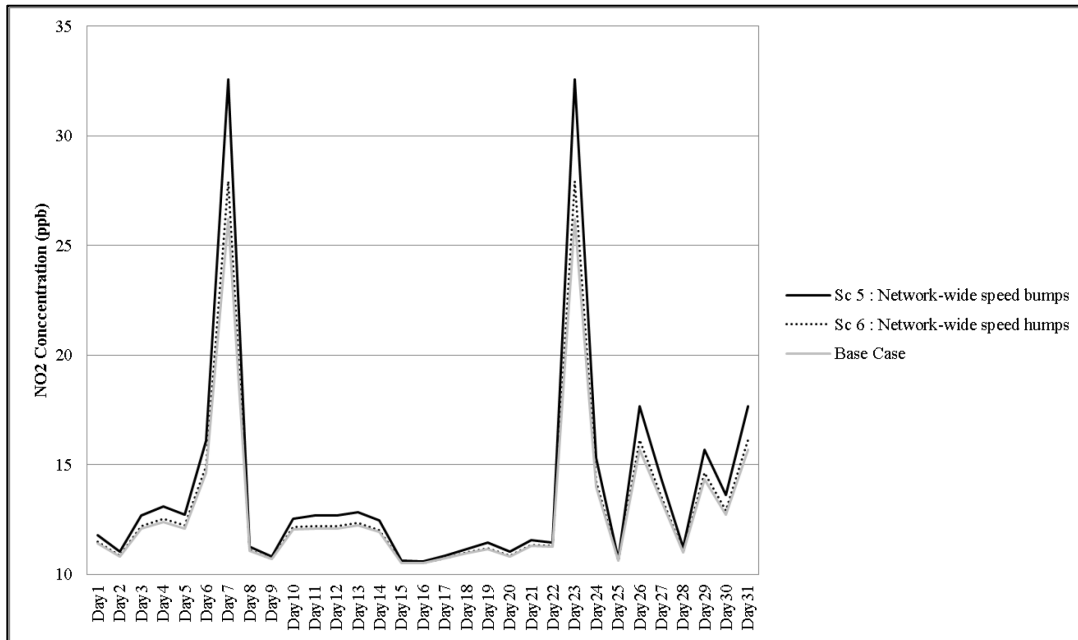


FIGURE 5. 6 Daily NO₂ concentrations along one road segment of Chambord corridor for base-case, scenario 5 and scenario 6.

5.4 Conclusion

In this chapter, results of the effects of traffic calming measures on air quality are presented. We observe that traffic calming measures do not have as large an effect on NO₂ concentrations as the effect observed on NO_x emissions. Based on daily meteorological conditions, road geometry and its orientation with respect to wind direction, changes in emissions can result in highly disproportional changes in pollutant levels. This demonstrates the importance of conducting dispersion modelling rather than inferring potential air quality effects based on changes in emissions. We observe that average NO₂ levels increase between 0.1% and 10% with respect to the base-case while changes in NO_x emissions vary between 5% and 160%. Also, the effects of wind speed and direction are investigated in this study. The results show that higher wind speeds decrease NO₂ concentrations on

both sides of the roadway. As the wind becomes more orthogonal to the roadway, the difference in NO₂ levels between the leeward and windward sides increases. Among the traffic calming measures, speed bumps produce the highest increases in NO₂ levels.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Traffic calming refers to a combination of physical changes in road design and speed management aiming at improving road safety especially for users of non-motorized transportation sharing the road with drivers. Traffic calming strategies are based on either one of two approaches: 1) black-spot approach or 2) area-wide approach. In the black-spot approach, isolated measures are planned and designed to be implemented on a particular segment of a road network, while area-wide approach measures are planned systematically and installed on the entire network.

Various traffic calming measures with the means of improving road safety have been implemented all over the world for decades. While the safety impact of traffic calming has been studied in depth, relatively few studies have been conducted to capture the environmental impact of traffic calming. Most of the literature presented many advantages such as the use of real drive-cycles, traffic volumes, and air pollution measurements to quantify the effects of traffic calming on air quality. However, they lack the capability of evaluating the effects of instantaneous speed changes and traffic volumes simultaneously and in isolation.

