

Overcoming Traffic Congestion.

A Discussion of Reduction Strategies and Behavioral Responses from a North American Perspective

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This paper addresses the issue of why measures designed to ease traffic congestion have met with limited success in North American cities. To this end, specific types of supply and demand strategies (i.e., roadway construction, jobs-housing balance and the compressed workweek) are discussed emphasizing behavioral responses to them. With respect to roadway construction, evidence of induced travel from recent studies undertaken in the United States is presented. With respect to the two remaining strategies, two studies conducted in Canada employing simulation models are described. Finally, activity-based travel demand models are discussed as a promising means for forecasting both anticipated and unanticipated behavioral responses to mitigation measures, thereby enabling policy makers to make informed decisions as to whether the measures merit implementation.

Keywords: activity analysis, activity-based models, compressed workweek, induced travel, jobs-housing balance, travel demand management, travel behavior, travel demand, traffic congestion

1. Introduction

Given the spatial separation of land uses in North American (i.e., Canadian and American) cities, travel is a necessity of daily life—that is, people *need* to travel in order to engage in out-of-home activities such as working, shopping and many forms of recreation. While several transport modes are readily available in most cities for meeting this need, the mode of choice is overwhelmingly the automobile¹. In the United States, for example, approximately 88 percent of workers drove to work either alone or with others in the year 2000 (U.S.

¹ As used in this paper, the term *automobile* encompasses all motorized vehicles that are owned or leased by households (i.e., cars, light-duty trucks, sport utility vehicles and vans).

Census Bureau 2003). By comparison, the percentage in Canada for 2001 was lower (i.e., 81 percent), but by no means less significant (Statistics Canada 2003). Such intense use of the automobile for fulfilling basic social and economic needs does, however, come with serious consequences that impact both individuals and society. These consequences include, among others, traffic congestion and emissions of air pollutants. Although the two are best known for their impacts on local environments (e.g., delay, smog), they also contribute to global environmental problems. This is especially true in the case of global warming. For this problem, the contributing factor is emissions of carbon dioxide (CO₂), the primary greenhouse gas emitted by human activities.

Since the early 1980s, the basic trends characterizing traffic congestion and automobile emissions in North American cities have diverged. On the one hand, traffic congestion has become much worse in cities of all sizes. In fact, in their annual survey of 75 American cities, researchers at the Texas Transportation Institute report that the average annual delay per peak road traveler (i.e., a measure of congestion's impact) has increased from 16 hours in 1982 to 62 hours in 2000 (Shrank and Lomax 2002). Many factors have contributed to this rapid growth in congestion including population and job growth, more intensive use of the automobile, failure to expand urban road networks and failure to make drivers bear the full cost of driving (Delucchi 1997; Downs 1992). On the other hand, in terms of amount, transport emissions of most air pollutants have decreased over time in Canada and the United States (see Table 1). The most notable exception to this trend is CO₂ emissions, which, according to the OECD (Organization for Economic Cooperation and Development) data shown in Table 1, have remained steady in Canada and increased in the United States.

To date, the successful reduction of most air pollutants from transport is due largely to the introduction and tightening of vehicle emissions standards, which incite improvements in vehicle technologies. These technologies either control emissions directly, such as catalytic converters², or improve vehicle fuel efficiency³. There is, however, growing concern that any gains in reducing transport emissions of air pollutants will be reversed in the short term for the following reasons. First, vehicle fuel efficiency has remained virtually unchanged since the mid-1980s (USDOT BTS 1998). This means that short-term reductions in transport emissions from vehicle stock rollover will be almost nonexistent as the average fuel efficiency of the on-road fleet approaches that of new vehicles. Second, the increasing popularity of less fuel-efficient light-duty trucks and sport utility vehicles suggests the possibility that the average fuel efficiency of the on-road fleet may decline, thereby increasing emissions. Third, vehicular traffic continues to grow without any sign of leveling off (OECD 1999). Eventually, this alone will offset any improvements in air quality from transport. More importantly, such growth will lead to more congestion in the absence of increased network capacity. In turn, emissions of several air pollutants will rise⁴. In the long term, however, it seems reasonable to speculate that any short-term growth in emissions will be offset, once again, by improved vehicle technologies such as hybrid automobiles, which greatly increase vehicle fuel efficiency.

² The use of catalytic converters, which is mandatory in Canada and the United States, actually increases CO₂ emissions.

³ Vehicle technologies that improve fuel efficiency, such as reduced vehicle weight, fuel injection and improved aerodynamics generally reduce air pollutant emissions. However, there are some exceptions to this. For example, the use of higher air-fuel ratios and combustion temperatures actually increase NO_x emissions.

⁴ Driving characteristics play an important role in emissions of air pollutants. For example, emissions of CO and CO₂ are highest when a vehicle is accelerating, decelerating or idling—conditions that are synonymous with traffic congestion. By comparison, NO_x emissions increase with speed.

While vehicle technologies have proven to be very successful to date in reducing emissions of most air pollutants, measures employed over the past four decades to curb congestion have met with limited success only. These measures fall into two groups. One group consists of strategies that alter the *supply* of transport facilities. Constructing new lanes and highways, adding extra buses to existing routes and investing in new transport modes such as light rail are all examples of supply options. By comparison, the other group includes strategies aimed at altering the *demand* for additional transport facilities. These options aim to achieve higher levels of performance from existing urban road networks by either optimizing network flow (e.g., synchronizing traffic lights, one-way streets) or reducing the demand for car use during peak periods (e.g., congestion pricing, alternative work schedules). The former set of strategies is referred to as *transportation system management* (TSM) and the latter, *travel demand management* (TDM). Today, transportation planners confront congestion in North American cities with all of these measures. However, given the costs associated with the construction and maintenance of infrastructure, in particular roadways, not to mention lessons learned from such endeavors in the 1960s and 1970s—that is, roads simply “fill up” long before they are forecast to do so—TSM and TDM are favored.

The purpose of this paper is to address the issue of why mitigation measures have met with limited success in reducing traffic congestion in North American cities. To this end, supply and demand strategies for curbing congestion are reviewed respectively in Sections 2 and 3 along with behavioral responses to them. Although any number of measures could be emphasized, discussion centers on roadway construction (supply) because of its importance in the past and TDM (demand) because of its increasing popularity today. Furthermore, with respect to TDM, two studies undertaken by the author with some colleagues are highlighted—one involving jobs-housing balance (Scott et al. 1997) and the other, the compressed workweek (Scott and Kanaroglou 2003). Finally, in Section 4, activity-based travel demand models are discussed as a promising means for modeling behavioral responses to mitigation strategies. Conclusions are presented in Section 5.

