SUSTAINABILITY OF MAJOR URBAN TRAVEL CORRIDORS IN A MULTI-NUCLEATED URBAN REGION: ROLE OF BUS RAPID TRANSIT, HIGHWAY TOLLS AND PARKING CHARGES

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ABSTRACT

This paper illustrates the effectiveness of demand management policies in a major travel corridor of a multi-nucleated urban region with an imbalance of housing and employment in satellite communities. By using the example of Ottawa (Canada), the structure of this type of urban form is characterized in terms of mobility problems and opportunities. Demand management policies are investigated for a multimodal travel corridor that features high quality freeway, parallel arterials, and a bus rapid transit (BRT) system. A modelling framework and the constituent models for the estimation of travel demand, fuel consumption and emissions including greenhouse gases are used to test the role of parking charges in the main city centre, bus rapid transit, bus fare and highway tolls in improving system level in-vehicle travel time, and reducing fuel consumption and emissions. Results of sensitivity analysis and effective scenarios are illustrated. Conclusions highlight the findings and suggest policy implications.

Keywords: Multi-nucleated urban region, sustainable transportation, travel corridor, bus rapid transit, parking charges, tolls, travel time, emissions, greenhouse gas emissions, fuel consumption, environment

1. INTRODUCTION

The transportation sector is the largest consumer of petroleum in Canada and accounts for 26 percent of Canada's total Greenhouse Gas (GHG) emissions. About 70% of these emissions come from road vehicles and roughly two-thirds of GHG emissions are generated within urban areas. In Canada, over 90% of passenger movements are made by automobile and an estimated 65 percent of automobile-kilometres in Ontario are accounted for by the urban sector (Transport Canada 2008, Environment Canada 2005). Clearly, automobile travel in urban areas consumes a high percentage of petroleum and is a major contributor to air pollution in urbanized regions as well as to the global warming problem.

Urban traffic growth is an on-going phenomenon. If increasing automobile travel demand cannot be managed, traffic congestion occurs. Also, trip lengths may increase as well. These are responsible for the inefficient use of energy, greenhouse gas emissions, air pollution, and other adverse socio-economic impacts in urban regions. Although progress has been made to enhance the fuel efficiency of road vehicles through mandated or voluntary standards and technology measures have played a major role, further action is necessary to reduce fuel consumption and emissions.

Specifically, in urban transportation, additional efforts are required to define and implement demand management measures to discourage the high use of the automobile and address the associated imbalance of travel demand and available road capacity. Urban transportation policy experts and planners are keen on the identification of means to reduce traffic congestion, conserve energy and reduce emissions.

Among other means available, there is a renewed interest in the joint planning of land use and transportation demand management strategies. Also, these are subjects of considerable debate due to information gaps on how to serve the transportation needs of various urban forms (e.g., a multi-nucleated urban form) in a sustainable manner. Owing to limited research, the available literature on the role of a balance of population and employment in outlying communities and combined effectiveness of key demand management measures in enhancing the sustainability of travel is very scarce. This paper is intended to contribute information on these subjects.

2. MULTI-NUCLEATED URBAN REGION AND TRAVEL CORRIDORS

2.1 Structure and Characteristics

Although the multi-nucleated urban form appears to be gaining favour around the world, it has not yet received the research attention that it deserves. Region-wide plans based on multi-nucleated concept have been viewed favourably due to the following reasons: lack of space within the central city boundaries or inability to assemble required land areas to accommodate growth, the need for affordable housing, and the attractive quality of life offered by satellite communities. However due to jurisdictional constraints or lack of planning foresight, the absence of job opportunities in the suburban bedroom communities of numerous urban regions has resulted in journey to work outside the community for almost all residents (Tayyaran and Khan, 1996a,b).

A satellite community with little employment opportunities, commonly called “a bedroom community”, involves extensive commuting to the central business district of the main city and other distant employment sites. If land use plans enable jobs to be located in satellite communities, or are increased incrementally, a reorientation of trip making would occur, reducing vehicle-kms of travel. This effect is based on the premise that, a high percentage of people would live closer to their jobs, if available locally, in order to minimize transportation expenses and commute times. Also, it is expected that if mixed land uses at relatively high densities in satellite communities are allowed by zoning by-laws, these would induce the use of nonmotorized transportation (NMT) for local travel and enable mass transit development for local and regional trips.

For improving traffic flow, energy efficiency, and reducing emissions, transportation and land use should be planned jointly. In theory, favourable urban forms can be used to achieve road traffic flow improvement, enhanced modal split for public transit and reduction of vehicle-kms (Young 1990). Past research studies have investigated the effect of urban land use designs on automobile-related air pollution. However, their results have been largely controversial due to lack of clear descriptors of land use forms. Smart growth guidelines can potentially play a role in achieving energy, GHG emission and air quality objectives in a multinucleated urban region (Smart Growth Network 2009). However, their application in the appropriate package form in the various parts of an urban region requires research attention.

2.2 Policy and Planning Challenges

If satellite communities are planned to feature joint housing and employment sites and are supported by public transportation for local as well as regional level travel, these are likely to become attractive growth nodes within the urban region. Although the balance of jobs and housing in satellite cities is a policy objective, due to in-filling of vacant or re-developable land at higher densities in the main city, the level of balance may not be as high in satellite communities as in the central city.

Even under such circumstances, the satellite communities offer travel, energy and environmental advantages as opposed to the sprawl concept. Over time, such communities can generate threshold level public transit travel demand for services to the central business district of the urban region for economic viability. Rapid transit service, whether bus-based or rail-based type, supported by local feeder buses, can be provided along corridors or “structural axes” that connect satellite communities with other parts of the urban area (Haines 1986, Birk and Zegras 1993).

Past research by Tayyaran and Khan (1996a,b) investigated the structure of multi-nucleated urban regions, characterized by a balance of employment and housing in satellite communities within an urban region. The energy conservation and air quality advantages of the multi-nucleated concept of urban development were investigated. Specifically, it was of interest to know, from a behavioural perspective, whether it is possible to reduce energy consumption and emissions by increasing job opportunities in subregions.

The research approach reflected the concept that some home-based work trips made by residents of a satellite community can be attracted to local job sites within the satellite community, provided that employment opportunities are made available as a part of land use planning. If home-based work trips produced by residents of a satellite community can be attracted to employment sites within that community as a result of an enhanced balance of housing and employment, and also if commuting to other satellite communities is also of limited scope, the overall region-wide vehicle-kms, energy, and emissions can be decreased.

As compared to the base condition with no employment opportunities in satellite communities, an enhanced job to household ratio will result in less travel in the congested travel corridors and on central city roads. This would lead to favourable level of service, energy consumption and emission effects.

For this reason, policy analysts and planners have recognized the multi-nucleated urban structure as an attractive concept from transportation and environmental perspectives, especially when compared to unstructured sprawl form of growth. For example, according to the Swedish Association of Local Authorities, in Sweden, with policy and planning support, each nucleus was developed with a high degree of self-sufficiency. Another challenge was that such satellite centres should serve as nodes in the public transportation system (Swedish Association of Local Authorities 1990).

Likewise, in Japan, a country that has innovated in sustainable development policy, many examples of multipolar urban regions can be found. The satellite communities are planned as subregional growth poles encompassing employment sites and all the amenities of a modern city. As a result of the efforts of policy experts and planners, a rapid transit link with the central business district of the major city became the standard practice (Khan 1993).

A number of policy challenges can be defined for ensuring the success of a multi-nucleated urban structure, including travel in multimodal corridors that link the satellite communities with the main city. These include: striving for a balance of jobs and housing, mixed land uses supported by sustainable modes for local travel, a rapid transit link to the central city, and defining demand management measures that can potentially lead to sustainability of travel in the multimodal corridors of the multi-nucleated urban region.

The research study reported in this paper attempts to answer the following questions.

(1) Is there a role for tolls on the freeway?
(2) How to quantify the role of a rapid transit service (if available) that links a satellite community with the central city and how to enhance its use?
(3) How to discourage the use of the automobile for travel in the multimodal corridors?
(4) Given the complexity of the travel forecasting modelling framework which does not permit reliance on elasticities obtainable from a single model, how to establish the relative roles of policy variables that are intended to enhance level of service, save fuel and reduce emissions?

2.3 The Multi-Nucleated Structure of Ottawa (Canada) and Travel Corridors

The City of Ottawa, covering an area of approximately 2,760 square kilometres, is a part of Canada's National Capital Area. Although the City of Gatinueau/Hull is in the Province of Quebec, its transportation system is closely linked with that of Ottawa (Figure 1). The Official Plan of the City of Ottawa incorporates three major urban centres outside the green belt as locations for allocating a part of city's future development (City of Ottawa 2009).

Three major travel corridors, namely the eastern corridor, the western corridor and the south-western corridor connect these outlying centres with the Ottawa-Gatineau/Hull central business districts. These corridors feature high volume commuter routes, good express bus transit services and the highest level of traffic congestion in the region experienced during peak periods. In addition to the bus rapid transit, the eastern and western corridors are served with freeways that can be converted to toll routes.