In this thesis, the effects of isolated traffic calming measures at a corridor level and area-wide calming schemes are estimated with respect to traffic volumes, vehicle speeds, and emissions using a combination of microscopic traffic

simulation, emission and dispersion modeling. The study area is set in Montréal, Canada, where a traffic simulation model for a dense urban neighborhood is extended with capabilities for microscopic emission estimation and dispersion modeling both at a link-level and at a network-level. Within this neighborhood, this research mostly focuses on a small sub-area that is facing increasing traffic volumes and speeds along several residential streets. Instantaneous link speeds and traffic volumes are extracted from the traffic simulation and are input into the emissions simulator. Hourly CO₂, CO, and NO_x emissions for the 352 links of the study area are quantified under a range of traffic calming scenarios. These include simulating speed bumps and speed humps at a corridor level and network-wide level, simulating speed limits, and simulating combinations of speed limits, speed bumps and speed humps. Later, the estimated NO_x emission factors as well as extracted traffic volumes and vehicle speeds are input within a dispersion model to quantify concentrations of NO₂ along several residential corridors under almost the same traffic calming scenarios employed for emission modeling.

The results provide important insights into the effects of traffic calming on vehicle-induced air pollutant emissions and air quality. In general, it is observed that total VKT on the network are lower due to the implementation of traffic calming. In spite of this decrease, network emissions are higher. While both isolated and area-wide measures lead to modest increases in network-wide emissions (on average, 1.50% in CO₂, 0.33% in CO, and 1.45% in NO_x under isolated measures and 3.84% in CO₂, 1.22% in CO, and 2.18% in NO_x under area-wide measures), link-level emissions along roads that have experienced traffic

calming and proximate alternative routes increase by up to 83% for CO₂ and 160% for NO_x indicating that localized impacts are inevitable especially in the Plateau which is characterized by dense urban canyons. Under both isolated and area-wide calming measures, speed bumps result in higher increases in emissions than speed humps.

The results for air quality modeling suggest that traffic calming measures do not have as large an effect on concentrations of NO₂ as the effect observed on NO_x emissions. Based on daily meteorological conditions, road geometry and its orientation with respect to wind direction, changes in emissions can result in disproportional changes in pollutant levels. This demonstrates the importance of conducting dispersion modelling rather than inferring potential air quality effects based on changes in emissions. We observe that average NO₂ levels increase between 0.1% and 10% with respect to the base-case while changes in NO_x emissions vary between 5% and 160%. Also, the effects of wind speed and direction are investigated in this study. The results show that higher wind speeds decrease NO₂ concentrations on both sides of the roadway. As the wind becomes more orthogonal to the roadway, the difference in NO₂ levels between the leeward and windward sides increases. Among the traffic calming measures, speed bumps produce the highest increases in NO₂ levels.

6.2 Limitations

This research is associated with a number of new findings pertaining to the effects of traffic calming on emissions and air quality under a range of scenarios.

Nonetheless, it is associated with limitations mostly related to data availability and computational burden. In particular, the lack of real drive-cycle information is a limiting factor especially in order to validate the traffic simulation in terms of replicating real drive-cycles in the study area. In addition, since our traffic simulation is limited in terms of simulating traffic calming measures, studying other calming measures such as curb extensions, road closures, and raised intersections was not feasible. In fact, bumps and humps were not modelled as such but expressed in the traffic simulation as “zones with lower speed limits”. Moreover, another limitation of this research is that even with today’s impressive computing power, the time it took to run the models is a substantial burden, making multiple scenarios and iterative runs prohibitively burdensome. On average, VISSIM takes approximately 9 hours to converge and 1 hour to generate instantaneous link speeds and traffic volumes under each scenario, and MOVES took approximately 8 hours to generate emission results. There are also limitations with respect to fleet composition and emissions; the assumption that every car represents the distribution of the fleet takes away some of the details in the emission modeling. Finally, this thesis also has some limitations regarding data including: more repetitions and longer sampling periods for traffic counts is ideal, air quality data does not exactly correspond with the simulation period, weather data is extracted from Montréal-Trudeau station, which does not express local temperature and wind conditions.

6.3 Recommendations for Future Research

This research is carried out to develop a microscopic traffic, emission and dispersion modeling system which aims to capture the effects of traffic calming schemes on emissions and air quality. Traffic calming has recently become at the spotlight throughout Canada. In fact, there is an ongoing study in National Collaborating Centre for Healthy Public Policy (NCCHPP) regarding the effects of traffic calming on road safety, air quality and noise levels. There were several implementations of different traffic calming measures throughout Montréal, especially within The Plateau neighborhood. Therefore, a “before and after study” should also be carried out in the future, where the models can be validated with actual data. Assessment of a range of dispersion models such as Gaussian, or computational fluid dynamics is also recommended in order to investigate the effect of modelling methodology on the resulting air pollution levels.

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