Table 1. Transport^a emission trends of air pollutants in Canada and the United States, 1980 to 1995

Year	CO ₂		CO		NO _x		PM ₁₀		SO ₂		VOC	
	Amount ^b	Share ^c	Amount	Share	Amount	Share	Amount	Share	Amount	Share	Amount	Share
<i>Canada</i>												
1980	129,600	29.8	-	-	-	-	-	-	-	-	-	-
1985	-	-	6,527	56.5	772	37.8	76	5.3	39	-	471	16.9
1986	-	-	6,485	56.8	762	37.2	-	-	41	-	490	17.6
1987	-	-	6,550	55.9	789	37.2	-	-	45	-	510	18.1
1988	-	-	6,403	54.8	783	35.5	-	-	47	-	520	18.0
1989	-	-	6,008	53.8	757	34.7	-	-	48	-	574	20.4
1990	-	-	5,647	53.2	731	34.7	81	5.3	51	-	632	22.3
1991	-	-	5,353	52.8	697	35.0	-	-	52	-	574	20.9
1992	-	-	5,008	50.4	660	33.7	-	-	53	-	526	19.7
1993	-	-	4,931	48.7	644	32.5	-	-	55	-	510	18.8
1994	-	-	4,787	47.5	625	31.3	-	-	56	-	490	18.1
1995	140,400	29.8	-	-	-	-	-	-	-	-	-	-
<i>United States</i>												
1980	1,251,500	26.2	71,561	73.5	7,821	37.0	360	6.1	473	-	8,146	36.3
1985	-	-	70,206	72.5	7,339	35.4	329	9.6	474	-	8,506	37.2
1986	-	-	66,540	71.9	7,052	34.8	323	9.7	478	-	8,050	36.3
1987	-	-	64,638	71.8	6,941	34.2	327	10.2	488	-	7,690	35.1
1988	-	-	64,484	71.1	6,950	32.4	335	10.1	501	-	7,521	33.8
1989	-	-	59,921	69.5	6,969	33.1	333	10.1	517	-	6,524	30.9
1990	-	-	57,025	70.3	6,793	32.5	324	10.8	518	-	6,218	30.4
1991	-	-	56,314	69.9	6,689	32.5	317	10.7	517	-	5,896	29.4
1992	-	-	54,304	68.6	6,750	32.6	311	10.3	525	-	5,508	27.7
1993	-	-	54,615	68.9	6,813	32.3	291	9.8	469	-	5,536	27.7
1994	-	-	56,094	69.1	6,960	32.4	291	9.8	273	-	5,807	28.3
1995	1,579,800	30.2	53,184	68.5	6,899	34.9	276	9.7	276	-	5,538	27.2

^a Except for CO₂, which includes all transport modes, emissions are from road transport only.

^b Measured in thousands of metric tons.

^c Contribution of amount specified to total emissions, measured in percent.

Source: OECD (1997)

2. Expansion of network capacity

Today, roadway construction is perhaps the most controversial measure for reducing traffic congestion in North American cities. On the one hand, its proponents argue that construction is necessary to keep pace with the travel demands of a growing population. To the general public, new lanes and highways are visible reminders that governments are responding to a “crisis.” On the other hand, critics charge that capacity expansion provides only ephemeral relief—that is, within a few years, roads are just as congested as they were before the investment. The reason for this, they contend, is that new capacity generates new traffic and attracts traffic from other routes. Such traffic is known collectively as *generated traffic* (Litman 2001).

Downs (1992) formulated the theory of *triple convergence* to explain why new capacity fails to alleviate congestion during peak periods. Assuming that people minimize their travel time, three behavioral responses occur immediately following a road improvement (see Table 2). First, drivers who were using other routes switch to those incorporating the newly improved road (i.e., spatial convergence). Second, drivers who were traveling at off-peak periods switch to the peak (i.e., temporal convergence). Finally, public transport users switch to driving their automobiles (i.e., modal convergence). As more and more drivers use the improved road, traffic volumes rise until congestion, once again, manifests itself.

The timing of a newly improved road’s return to a congested state is governed by several factors in addition to those underlying triple convergence. One such factor is the natural growth in travel demand attributed to population and employment growth. Cities experiencing high growth rates can be expected to “fill up” any newly added capacity more quickly than those experiencing low growth rates. Other factors encompass both short-run and long-run behavioral responses to new capacity (see Table 2). Over the short run, for example, drivers may choose to travel to farther destinations without increasing their travel-time budgets. New trips may also be generated as existing destinations become more accessible. Over the long run, improved network capacity typically leads to land-use change, especially at the peripheries of cities. Examples of such change include the development of *power centers* (i.e., “big box” retail) and *edge cities*, both of which are automobile-oriented. In turn, such developments may lead to reduced public transport service and increased household automobile ownership levels (Litman 2001; Noland and Lem 2002). The end result is more trips by automobile, which increase congestion.

Table 2. Behavioral responses to network capacity expansion

Response	Type of Trip	Change in VMT
<i>Short run</i>		
Route switching: new route is shorter than previous one	Diverted	Decrease
Route switching: new route is longer than previous one	Diverted	Increase
Rescheduling of trips from non-peak to peak periods	Diverted	No change
Public transport users switch to their automobiles	Induced	Increase
Drivers choose to travel to farther, existing destinations	Diverted	Increase
New trips by automobile to existing destinations	Induced	Increase
<i>Long run</i>		
Drivers choose to travel to farther, new destinations	Diverted	Increase
New trips by automobile to new destinations	Induced	Increase
New trips by automobile due to reduced public transport service	Induced	Increase
New trips by automobile due to rising ownership levels	Induced	Increase

At the facility level, the behavioral responses to newly added capacity, listed in Table 2, either generate new trips (i.e., induced trips) or divert existing trips from other routes, times, modes and destinations. Over the short run, most generated traffic consists of diverted trips, whereas over the long run, induced trips comprise an increasing proportion of such traffic. At the same time, diverted trips can increase, decrease or have no effect on vehicle miles of travel (VMT). Conversely, induced trips always increase VMT.