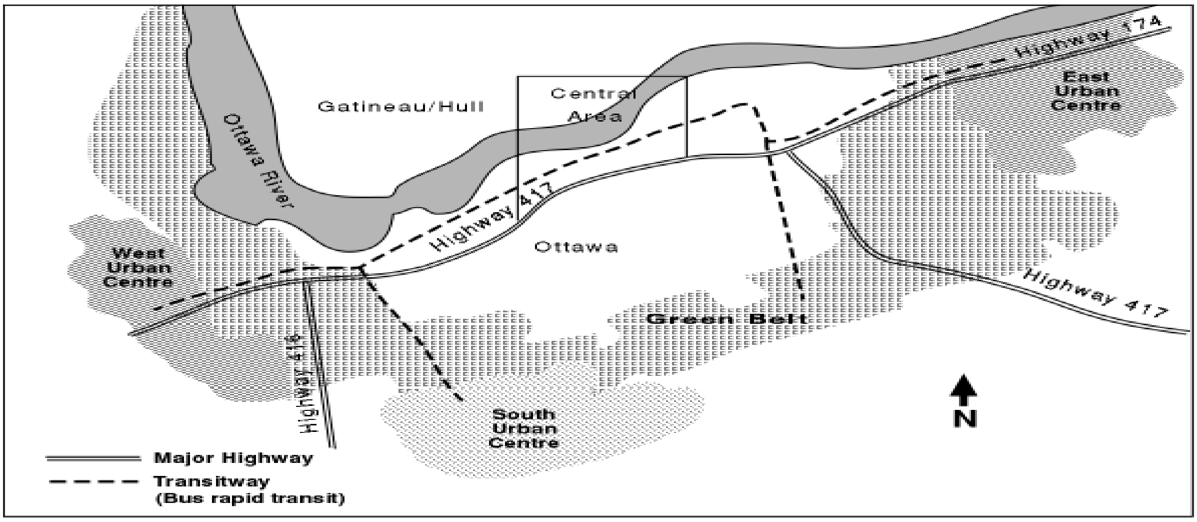

Figure 1. Multi-nucleated urban area and travel corridors (Ottawa, Canada)

The population distribution of Ottawa shown in Table 1 suggests that an increasing proportion of the population will locate outside the greenbelt. In 2011, 45.5% of population will locate outside the greenbelt and in 2021, about 50% of the residents will live in satellite centres and rural communities (City of Ottawa 2009).

Table 2 presents the ratio of employment/household, which is an indicator of employment to housing balance (Ottawa 2009). Although for the first tier satellite centres, this balance will improve over time, it will be about one half the ratio for the city inside the greenbelt. This implies that a substantial proportion of the residents of the urban communities outside the greenbelt will commute to the central city for work purposes.

3. CASE STUDY OF A MULTI-MODAL TRAVEL CORRIDOR

In this research, the corridor linking the Ottawa central area with the eastern urban centre was selected as a case study (Figure 1). The travel demand, infrastructure and other factors correspond to year 2011. The forecasts of land use, population, employment, car ownership, and travel-related information used in the modelling framework were obtained from the City of Ottawa.

Table 1. Population distribution, Ottawa (Canada)

	1991	2001	2011	2021
	In thousands	In thousands	In thousands	In thousands
Inside the greenbelt	492 (70.2%)	517(64.6%)	562(55.5%)	588(49.3%)
First tier statellite communities outside greenbelt	139(19.8%)	203(25.4%)	353(34.9%	489(41.0%)
Second tier satellite and rural communities	70(10.0%)	80(10.0%)	97(9.6%	115(9.7%)
Total	701(100.0%)	800(100.0%)	1,012(100.0%)	1,192(100.0%)

Source: City of Ottawa (2009)

Table 2. Employment/Households ratio in parts of Ottawa (Canada)

	1991	2001	2011	2021
Inside the greenbelt	1.71	1.81	1.86	1.82
Satellite cities outside greenbelt	0.63	0.89	1.27	1.15
Rural communities	0.62	0.67	0.76	0.71

Source: City of Ottawa (2009)

The travel corridor will be served by high quality freeways (i.e., Highway 417, Highway 174), arterial roads (e.g., Montreal Road, St. Joseph Blvd.) and the bus rapid transit infrastructure (i.e., the Transitway). Highway 417 (Queensway) and Highway 174 will connect the eastern community centre and the Ottawa central area with 3 lanes for each direction of travel. Highway 174 is expected to be upgraded in all aspects to freeway standard by year 2011. The arterial roads will serve mixed traffic, including automobiles and buses.

The Transitway (called a busway in the general literature) is an exclusive roadway or lanes on a roadway intended for the exclusive use of buses. The rapid transit infrastructure is developed, based on collection/distribution, transfer at stations, and a dedicated line haul facility on a separate right of way. In the case of Ottawa, the line haul facility is a separate specially designed road or a freeway right-of-way but separated from other lanes of the freeway. For rapid movement of high occupancy buses, the Transitway in Ottawa excludes other (smaller) high occupancy vehicles (HOVs) such as van pools.

Bus rapid transit (BRT) in Ottawa, owing to the Transitway and the flexible service potential of the bus technology, offers many ways of providing the door-to-door public transportation. A major attraction of this system is the direct express service which provides the collection/distribution as well as the rapid line haul components without the need to change buses.

The Transitway rapid service between stations can be used by a variety of users. These include passengers who use feeder bus service, can walk to the station, and users of kiss-and-ride or park-and-ride or bike-and-ride access modes. A third type of service is the general urban area-wide transit service that uses the Transitway for a part of the overall route. The use of the Transitway enhances its average overall speed and at the same time, the frequency of service between some stations on the Transitway is enhanced (Khan, Taylor, and Armstrong 2004).

From a user perspective, the level of service of a public transit system can be characterized by overall average speed, service frequency, ease of access/egress, one-seat ride, short walk to station, ride quality, schedule adherence, and personal costs. Of all the factors noted here, for peak period riders, the travel time, reliability and reduced need to transfer from one vehicle to another are of special importance.

Attitude surveys and actual experience in Ottawa suggest a strong preference for the reduction of transfers and waiting times. Surveys show that the “trip in pieces” has reduced the transit ridership potential in many urban areas. In Ottawa, some of the attractive features of the transit services are the express bus network offering, in addition to favourable time, cost, and frequency attributes, and the high degree of “one-seat” ride.

In analyzing bus rapid transit capacity and service, its distinct characteristics must be taken into account (Siddique and Khan 2006). The hourly capacity of a single rapid transit lane is determined by the number of vehicles that can pass a given point during one hour. On the basis of the number of passengers carried in each vehicle, capacity can be expressed in terms of passengers/hour. At the stations, stopping lanes are extended in both directions to provide for loading/unloading and deceleration/acceleration functions. Buses which are not required to stop at a particular station can therefore proceed through the station area relatively unimpeded.

The demand management case study was intended to determine the role of parking charges in the central area, bus rapid transit, bus fare, and tolls on freeway in reducing in-vehicle travel time as well as fuel consumption and emissions per passenger-km during the p.m. peak period in the multimodal travel corridor. Available literature did not offer guidelines about the relative effect of these demand management measures in enhancing the sustainability of travel. Therefore, it was decided to find out the relative effectiveness of these measures in support of transportation policy decisions.

4. MODELLING FRAMEWORK

4.1 Modelling the Multimodal Network

A modelling framework and the constituent models were developed for the estimation of travel demand, service quality as measured by travel time, fuel consumption, air quality pollutants, and GHG emissions. It should be noted that fuel consumption of bus and auto traffic was estimated under hot stabilized conditions and it was assumed that the engine is properly tuned.