Economists have long recognized the potential contribution of induced travel to traffic congestion. The reason for this is that induced travel is based on the concepts of supply and demand. New network capacity (i.e., an increase in supply) reduces the generalized costs of travel by reducing travel times. As the cost of travel declines, the quantity demanded increases. In other words, when confronted with additional capacity, drivers undertake both new and longer trips.

Although economic theory posits its existence, induced travel remains a center of debate between proponents and critics of roadway construction (Cervero 2002; Noland and Lem 2002; Rodier et al. 2001). Initially, the debate focused on the fundamental existence of induced travel as verified by empirical evidence. Noland and Lem (2002) suggest that this debate was complicated by two factors. First, there was some disagreement among researchers concerning the definition of induced travel. For example, should induced travel include only new trips (i.e., induced trips) or should it also include diverted trips? Litman (2001) suggests that induced travel should include only new trips. Conversely, many other researchers define induced travel to be an increase in VMT, which would include both new and diverted trips (see Table 3). Second, induced travel effects must be disentangled from other factors that drive travel demand growth. Such factors include population and employment growth, increases in income and increasing numbers of women in the workforce, to name a few (Noland and Lem 2002).

Table 3. Summary of recent studies of induced travel in the United States

Study	Objective (wrt = with respect to)	Data (observations and time frame)	Methodology	Findings
Hansen and Huang (1997)	Estimate elasticity of annual VMT wrt state highway lane miles	30 urban California counties; 14 California MSAs and CMSAs; 1973-90	Cross-sectional, aggregate modeling variations of the distributed lag fixed effects regression model	Elasticities for preferred models (lags and fixed effects included): 0.21 (short run) and 0.62 (long run) for counties; 0.19 (short run) and 0.94 (long run) for metropolitan areas
DeCorla-Souza and Cohen (1999)	Forecast daily VMT induced by a 50% expansion of freeway capacity while accounting for initial levels of congestion	Hypothetical, eight-mile long corridor with a freeway and arterials	Scenario testing using the sketch-planning model SMITE (Spreadsheet Model for Induced Travel Estimation); six scenarios tested using three congestion levels (low, moderate and high) and two elasticities ^a (-0.5 and -1.0)	Freeway VMT increases due to diverted and induced traffic: 32% (low, -0.5) to 48% (high, -1.0); arterial VMT decreases due to diverted traffic: -9% (low, -1.0) to -13% (high, -0.5)
Barr (2000)	Estimate elasticity of annual household VMT wrt average daily household travel time	27,409 households from the 1995 NPTS (Nationwide Personal Transportation Survey)	Cross-sectional modeling using ordinary least squares regression; 15 models estimated using all households; additional models estimated after stratifying households	Elasticities (all households): -0.35 to -0.58
Fulton et al. (2000)	Estimate elasticity of daily VMT wrt highway lane miles; test for causality	District of Columbia (1984-96), Maryland (1969-96), North Carolina (1985-96) and Virginia (1970-96) counties	Cross-sectional, aggregate modeling fixed effects; base, difference (growth) and two-stage least squares regression models estimated	Elasticities: 0.33 to 0.59 for base models; 0.15 to 0.61 for difference models; 0.29 to 0.64 for two-stage models; Granger causality test indicates that lane-mile growth precedes VMT growth
Noland and Cowart (2000)	Estimate elasticity of daily VMT per capita wrt lane miles per capita and freeways and arterials considered)	70 urban areas found in the TTI's (Texas Transportation Institute) annual report on mobility; 1982-96	Cross-sectional, aggregate modeling variations of the fixed effects regression model; two-stage least squares regression models estimated to correct for simultaneity bias	Elasticities: 0.28 (short run) and 0.90 (long run) for fixed effects model with a one-year lag; 0.65 to 0.68 for fixed effects models without lags; 0.28 to 0.76 for two-stage models

Strathman et al. (2000)	Estimate elasticity of annual VMT per worker wrt lane miles per million people (only freeways and arterials considered) in the context of decisions concerning residential and workplace location and mode to work	12,009 workers residing in 48 urban areas (obtained from the 1995 NPTS); road capacity data obtained from the TTI's annual report on mobility	Cross-sectional modeling using a SUR (seemingly unrelated regression) model consisting of four equations; three instrumental variables estimated and included in the system of equations	Elasticities: 0.29 for direct effect; 0.03 for indirect effect
Noland (2001)	Estimate elasticity of annual VMT wrt lane miles per capita (only non-local roads considered)	50 U.S. states; 1984-96	Cross-sectional, time-series aggregate modeling controlling for fixed effects (U.S. states only); single equation and SUR models estimated by road type	Elasticities: 0.63 to 0.89 for single equation models without lags; 0.69 to 0.83 for SUR model without lags; 0.23 to 0.51 (short run) and 0.71 to 1.16 (long run) for distributed lag SUR model with a one-year lag
Rodier et al. (2001)	Estimate elasticity of daily VMT wrt lane miles; evaluate effects of land-use change and destination choice on induced travel	Sacramento, California; 1990-2040	Scenario testing using an integrated transportation and land-use model called MEPLAN; five scenarios tested: modest expansion of road network (base scenario) and four beltway scenarios	Elasticities: 0.4 (2015) and 0.6 (2040) accounting for destination choice; 0.8 (2015) and 1.1 (2040) accounting for destination choice and land-use change
Cervero and Hansen (2002)	Disentangle causal linkages between road supply, as measured by lane miles, and travel demand, as measured by VMT (only state roads considered)	34 urban California counties; 1976-94	Cross-sectional, time-series aggregate modeling controlling for fixed effects (counties only); road supply and travel demand models estimated simultaneously using three-stage least squares regression	Elasticity of VMT wrt lane miles (induced travel): 0.59; elasticity of lane miles wrt VMT (induced investment): 0.33
Mokhtarian et al. (2002)	Compare traffic growth on improved highway segments against growth on "similar" unimproved segments to assess the potential effect of induced travel	18 matched pairs of California state highway segments; pairs consist of one segment improved between 1969 and 1977 and one unimproved segment; 1976-96	Matched-pairs testing using three approaches: overall growth comparisons, repeated measures analysis and analysis of matched mean profiles	No statistical difference in traffic growth between the two types of segments

a Elasticity of daily VMT wrt a reduction in travel time per mile. An elasticity of -0.5 means that a 10% reduction in travel time per mile will result in a 5% increase in daily VMT.