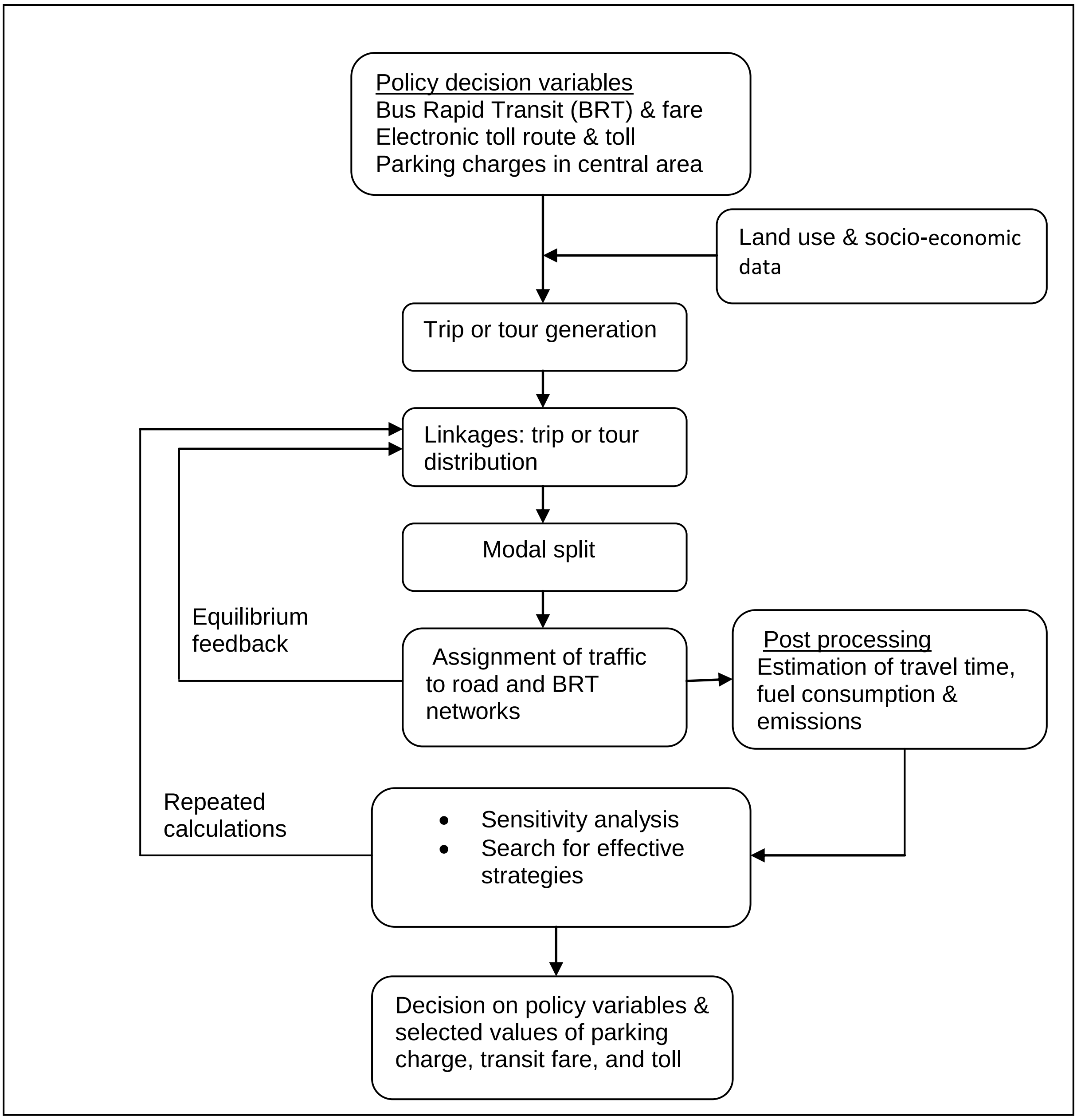

Figure 2. Methodological framework

The travel demand models were developed for the estimation of the number of trips between origins and destinations by applicable modes on available routes. From these, the energy and emission effects were found.

Travel demand was predicted for the afternoon peak period of 2.5 hours duration. The EMME/2 software was used as a framework for this research (INRO 1999). See Figure 2. Although the modelling framework is designed to study the effects of land use on travel, the loop back to activate potential land use changes owing to transportation performance cannot be investigated due to the absence of a land use model and it was not the intent to include one in the first place. The housing and employment location decisions are not likely to be influenced in a major way by transportation system performance. Other variables such as availability and price of land in satellite communities can easily dominate the transportation performance variable.

Although the state of knowledge has been improving in the tour-based approach to modelling travel generation and inter-zonal linkages, it was decided to work with trips instead of tours for the following reasons. The first reason was lack of data at the time that this research was in progress. Second, the tour modal split models were not as advanced as tour generation and distribution models. This observation is valid today. Third, there was no research-based evidence that tour-based modelling methods produce better forecasts than the trip-based approach (Hatzopoulou and Miller 2007, City of Ottawa 2008).

Two types of trips were defined for the p.m. peak period. These are: home-based work trips and non-work trips that consisted of home-based as well as non-home-based trips. During the p.m. peak period, most trips that leave the central area are home-based work trips. Trip generation (production and attraction) models were developed. In spite of efforts to find a basis to estimate changes in trip generation due to transportation system performance (e.g., the potential effect of accessibility index on trip generation), no statistical correlation was uncovered. Therefore, according to the trip generation models, changes to the network are assumed to have no effect on trip productions and attractions. This appears to be a common observation in the transportation modelling field.

Doubly constrained gravity models were calibrated for trip distribution for the two types of trips and the impedance functions of the gravity model were estimated by using EMME/2 software through an iterative process. The impedance functions used were of exponential type and the impedance was travel time. The impedance function formulation enabled the incorporation of automobile as well as public transit travel time for the mixed use part of the network.

For work trips, a logit modal split formulation was employed that includes car (auto driver), car pool (auto passenger), and bus (transit passenger). The modal split model is disaggregate type, based on individual level data. For non-work trips, diversion curves based on relative performance of auto and transit were used to predict modal split during the afternoon peak period.

The final step of the travel demand model is the assignment of traffic to the multimodal network. The volume-delay functions for network in the EMME/2 framework were obtained from the municipal government sources. The EMME/2 software enabled the equilibrium assignment based on the capacity restraint technique. The use of volume-delay functions made it possible to achieve route split equilibrium state where the traveller is not able to minimize travel time by choosing other routes. An exogenous method was used to estimate the volume of vehicles other than automobiles and transit buses (e.g., commercial trucks). Further, a peak hour factor of 0.5 was used to convert peak-period trips to peak hour trips.

The traffic assignment capabilities of the EMME/2 were employed to assign automobile and public transit vehicles to the multimodal network. For mixed traffic operations, the transit vehicles were taken into account in the calculation of the link capacity. In this approach, the transit vehicles were defined in terms of auto equivalent units for the estimation of the available link capacity.

Since EMME/2 was selected as a modelling framework in this research, it was necessary to develop travel time functions for buses in the transit network. In Emme/2, travel time of transit lines were specified by travel time functions. These functions define the travel time on each segment of the line, and are integrated into the transit assignment procedure of the EMME/2.

For the transit bus, a multi-path transit assignment technique was used to allocate transit person trip origin-destination matrices to the transit network. The multipath transit assignment enables the minimization of total travel time which is a weighted sum of in-vehicle travel time, boarding/alighting time, access/egress time and waiting time. A peak hour factor of 0.45 was used to convert from peak-period transit person trips to peak-hour transit person trips.

In order to assess the calibration of the entire travel demand forecasting model, a check was made on the simulated link-level results of the models against the observed field data. That is, auto link volumes obtained through the assignment were compared with the observed traffic volumes. The correlation analysis showed an R^2 of 0.93, which indicates a highly acceptable degree of agreement between the EMME/2 results obtained by using the volumes sourced from the models and the observed traffic counts.

4.2 Modelling the Transitway

The Transitway (i.e., the busway) is an essential part of the multimodal corridor case study. In order to investigate the performance of the Transitway under various levels of travel demand, it became necessary to develop a Transitway macroscopic simulation model (TRANSIM). This model can be used to study changes to various components of travel time, speed, energy, and emissions on the Transitway for various demand levels. The model was calibrated for the Ottawa Transitway by using realistic input data (Zargari and Khan 1998).

The simulation model can represent all phases of vehicular operation with a reasonable degree of accuracy. For analyzing traffic stream flow, the model can estimate the values of three key variables (i.e., flow rate, speed and density) at every point on the Transitway at all times during the analysis period. The model is designed to include the stochastic characteristics of bus operation on the facility.

The outputs of the model include: average travel time (including times for loading and unloading of passengers), average speed, average dwell time, total boarding and alighting passengers, vehicle-kms, average passengers/bus, total passenger movement, fuel consumption and emission estimates including CO, HC, NO_x and CO_2. The length of the Transitway between stations, capacity of station, size of buses and volume (veh/h) on Transitway have an important effect on maximum passenger movement.

4.3 Fuel Consumption of Buses Operating on the Transitway

Due to the absence of a fuel consumption model that could be used for the Transitway and its buses, it was decided to modify the heavy vehicle fuel consumption model ARFCOM (i.e., the Australian Road Research Board Fuel Consumption Model) (Australian Road Research Board 1988, Zargari and Khan 2003). The usefulness of the Transitway simulation model was enhanced by incorporating the bus energy consumption model. This model estimates bus fuel consumption in terms of litres/km for each of the four modes of driving on the Transitway, namely acceleration, cruise, deceleration and idle.

The fuel consumption results of this model were checked against the Ottawa-Carleton Transportation Commission (OC Transpo) average bus fuel consumption data for various types of buses. A comparison of the average fuel consumption of articulated and standard buses as found from OC Transpo data and estimates obtained from the model showed favourable results (Zargari and Khan 2003).

For application purpose, a macro was prepared in the EMME/2 format, based on the bus fuel consumption model, and was used to estimate bus fuel consumption on the Transitway. Bus fuel consumption for access to and egress from the Transitway was estimated by using another macro developed by INRO Consultants for use in EMME/2, based on average speed and total vehicle-kms.

4.4 Fuel Consumption of Automobile and Bus in Mixed Traffic

For the estimation of automobile fuel consumption, INRO Consultants developed an EMME/2 macro for macroscopic analysis. This macro was not prepared for public use, but its use was authorized in this study. The macro estimates fuel consumed by automobile travel in the network that consists of a variety of link types. The estimation is based on traffic variables which are generated by the modelling framework and also automobile characteristics (i.e., weight, engine size). The macro calculates fuel consumption based on average speed in the network for given distance. The average speed is based on travel time and distance matrices that reflect link characteristics such as geometrics and traffic volume.

The macro enabled us to change values of parameters to reflect conditions of the case study. The macro began with an equilibrium assignment incorporating associated volumes and speeds. For each link, the average speed was computed based on travel time and distance matrices which were generated by the EMME/2. Then, fuel consumption rate was calculated, based on average speed and automobile characteristics. Finally, the fuel consumption was obtained by using fuel consumption rate and total vehicle kilometres.