Beginning in the late 1990s, several studies were undertaken in the United States to verify empirically the existence of induced travel. These studies are summarized in Table 3. Although they vary methodologically, the majority of studies measure induced travel as the elasticity of VMT with respect to lane miles. For example, an elasticity of 0.5 would suggest that for every 10 percent increase in lane miles, VMT increases by five percent. A notable exception to this form of measurement is found in the work by Barr (2000). In this study, induced travel is measured as the elasticity of VMT with respect to travel time. This implies that such elasticities will be negative. For example, an elasticity of -0.5 would suggest that for every 10 percent reduction in travel time, VMT increases by five percent. The elasticities shown in Table 3 suggest that there is a significant relationship between new road capacity and VMT growth after controlling for other factors driving VMT growth. In other words, these studies have verified the existence of induced travel. Furthermore, in those studies examining both short-run and long-run elasticities (i.e., Hansen and Huang 1997; Noland 2001; Noland and Cowart 2000), the latter are considerably higher than the former as would be expected. In fact, in the long run, the elasticities suggest that new capacity will be filled by induced VMT—that is, the elasticities are close to 1.0.

Besides verifying the existence of induced travel, two studies have investigated causal linkages between increases in road capacity and increases in VMT. Fulton et al. (2000) used a Granger causality test to determine whether lane-mile growth precedes VMT growth or vice versa. They found the former to be true. In a more rigorous investigation, Cervero and Hansen (2002) estimated road supply and travel demand models simultaneously using three-stage least squares regression. They found strong reciprocal relationships between road investment and travel demand—that is, road investments induce travel demand and travel demand induces road investments. However, the former effect was found to be stronger than the latter effect (i.e., an elasticity of 0.59 versus an elasticity of 0.33).

Given the overwhelming evidence supporting the existence of induced travel, concern has now shifted to policy—specifically, the extent to which current travel demand forecasting models are able to account for induced travel (Cervero 2002). Today, many metropolitan areas in Canada and the United States, not to mention other cities around the world, forecast travel demand using some variant of the Urban Transportation Modeling System (UTMS), which represents the state-of-the-practice in such modeling. UTMS is also known as the four-stage model because it consists of four sub-models that are executed sequentially: trip generation, trip distribution, modal split and traffic assignment. In the vast majority of cases, the modeling system is calibrated for the morning peak period only, which implies that it is unable to forecast travel at other times of the day. Given its rigidity, UTMS is unable to encapsulate all of the behavioral responses to new capacity, which give rise to induced travel (DeCorla-Souza and Cohen 1999; Noland and Cowart 2000). Of those responses listed in Table 2, only destination (short run), mode and route switching would be captured. In the only study that has attempted to disentangle the contributions of specific behavioral responses to induced travel, Rodier et al. (2001) find that UTMS accounts for only half of the induced travel effect over the long run (see Table 3). This implies that current travel demand forecasting models will overstate the purported benefits of new capacity (i.e., travel time savings, reduced congestion and reduced emissions of harmful air pollutants). In turn, if induced travel is to be encapsulated in its entirety in travel demand forecasting models, thereby increasing the reliability of forecasts, new approaches to such modeling are needed. One such approach, discussed in Section 4, is activity-based travel demand modeling.

3. Travel demand management

3.1 Strategies

As discussed above, roadway construction provides temporary relief, at best, from peak-period traffic congestion. This is not surprising given the fact that it is not aimed at reducing the actual cause of congestion—that is, the demand for car use. In fact, the studies summarized in Table 3 concerning induced travel suggest that additional capacity has just the opposite effect—it actually increases car use. For reasons such as these, many strategies subsumed under travel demand management (TDM) are popular, less costly alternatives for managing congestion in North American cities today.

Many strategies have been proposed for reducing the demand for peak-period car use (see, for example, those listed in Table 4). Vlek and Michon (1992) suggest that such strategies can be categorized according to their degree of coerciveness, which implies that some strategies are better at achieving desired behavioral responses than others. For example, various forms of auto restraint in downtown areas, such as the banning of on-street parking or the banning of non-commercial traffic altogether, are more likely to reduce car use than simply promoting a greater balance of jobs and housing. The reason for this is that auto restraint either constrains or, in some cases, eliminates drivers' choices. Jobs-housing balance does neither. The categories of TDM strategies identified by Vlek and Michon (1992), ordered from more to less coercive, are: physical changes (e.g., banning non-commercial traffic); law regulation; economic incentives; information, education and prompts; socialization and social modeling; and institutional and organizational changes (e.g., alternative work schedules).

Table 4. TDM strategies classified according to Steg and Vlek's (1997) push-pull scheme

<i>Push strategies</i>
Taxation of cars and fuel
Banning non-commercial traffic from city centers
Road pricing
Banning on-street parking
Telecommuting
Jobs-housing balance
<i>Pull strategies</i>
High occupancy vehicle (HOV) lanes
Park and ride schemes
Improved public transport service
Public information campaigns concerning the negative effects of driving

Other ways of classifying TDM strategies have also been suggested. Steg and Vlek (1997), for example, distinguish between strategies that discourage car use (i.e., push strategies) and those that encourage the use of alternative modes, including ridesharing (i.e., pull strategies). Table 4 lists several TDM strategies classified according to Steg and Vlek's (1997) push-pull scheme. Finally, Plane (1995) distinguishes between transportation and non-transportation strategies. The latter category includes such measures as alternative work schedules, jobs-housing balance and telecommuting. Two studies evaluating specific non-transportation strategies are discussed next.

3.2 Effectiveness of strategies: evidence from Canada

Jobs-housing balance

Many policy makers in Canada and the United States believe that traffic congestion and automobile emissions can be reduced by addressing local imbalances in the relative locations of jobs and housing (Giuliano 1991; Wachs et al. 1993). Underlying this TDM strategy is the assumption that people choose to minimize their commuting costs when selecting locations for jobs and housing. Empirical evidence from studies of *excess (wasteful) commuting* suggests, however, that this may not be the case—that is, people are utility maximizers, not cost minimizers (see, for example, Hamilton 1982, 1989; Cropper and Gordon 1991; Small and Song 1992; Giuliano and Small 1993). Furthermore, as suggested above, jobs-housing balance is not a coercive strategy in that it does not constrain locational choice. For these reasons, studies concerning the effectiveness of jobs-housing balance are mixed. On the one hand, studies by Cervero (1989) and Nowlan and Stewart (1991) support the views of policy makers. On the other hand, more recent studies by Wachs et al. (1993) and Scott et al. (1997) refute them. The latter study is described below.

Scott et al. (1997) use IMULATE¹, a state-of-the-art integrated transportation and land-use model, to examine the impact of commuting efficiency—that is, the degree to which people live near their jobs—on congestion and automobile emissions in the Hamilton CMA (see Figure 1). The basic structure of IMULATE is shown in Figure 2. POPMOB, the population mobility and demographic sub-model, predicts changes, at five-year intervals, in the distribution of households across census tracts in the region. TRANDEM, the travel demand sub-model, estimates the total number of trips by mode between all census tracts for a one-hour period during the morning rush hour. The modal split depends on a matrix of interzonal travel times, which accounts for congestion on the region's road network. Automobile trips are assigned, using a stochastic user equilibrium routine, to the more than 1500 links comprising the region's road network. The traffic assignment is then used to generate a new matrix of interzonal travel times, which is returned to TRANDEM. This matrix alters the modal split. TRANDEM estimates a new matrix of interzonal automobile trips, which is compared to that generated during the previous iteration. This iterative procedure continues until there is no longer any change in the automobile trips matrix. Consequently, TRANDEM converges. MOBILE5C, the United States Environmental Protection Agency's source emissions model modified for the Canadian automobile fleet, then uses the matrix of automobile trips to estimate link emissions of non-methane hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x).

IMULATE is first used to generate estimates of congestion and automobile emissions for two commuting scenarios: a base scenario of estimated commuting flows for 1991 and an optimal scenario wherein the mean commuting time for all workers is minimized. The latter scenario corresponds to a situation in which all workers choose to minimize their commuting costs, thereby facilitating more efficient commuting by living as close as possible to their places of employment. In turn, given the existing distributions of jobs and housing, the externalities associated with such commuting are minimized—that is, both traffic congestion (Figure 3) and automobile emissions (Table 5) are reduced considerably in the optimal scenario. The reason suggested by Scott et al. (1997) for this is that the estimated commuting pattern (i.e.,

¹ Integrated Model of Urban LAnd use, Transportation, energy and Environment. Anderson et al. (1994) present a comprehensive discussion of IMULATE.

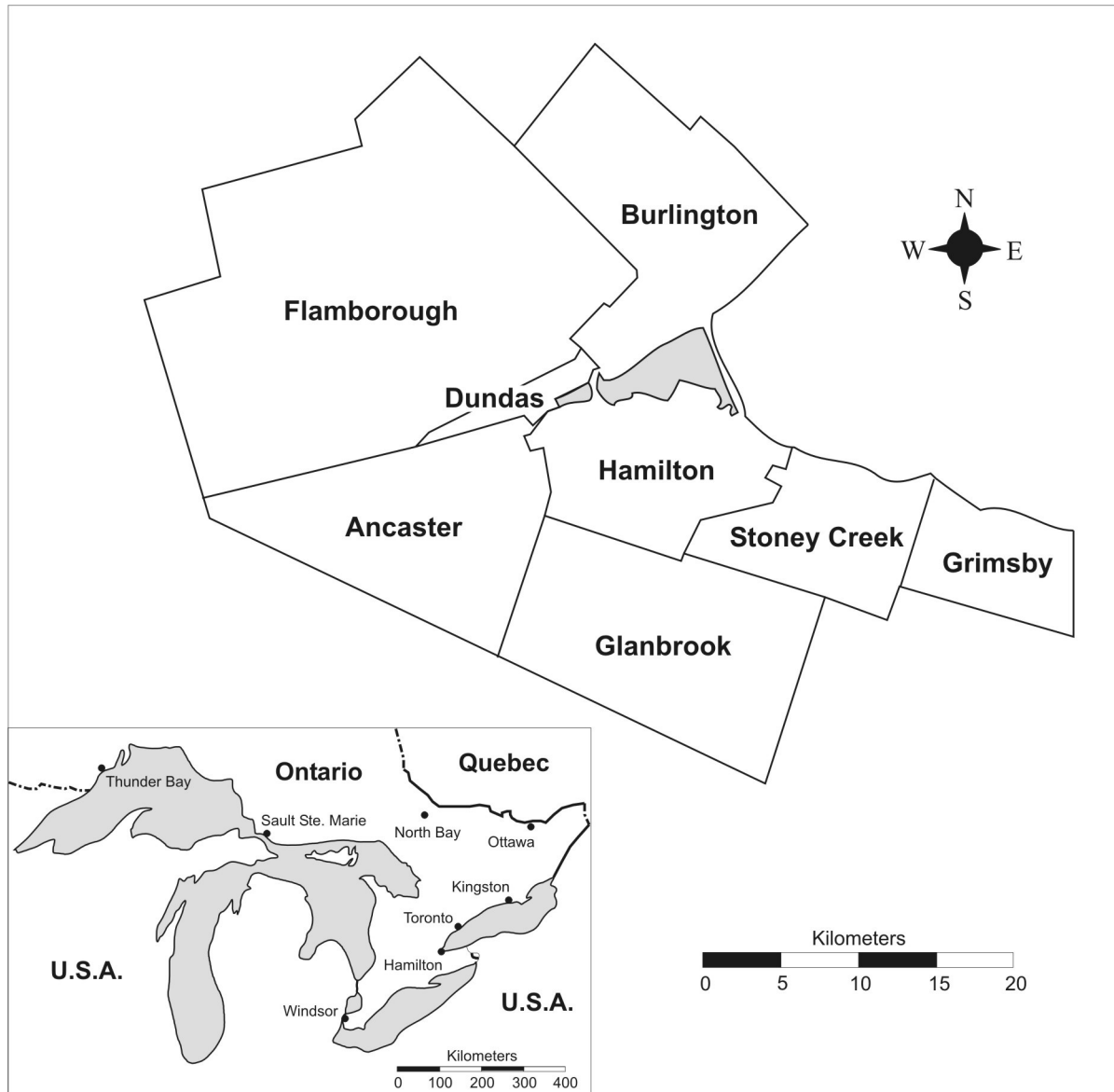


Figure 1. Municipalities in the Hamilton CMA.