Fuel consumption for light duty vehicles in the study year 2011 took into account technology improvements and over-the-road fuel efficiency rates. Due to technology improvements, the fuel consumption rate of buses in the future was projected to be 90% of the mid 1990s rate. The average bus that will be operating in 2011 was assumed to be manufactured after 2000.

4.5 Estimation of Emissions

The Transitway simulation model can estimate emissions including HC, CO and NOx, based on MOBILE5c. The CO_2 emission is estimated by using fuel consumption and the emission factor. For vehicles in mixed use traffic, INRO Consultants developed an EMME/2 macro for the analysis of pollutant emissions. This macro was not prepared for public release, but its use was authorized in this research. For the estimation of emission rates, required parameters such as weather (the season) and the vehicle fleet (i.e., age distribution, average weight and engine size) were used.

The development of the emission macro required the following steps: (a) estimation of the emission rates by the use of MOBILE5c, (b) development of emission rate curves, and (c) calculation of traffic assignment and the resulting emissions. The emission macro was used on a link basis.

From fuel consumption estimates, the GHG emissions were calculated. The GHG emissions of interest are: carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O). The magnitudes of these emissions per litre of fuel vary by type of fuel, engine and emission control technologies. In order to find the CO_2 equivalent of these gases, equivalency factors were used which reflect their relative long term greenhouse effect. The equivalency factors are 1 for CO_2, 21 for CH_4, and 310 for N_2O.

4.6 Application of Models

The methodology developed in this research was used in a sensitivity analysis manner in order to identify the relative importance of policy variables in improving in-vehicle travel time (per passenger km), save fuel (litres/passenger-km) and reduce emissions (gms/passenger-km). The rationale for the use of in-vehicle travel time (sec/passenger-km) rather than door-to-door travel time is its response to policy changes and also it captures better the effect of bus rapid transit. A direct search method reported by Zargari and Khan (2003) enabled the identification of effective scenarios.

The EMME/2-based traffic assignment method enabled the inclusion of road tolls. For this purpose, impedance functions were developed that incorporate the effect of the road tolls. Thus the route choice was based on the sum of travel times and freeway tolls that were converted into equivalent time by using value of time found from a travel survey in the area. The value of time can change the unit of the cost variable into the travel time unit. As expected, the value of time for work trips was higher than for non-work travel. These estimated values of time were based on average wage rate. On the basis of trip purpose data for the p.m. peak period in the case study, a weighted value of time was estimated.

For finding equilibrium level flows in the network, the values of policy variables and the calculated responses of system performance were fed into the travel demand models (i.e., trip distribution, modal split and route split). The new estimates of system performance were fed again into the model, thus allowing more interaction between demand and performance. The feedback process continued until approximate equilibrium between supply and demand was achieved.

The Transitway simulation model (TRNSIM) was used to simulate operations under various traffic conditions (i.e., volume of buses). The station locations were specified to create realism in simulations. On the basis of inputs and outputs, transit volume-delay functions were developed, Buses/h was regarded as an appropriate variable for the estimation of travel time under various traffic conditions by using regression analysis (i.e., log linear form). The regression analysis gave an R^2 of about 0.95, high t and F values for all of the functions. Therefore, these functions were regarded to be appropriate for estimation of travel time on the Transitway in the transit assignment.

Fuel consumption and emissions were calculated by using the macros described in Sections 4.3 to 4.5. That is, fuel consumption and emissions for bus operation on the Transitway were estimated by using the macro included in the TRANSIM model and Section 4.3 provides details. In the case of light duty vehicles and buses operating in mixed traffic, Section 4.4 covers the fuel consumption macro. Section 4.5 provides a description of the methodology that was used to estimate emissions.

5. TRAVEL DEMAND MANAGEMENT SCENARIOS

As a part of demand management strategies, tolls were assumed for the freeway, implemented through electronic toll collection technology. Given the policy of charging a fee for the use of the freeway, an assumption was made in this case study that ramps were not metered. The arterials were assumed to be controlled by the City of Ottawa central traffic control system. It was understood that the arterials serve the access and egress function for the freeway in addition to their line haul function in the corridor. That is, a traveller could avoid the payment of highway toll and use the arterial roads from origin to destination.

For the case study, three modes (bus, car and carpool) were specified. It was assumed that in accordance with the policy of the City of Ottawa, the Transitway is used only for buses.

Due to its access control nature, the Transitway enables the achievement of bus speeds that are much higher than achievable in mixed traffic environment. The Transitway-based rapid transit service is much more attractive to the passenger than buses operating in mixed traffic.

Forecasts of land use and socio-economic conditions (i.e., population, employment and car ownership) were obtained from the City of Ottawa for 2011. During the p.m. peak period, most trips from the central business district are home-based work trips. According to literature, work trips in urbanized areas show some sensitivity to travel cost and travel time. Increasing charges for the use of the automobile during peak travel periods can manage demand by shifting some travellers to other modes.

Travel cost for the automobile users includes parking charge in the central area, toll on the freeway (if applicable) and vehicle operating cost. For a bus user, fare is the only cost, unless the access to the Transitway station involved the use of the automobile. Travel cost elements that can be influenced by demand management strategies are used in this case study as the policy variables. As noted earlier, these are parking charges in the central business district of Ottawa, tolls and bus fare.

Reasonable ranges of values for the policy variables were determined (i.e., parking charge, fare, and toll). Thus, based on available knowledge, a range of $2.60--$9.50 (in 2008 dollars) was assumed for parking charge/day in the central business district (CBD), $1.50-$3.85 (in 2008 dollars) for public transit fare/trip, and the toll was varied from 0 to $0.43/km (in 2008 dollars).

The parking charges might appear rather low, but it should be noted that these are averages in 2008$ and cover the entire central district. While parking charges are high in the core of the district, this is not the case everywhere in the central district. Given the sustainability objective, it is not logical to increase bus fares. But, in this case study, the intent was to find relative effects of changes to the policy variables. Freeway toll is another policy variable. The range of 0-43 cent/km (in 2008$) is regarded to be reasonable as a link-based toll.

The methodology applied here relies mainly on sensitivity analysis. This paper is reporting details of the sensitivity analysis in order to show the role of policy variables in managing travel demand and making travel in the corridor sustainable. The base case (i.e., the starting point of the analyses) was developed by using minimum values of policy variables. A previous paper published by the authors presents the use of a direct search method for the identification of the values of the policy variables that lead to the most favourable travel, fuel consumption and emissions (Zargari and Khan 2003).

6. RESULTS AND DISCUSSION

As noted above, the base case was defined to represent minimum values of policy variables. In order to study changes in travel and impact factors in response to variations in these variables, the base case scenario of the case study was used as the starting point.

6.1 Effect of Parking Charges

Next, the effect of changes in parking charges was studied while keeping the values of other policy variables constant. While both fare/trip and toll/km on the freeway were constant, average parking charge was changed from $2.60 to $9.50 (in 2008$) by step lengths of $0.85. Figures 3 to 5 show results of this sensitivity test. It can be observed that while other variables are held constant at the base level, increasing parking charges leads to increase of bus modal share, and reduction of fuel consumption and emissions per km. Also, the results show that in-vehicle travel time/pass-km decreases with increasing average parking charge/day.