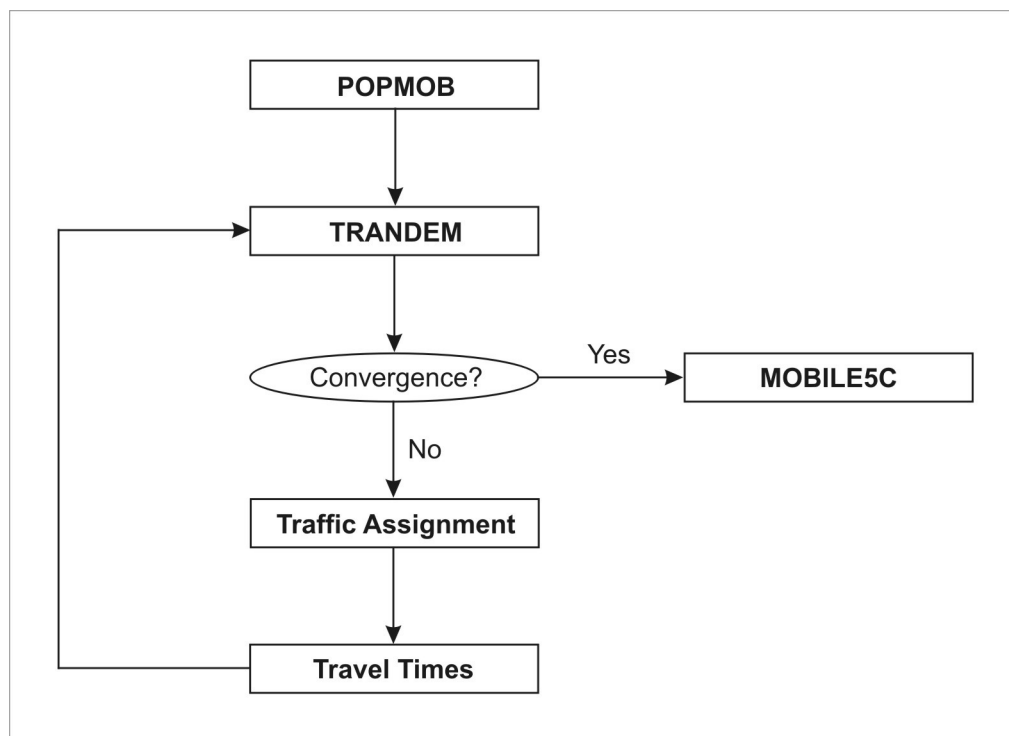


Figure 2. Basic structure of IMULATE.

base scenario) is found to be inefficient as measured by an excess commute² of 73 percent for the region (see Table 6).

Table 5. Aggregate emissions of HC, CO and NO_x for two commuting scenarios (Scott et al. 1997)

Pollutant	Base Scenario (kg)	Optimal Scenario (kg)	Difference (%)
HC	7,666	2,636	66
CO	83,061	31,469	62
NO _x	7,200	3,199	56

Table 6. Excess commuting for workers residing in municipalities of the Hamilton CMA (Scott et al. 1997)

Municipality	Jobs Per Resident Worker	Commute Type		
		Required (min)	Base (min)	Excess (%)
Burlington	1.16	2.43	22.04	89
Dundas	0.62	3.44	28.38	88
Stoney Creek	0.77	6.59	27.26	76
Hamilton	1.11	6.61	21.58	69
Ancaster	0.54	7.54	27.54	73
Flamborough	0.66	9.34	30.80	70
Grimsby	0.02	17.32	42.17	59
Glanbrook	0.36	18.26	32.44	44
Region	1.00	6.35	23.64	73

² Scott et al. (1997) define *excess commute* as the difference in average commuting times between the base and optimal scenarios expressed as a percentage of the base scenario.