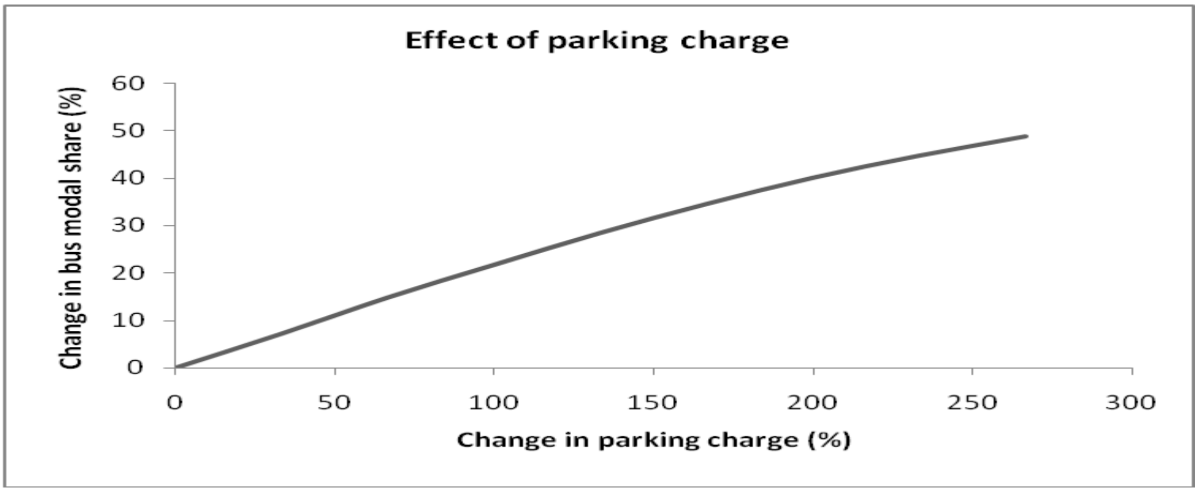

Figure 3. Change in bus modal share due to change in parking charge

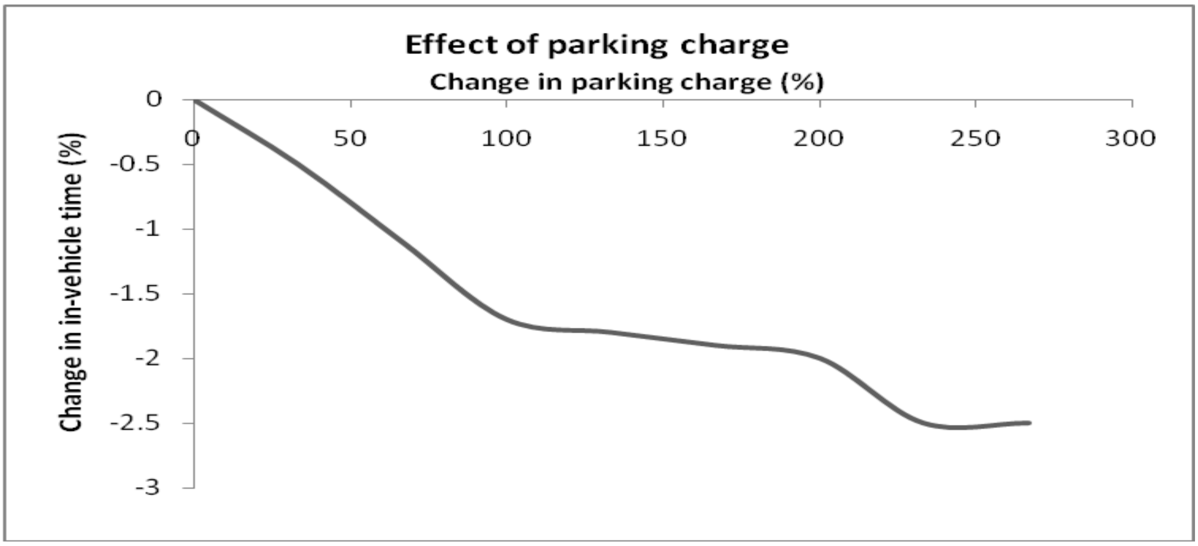

Figure 4. Change in in-vehicle time due to change in parking charge

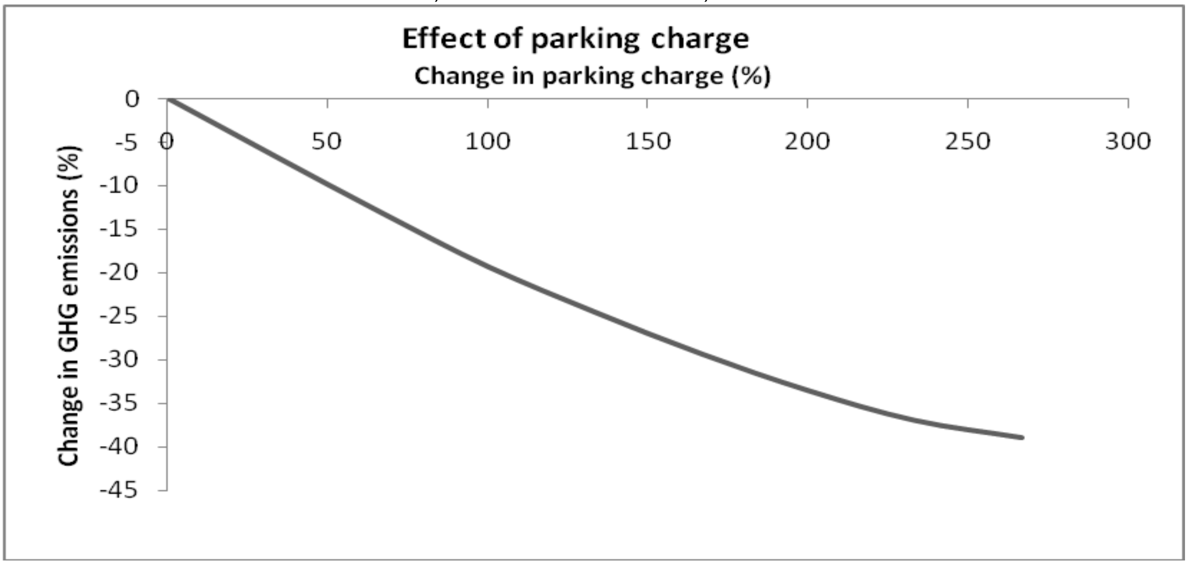

Figure 5. Change in GHG emissions due to change in parking charge

While fare/trip of transit bus and toll/km on the freeway are constant, travellers can be discouraged to use their automobiles in the central area owing to increased parking cost. Thus, the use of transit bus can be encouraged (Figure 3). Due to this change, there will be less auto trips on the freeway as well as on the arterials. Therefore fuel consumption and emissions will decrease in the corridor.

6.2 Effect of Public Transit Fare

Next, changes were made to fare/trip while both average parking charge/day and toll/km on freeway were held constant. The average fare per trip was changed from \$1.30 to \$3.85 (in 2008\$) by step length of \$0.45. The results are shown in Figures 6 to 8.

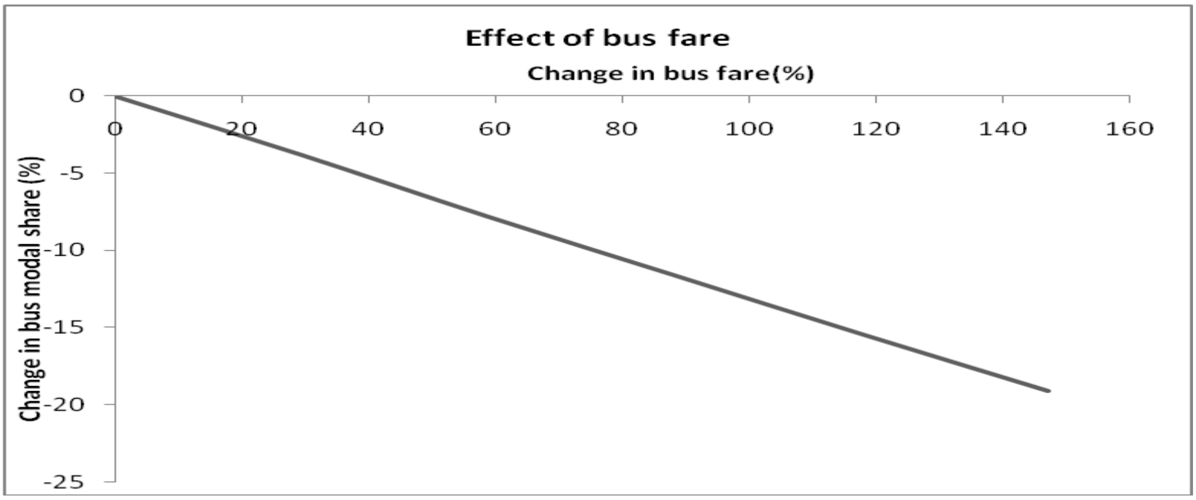

Figure 6. Change in bus modal share due to change in bus fare

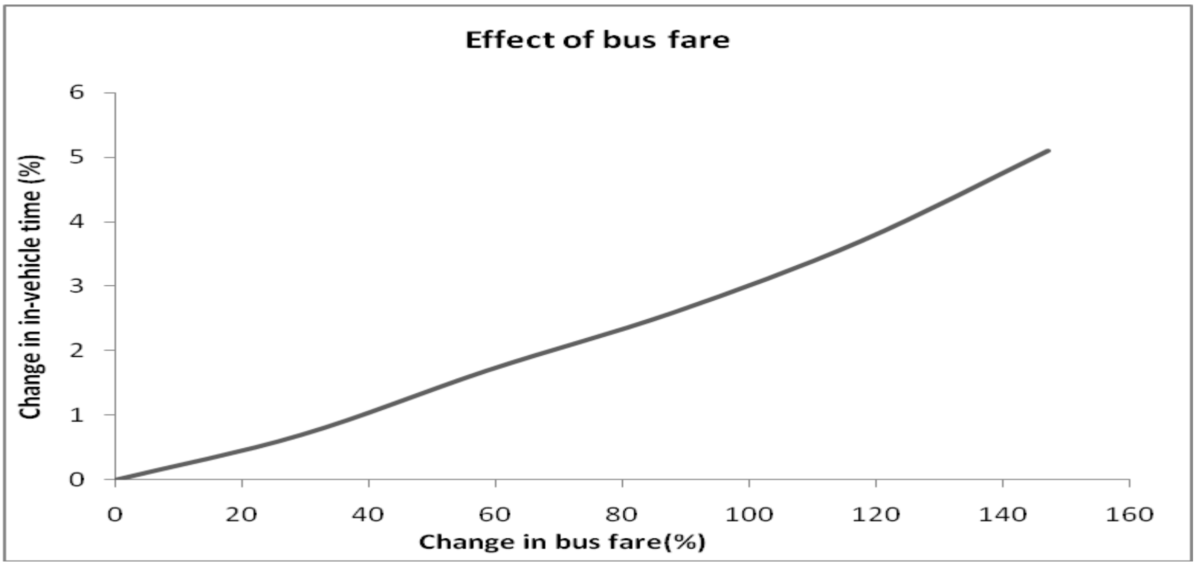

Figure 7. Change in in-vehicle time due to change in bus fare

As expected, as average fare/trip increases in the corridor, while other variables are held constant at the base scenario level, in-vehicle travel time/pass-km, fuel consumption/pass-km and emissions/pass-km will increase. The reason is that while parking charge/day in the central area and toll/km on freeway are held constant, increasing average fare/trip encourages people to use automobiles and the bus modal share will drop (Figure 6). Due to this change, there is more congestion on the freeway as well as on the arterials.

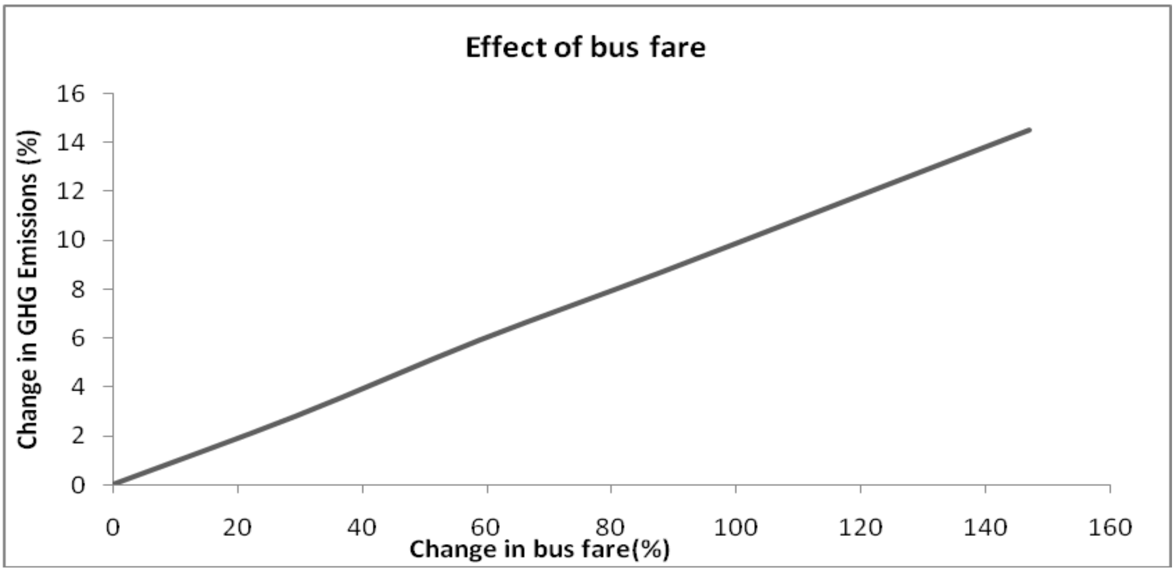

Figure 8. Change in GHG due to change in bus fare

6.3 Effect of Freeway Tolls

Figures 9 to 11 show sensitivity test results for freeway tolls. While both fare/trip and parking charge/day were held constant (at the base level), toll was changed from 0 to 43 cents/km (in 2008$) by using a step length of 5 cents/km. Between 0 and 43 cents/km, if toll/km on the freeway increases, while other variables are held constant at the base level, bus modal split will increase and fuel consumption/pass-km and emissions/pass-km will decrease (Figures 9 and 11).

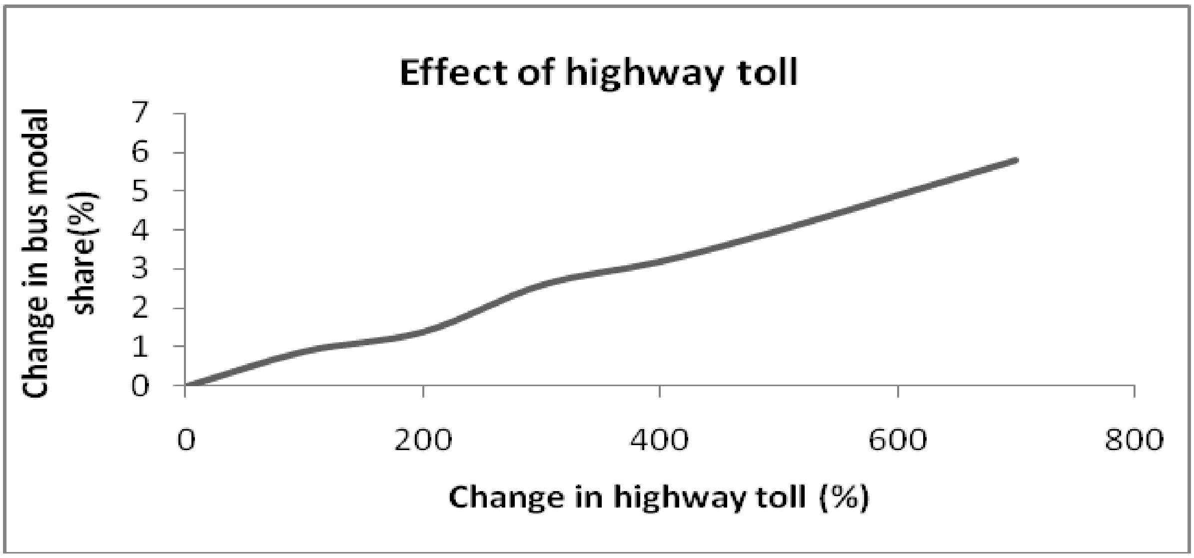

Figure 9. Change in bus modal share due to change in highway toll

Also, as toll increases between 0 and 17 cents/km, in-vehicle travel time/pass-km will decrease. If the toll charge continues to increase beyond 17 cents/km, in-vehicle travel time will increase, provided that parking charges and bus fare are held at the base level (i.e., $2.60/day parking charge and $1.50/trip bus fare). The reason is the increasing automobile traffic on arterials, leading to high levels of delay. While fare/trip for transit bus and parking charge/day are held constant, through freeway tolls, auto users can be discouraged to use the congested freeway. In addition to route shifts resulting in the use of parallel arterials, travellers shift to public transit. It should be noted that if parking charges are increased to $6.90/trip and bus fare remains constant, in-vehicle travel time will begin to rise gently beyond the toll rate of 8.50 cents/km.

Increased use of public transit results in decreases in fuel consumption (ml/pass-km) and emissions (gm/pass-km). Beyond the optimal values of toll/km, it becomes counter-productive to raise tolls that lead to highly congested arterials. As expected, route shifts are likely to materialize before transit is chosen for commuting (Mekky 1995). For this reason, this variable has a relatively lower effect than other policy variables.

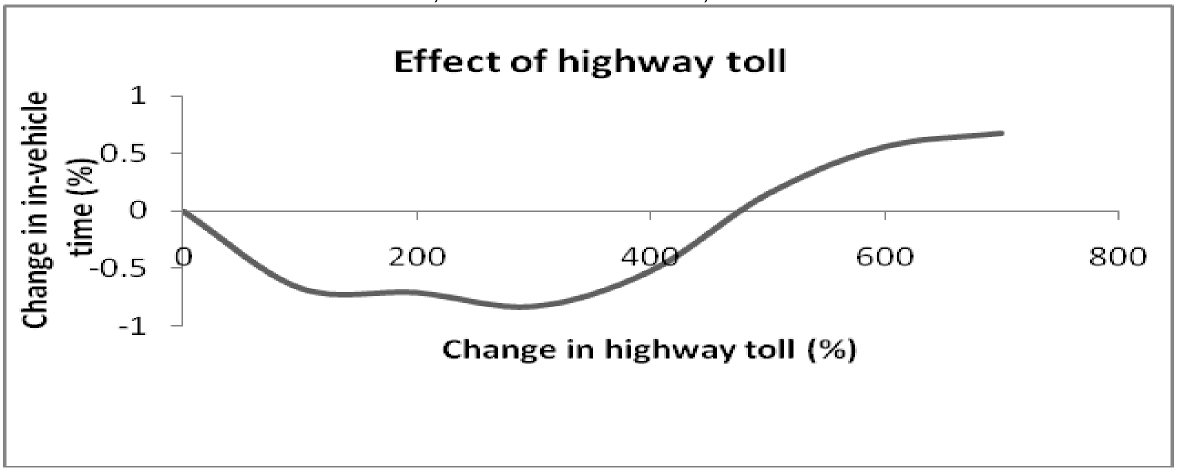

Figure 10. Change in in-vehicle time due to change in highway toll

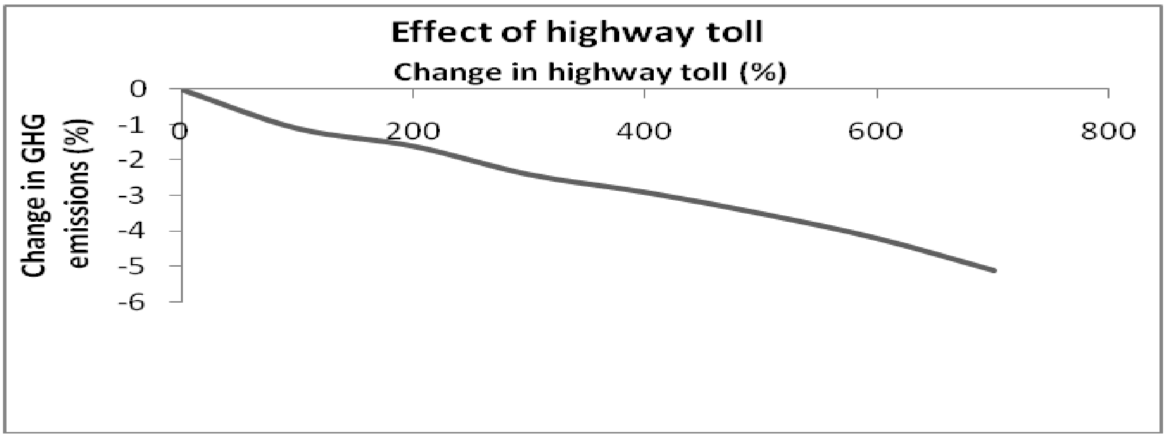

Figure 11. Change in GHG emissions due to change in highway toll

6.4 Search for Effective Scenarios

The first scenario of the case study based on minimum values of policy variables is the starting point to search for those values of policy variables that show high effectiveness in improving bus modal split and reducing in-vehicle time, fuel consumption and emissions. The sensitivity analysis confirms that it is desirable to keep bus fare at the base level.