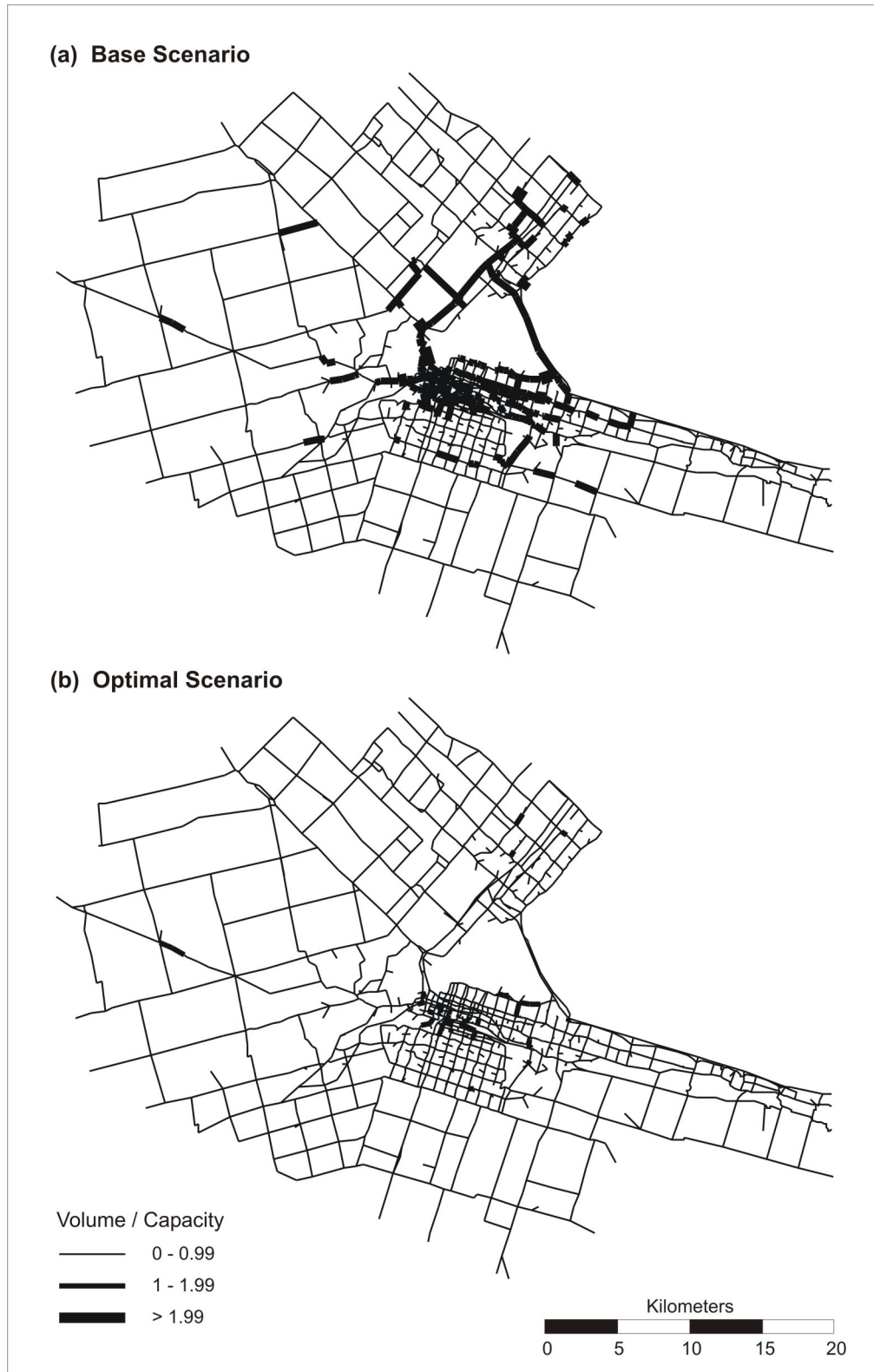


Figure 3. Congestion in the Hamilton CMA (Scott et al. 1997).

Scott et al. (1997) then evaluate jobs-housing balance as one means for encouraging more efficient commuting. They use two measures, shown in Table 6, for this: jobs per resident worker and the average required commute, which is the mean commuting time for workers under the optimal scenario. Giuliano and Small (1993) remark that the average required commute is a rigorous measure of jobs-housing balance in that it defines the mean commuting time that workers must travel to balance their residential and employment opportunities.

As noted by Scott et al. (1997), jobs and housing are always balanced at the regional level of analysis for people who choose to work and live in the region. This is indeed the case for the Hamilton CMA, which has a ratio of one job per resident worker (see Table 6). The researchers also find that the mean minimum time that workers must travel to balance their jobs and housing, as measured by the average required commute, is 6.35 minutes, which leaves 73 percent of the average base commute (i.e., the mean commuting time that workers actually spend traveling) unexplained. This finding, supported by similar findings at the municipal level of analysis (see Table 6), leads the researchers to conclude that a considerable proportion of commuting cannot be explained by geographical imbalances in the distributions of jobs and housing. Scott et al. (1997) note that workers consider many factors besides commuting costs in their locational choices. In other words, workers are utility maximizers, not cost minimizers as assumed under jobs-housing balance. For this reason, the researchers also conclude that jobs-housing balance is unlikely to facilitate more efficient commuting, thereby reducing traffic congestion. Obviously, this implies that jobs-housing balance will not meet the expectations of policy makers.

Compressed workweek

The compressed workweek is one form of alternative work schedule³ that has been proposed to reduce the demand for peak-period car use (Plane 1995). Under a compressed workweek, employees work the same number of hours as usual (e.g., 40 hours), but report to work only three or four times per week. In most cases, this means that workers travel during off-peak periods, which implies that those who drive do not contribute to rush-hour congestion. For this reason, its appeal as a viable TDM strategy is obvious. However, according to Hung (1996), few studies have investigated the compressed workweek from the perspective of traffic reduction. This implies that the work by Scott and Kanaroglou (2003) offers timely insight into a largely overlooked TDM strategy.

Scott and Kanaroglou (2003) offer a credible explanation for this oversight—that is, the outcome from the compressed workweek is so obvious that it requires no further investigation. However, they note that such a presumption fails to consider any additional impacts of the compressed workweek such as those pertaining to travel during the remainder of the working day and to travel on non-working days. In other words, the compressed workweek can have unintended consequences, which may or may not detract from its original intent—that is, congestion mitigation.

Scott and Kanaroglou (2003) use the *Activity Generation* module of an activity-based travel demand forecasting system described in Scott (2000) to uncover any additional travel-related impacts of the compressed workweek. The trivariate ordered probit models underlying this module are described elsewhere (see Scott and Kanaroglou 2002). These models capture interactions between household heads in terms of the number of non-work activities that they undertake outside the home both alone (i.e., without the other head) and together on a typical

³ Other TDM strategies included in the category of alternative work schedules are: flexible work hours, staggered work hours and job sharing / part-time work (Plane 1995).

weekday. The module also includes univariate ordered probit models for households containing only one head. All models were estimated using travel diary data obtained for the Greater Toronto Area (GTA).

The researchers investigate two scenarios by making three assumptions. First, only full-time workers can adopt a compressed workweek. Second, for those who do, they must work four 10-hour days. Third, all such workers work on the same days and have the same day off. Based on these assumptions, the first scenario (i.e., Scenario 1) corresponds to a workday for full-time workers adopting the TDM strategy, and the second scenario (i.e., Scenario 2) corresponds to their day off. Furthermore, for each scenario, the proportion of full-time workers in the GTA adopting a compressed workweek was varied (i.e., five, 10, 15 and 20 percent). Scott and Kanaroglou (2003) realize that such scenarios are unlikely to occur in reality—that is, all workers adopting a compressed workweek are unlikely to work on the same days and have the same day off. The researchers point out, however, that such scenarios are justified in that they define the maximum impacts to be expected from a large-scale adoption of the compressed workweek.

The results from Scott and Kanaroglou's (2003) investigation are presented in Tables 7, 8 and 9. The first of these tables, Table 7, documents the daily number of non-work, out-of-home activities predicted under each scenario as well as for a base run—that is, the situation prior to implementation of the compressed workweek. These runs serve as points of departure for evaluating each scenario.

Table 7. Daily number of non-work, out-of-home activities estimated for the heads of households in the GTA, 1986 (Scott and Kanaroglou 2003)

Full-time Workers Adopting Strategy (%)	Base Run	Scenario 1 ^a	Scenario 2 ^b
0	1,788,714		
5		1,780,865	1,861,674
10		1,768,086	1,922,807
15		1,757,845	1,993,012
20		1,744,414	2,057,319

^a Extended workday (i.e., 10 hours) for compressed workweek participants.

^b Day off for compressed workweek participants.