Also, the detailed study of highway toll suggests that this policy variable does play a role, but there is a need to exercise caution in increasing its value so that it does not become counter-productive. Therefore, it is logical that the toll can be increased up to a reasonable level, identifiable in conjunction with values of other policy variables. As for parking charges, these can be increased in association with modest increases in toll levels.

A direct search method was used as an aid to identify effective scenarios that give favourable results in terms of reducing in-vehicle times, fuel consumption and emissions. Interested readers can find a description of the direct search method in Zargari and Khan

(2003). On the basis of the sensitivity analyses and with the help of the direct search method, a number of effective scenarios were identified. Figures 12 to 16 show a comparison of their effectiveness vis-à-vis the base case.

As previously noted, in the base case, the bus fare is $1.50/trip, parking charge is $2.60/trip and no toll is charged for the use of the freeway. Effective scenario 1 is based on bus fare of $1.50, highway toll of 8.50 cents/km, and parking charge of $6.90/day. In the second effective scenario, the parking charge is set higher (at $9.50/trip) as compared to effective scenario 1. A third effective scenario was found, which is similar to effective scenario 2 except the toll charge is raised to 17 cents/km. All rates are in 2008 dollars.

The effective scenario 1 produces better results in terms of minimizing in-vehicle travel time while effective scenarios 2 and 3 result in higher modal split for bus and give favourable results for fuel consumption and emissions. But these show slightly higher in-vehicle travel time as compared with effective scenario 1. The difference between effective scenarios 2 and 3 is the level of highway toll. In effective scenario 3 the toll is set at 17 cents/km, which is twice the toll rate for effective scenario 2.

An examination of Figures 12 to 16 suggests that effective scenarios 2 and 3 are almost identical in terms of impact, except the in-vehicle time for effective scenario 3 is higher than for scenario 2 (Figure 13). The reason is that a high toll is causing a route shift from the toll route to arterials which become congested and as a result the system level average in-vehicle travel time rises.

This phenomenon was also observed in the sensitivity analysis results. As shown in Figure 10, as the toll is gradually increased, initially the in-vehicle travel time decreases. For a given combination of values of bus fare and parking charge, an optimal toll rate can be found beyond which the system level in-vehicle travel time starts to rise. This is the reason for effective scenario 3 with a toll rate of 17 cents/km (in 2008$) to exhibit a higher in-vehicle travel time as compared to effective scenario 2. As noted earlier, these two scenarios are identical in other respects, except that in effective scenario 3, the toll rate is set higher than for scenario 2.

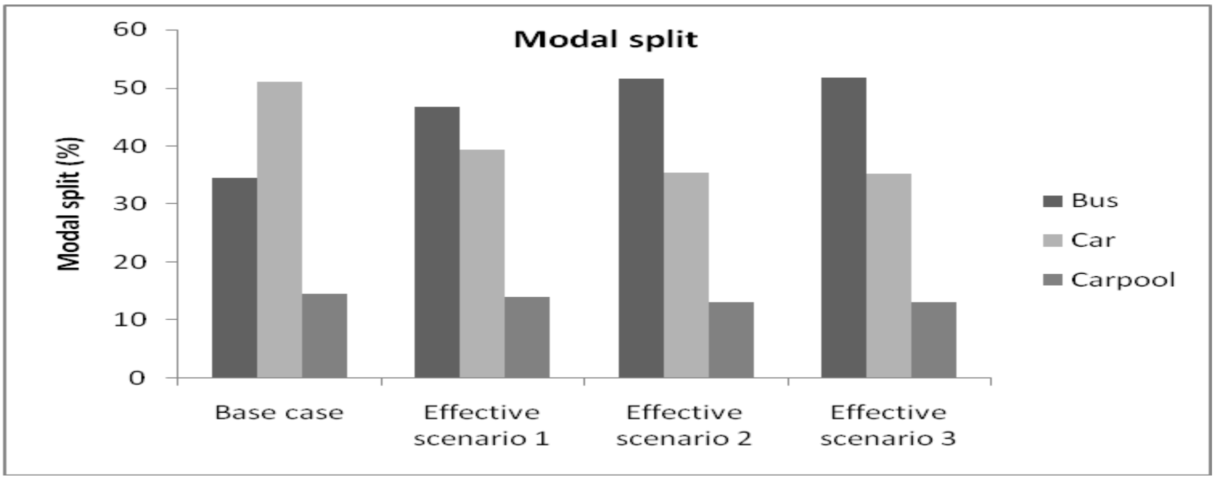

Figure 12. Modal split comparisons for effective scenarios

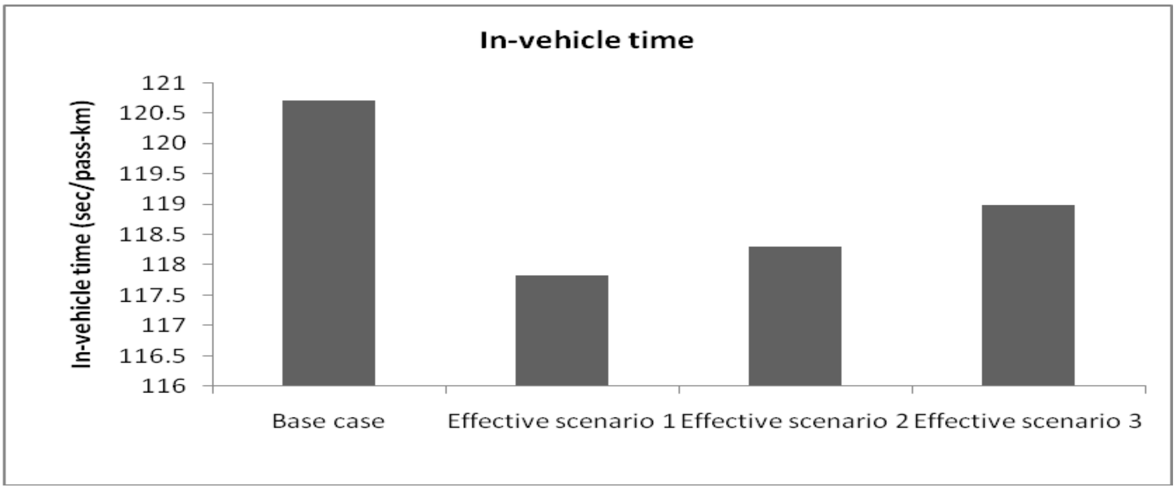

Figure 13. In-vehicle time comparisons for effective scenarios

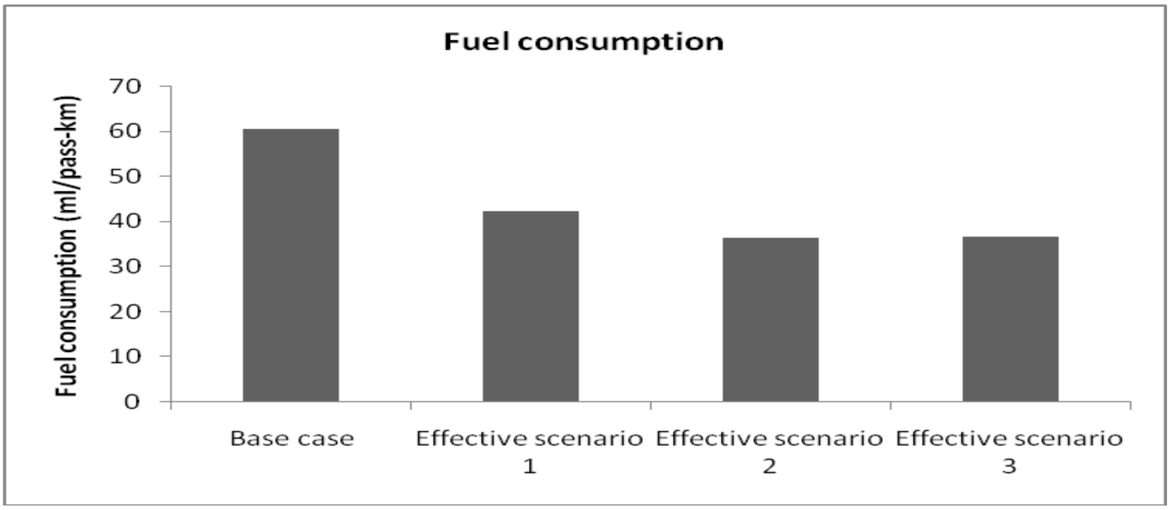

Figure 14. Fuel consumption comparisons for effective scenarios

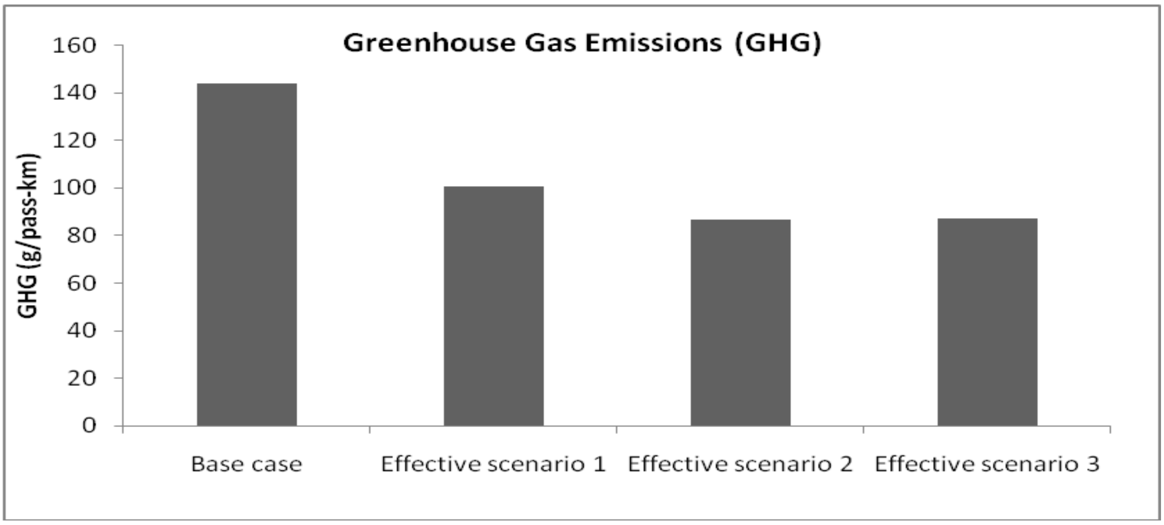

Figure 15. GHG emissions comparisons for effective scenarios

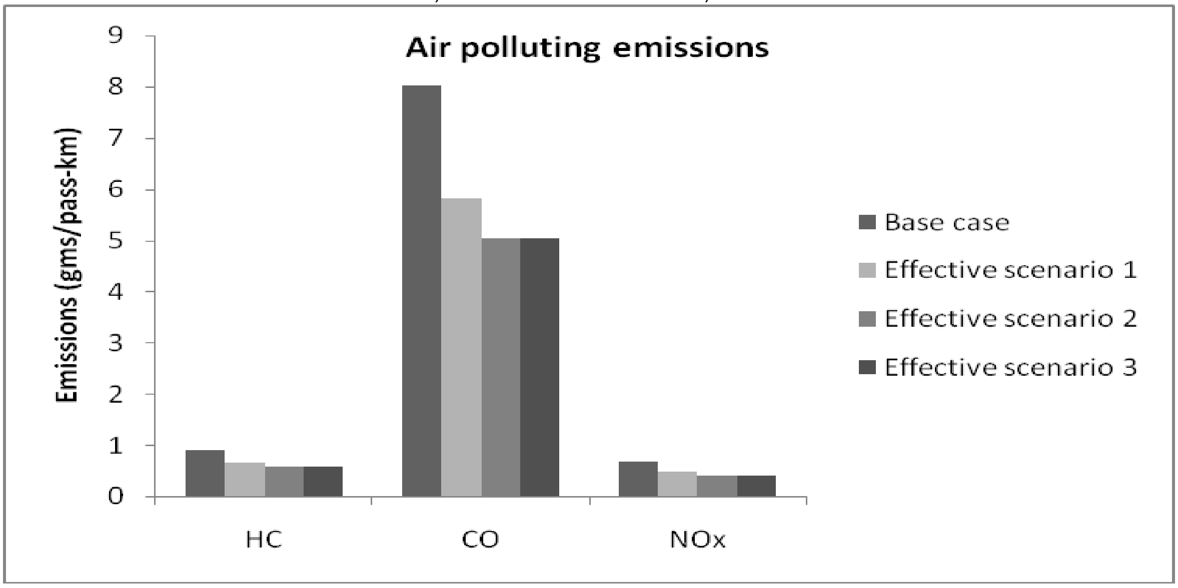

Figure 16. Air polluting emission comparisons for effective scenarios

6.5 Discussion

The effects of policy variables are logical. Increasing parking charges is desirable from a sustainability perspective. As bus fare rises, bus modal share drops and effects on in-vehicle travel time, fuel consumption and emissions are adverse to sustainable mobility.

Increases in tolls produce favourable effects up to an optimal level that can be found for any specified values of other policy variables. Beyond that level, much route shifting occurs which overwhelms the arterials and therefore the weighted average in-vehicle travel time starts to increase, which is not desirable.

Taken together, there is a role for parking charges, bus fare and highway toll to serve as policy variables in order to manage demand in the corridor. However, it is prudent to find out that combination of the values of these policy variables that are effective in improving the travel conditions in the corridor and also reducing environmental effects.

It was found that effective values of policy variables to obtain the best results regarding in-vehicle travel time/pass-km are not the same as for fuel consumption and emissions per passenger-km. These results are logical since fuel and emissions are minimized under conditions that are highly favourable to public transit. On the other hand, in-vehicle travel time is minimized under balanced transportation conditions.

For practical implementation of demand management instruments, it is of course, necessary to define one set of effective values of decision variables for a given application context. This can be achieved by simulating overall urban level travel and the identification of the effective scenario. If major corridors are studied independently, their results can be compared and a common set of answers can be adopted for practical implementation (e.g., average of the answers obtained for the various corridors). Another implementation issue is that of transit commission's option for a fare level that is different than the "effective" fare. In such a case, the fare to be charged can be used as a starting point and values of other variables can be found from the use of methodology described in this paper.

A mechanism for implementing parking charges can be developed based on the concept of a "weighted average" parking charge. In this method, the proportion of each type of parking (i.e., long term contracts and short term charges) has to be estimated and then an attempt can be made to influence parking charges for each type of parking (e.g., through special taxes).

7. CONCLUSIONS AND POLICY IMPLICATIONS

This paper describes philosophical and methodological advances in meeting the challenges of providing sustainable mobility in the multimodal travel corridors of multi-nucleated urban regions.

The imbalance of population and employment in satellite communities of a multi-nucleated urban region contributes to high level of commuting in major travel corridors. Therefore, one policy instrument that can be used to reduce congestion on highways and roads in the corridor is to enhance the employment opportunities in satellite communities.

The demand management methodology enables the investigation of travel service quality, energy, and emission effects of a combination of policy variables (i.e., freeway tolls, parking charge, rapid transit, and transit fare) in an urban travel corridor. It enables the identification of relative effects of policy variables and can lead to effective scenarios for demand management.

For travel corridors of a multi-nucleated urban region, the methodology can model BRT as well as tolling on the freeway and can estimate fuel consumption and emissions.

The methodology has much potential in assisting urban transportation planners and policy analysts to find the most appropriate demand management strategy in terms of values of policy variables that would lead to most favourable effects.

The results of the Ottawa (Canada) corridor study suggest the following conclusions:

(a) The effective scenarios for saving fuel and reducing emissions and in-vehicle travel time occur when the modal share for bus rapid transit is high.
(b) There is a role for highway tolls in conjunction with other demand management (policy) variables. However, care should be exercised in raising tolls which results in route shifts to arterials before travellers decide to move to public transit for commuting.
(c) At moderate bus fare level, increasing parking charges and tolls are effective in inducing the use of public transit in urban corridors. That is, link-based congestion pricing (i.e., freeway tolls) if supplemented by high parking charges encourages the

use of public transit. However, extreme values of policy variables (e.g., high tolls, high parking charges) need not be the important ingredients for effective strategies.

(d) The demand management instruments or policy variables (i.e., transit fare, parking charges, and freeway tolls) have a high effect on modal split.

(e) The effective values of policy variables found from different corridor studies within the region can be averaged for practical implementation. Weighted average parking charges can be found from the proportion of short term and long term (contract) type of parking demand. The presence of municipal parking facilities, special taxes, and policies on parking supply can assist in influencing parking charges.

(f) The methodology reported here can be used in conjunction with any land use plan since inputs to the travel forecasting model can characterize the spatial distribution of population, employment, car ownership, the formation of major travel corridors, and integrated multimodal transportation systems that serve major corridors.

Acknowledgements

Financial assistance from the Natural Sciences and Engineering Research Council (NSERC) of Canada is acknowledged. The cooperation of City of Ottawa and the OC Transpo in providing data is much appreciated. The views expressed are those of the authors.

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