Detailed results for Scenario 1 are found in Table 8. As can be seen, the number of activities undertaken by household heads decreases steadily as the proportion of full-time workers adopting a compressed workweek increases. However, as noted by the researchers, these findings are not staggering. For example, even with a 20 percent adoption rate, the reduction in activities is only about 2.5 percent. Taken in context, this finding is to be expected. Workers simply have less time on the days they work to participate in discretionary activities such as running errands, going shopping and visiting family and friends. Instead, according to Table 9, it appears that such activities are saved for the day off. As can be seen in the table, the number of activities increases dramatically with the proportion of compressed workweek participants. A 20 percent adoption rate, for example, is associated with a 15 percent increase in activities.

The findings from Scott and Kanaroglou's (2003) study clearly demonstrate that the compressed workweek may impact the travel environment in ways that are not anticipated by policy makers. At one extreme, in addition to its role in mitigating peak-period congestion, the TDM strategy has the potential to reduce the overall demand for car use on working days by a modest amount. While this added benefit may be welcomed by policy makers, the researchers caution that such reductions in car use may be more than offset by a dramatic rise

in travel on days off, some of which may occur during peak periods, thus adding to congestion. Given their findings, the researchers conclude that a large-scale adoption of the compressed workweek will either maintain the status quo (i.e., congestion levels remain the same) or increase congestion in cities.

Table 8. Impact of the 10-hour workday (Scenario 1) on the daily number of non-work, out-of-home activities estimated for the heads of households in the GTA, 1986 (Scott and Kanaroglou 2003)

Full-time Workers Adopting Strategy (%)	Percentage Change from Base Run by Number of Episodes					
	0	1	2	3	4	All
5	0.198	-0.198	-0.531	-0.956	0.020	-0.439
10	0.490	-0.468	-1.235	-2.966	0.008	-1.153
15	0.736	-0.709	-1.921	-4.263	0.020	-1.726
20	1.060	-1.054	-2.760	-6.029	0.032	-2.477

Table 9. Impact of the day off (Scenario 2) on the daily number of non-work, out-of-home activities estimated for the heads of households in the GTA, 1986 (Scott and Kanaroglou 2003)

Full-time Workers Adopting Strategy (%)	Percentage Change from Base Run by Number of Episodes					
	0	1	2	3	4	All
5	-1.290	0.025	3.455	16.257	0.008	4.079
10	-2.413	0.182	6.435	29.379	0.008	7.497
15	-3.687	0.288	9.888	44.556	0.008	11.422
20	-4.870	0.491	12.896	58.541	0.008	15.017

4. Activity-based travel demand modeling

Shiftan and Suhrbier (2002) aptly note that although activity-based travel demand modeling has been discussed in the literature since the 1970s, progress toward developing operational models is a very recent phenomenon. In part, most such efforts in Canada and the United States owe their existence to the Travel Model Improvement Program (TMIP), which was announced in the United States in the early 1990s (USDOT 1993). To date, this program remains the most ambitious undertaking by any country in the world to remedy the many deficiencies of UTMS by replacing it with new, policy-sensitive models.

Activity-based travel demand models treat travel explicitly as a demand derived from the need to participate in out-of-home activities. In other words, activities are modeled, not the trips themselves. With few exceptions to date, the decision-making unit in operational modeling efforts, as opposed to the conceptual frameworks underlying them, is the individual. To meet expectations concerning the accuracy and reliability of forecasts, Scott and Kanaroglou (2002, 2003) argue, however, that such models be implemented at the household level, taking into account interactions among household members. They offer two reasons for this. First, models developed for individuals are incapable of handling complex responses to TDM strategies. For example, a person who performs an activity during the evening commute may forgo the activity when working a compressed workweek. This response obviously favors the alternative work-schedule strategy. However, the model does not consider that this activity may be reassigned to another household member who also undertakes it after work. In this case, the TDM strategy may prove ineffective in reducing the demand for car use during peak periods. Second, such models do not account for joint out-of-

home activities—namely, activities in which more than one household member participates. This means that predictions of activity-travel behavior are likely to be inaccurate. For example, multiple out-of-home activities may be predicted for household members when, in fact, only one exists.

Two approaches have been proposed for implementing activity-based travel demand models. The first method models “tours,” which are sequences of activities that begin and end at home. To date, several tour-based models have been implemented for cities in the United States including Boise, Idaho (Shiftan 1999) and Portland, Oregon (Bowman et al. 1999). The second more comprehensive method is *microsimulation*. Miller (1996) defines microsimulation as an approach to modeling systems that are both dynamic (i.e., they evolve over time) and complex in which the model is formulated at the disaggregate level of individual decision-making units such as households, their members and firms. Microsimulation is an attractive approach for evolving decision-making units and characteristics of a city over time, thereby making medium- and long-term forecasting possible (Kitamura et al. 1996; Miller 1996; Miller and Salvini 1997, 1998; Stopher et al. 1996). Its other advantages for activity-based travel demand modeling include data efficiency, behavioral interpretation, representation of complex interactions and mechanisms that affect behavior, flexible aggregation of results and increased policy sensitivity (Kanaroglou and Scott 2002). In part, these advantages are derived from the ability to represent an entire population within a microsimulation framework. This population can be synthesized by using one of two methods: that by Wilson and Pownall (1976) or that by Beckman et al. (1995). Finally, microsimulation has also benefited from the paradigm shift that occurred in the computing and information sciences in the early 1990s—that is, the shift from structured to object-oriented programming. *Object orientation* is, however, more than an approach to computer programming. It also encompasses a rigorous conceptual methodology for modeling complex systems and processes such as those constituting an activity-based travel demand model. Although none have been fully implemented as yet for a city, work is progressing on several such microsimulation models including ILUTE (Integrated Land-Use, Transportation and Environment modeling system) (Miller and Salvini 1997, 1998), SAMS (Sequenced Activity Mobility Simulator) (Kitamura et al. 1996) and SMART (Simulation Model for Activities, Resources and Travel) (Stopher et al. 1996). For reasons cited above, activity-based travel demand models offer policy makers a superior alternative to UTMS for forecasting behavioral responses to supply and demand strategies aimed at reducing traffic congestion. One key advantage of these models is their ability to consider lateral or secondary impacts to TDM strategies (Scott and Kanaroglou 2002, 2003; Shiftan and Suhrbier 2002). Scott and Kanaroglou’s (2003) work concerning the compressed workweek suggests that such impacts can detract significantly from the original intents of such strategies. Another key advantage of activity-based travel demand models is their capacity to account for *all* (i.e., both short and long run) behavioral responses that arise from an improvement in road capacity. In other words, induced travel is fully represented in such models, along with trips diverted from one period of the day to another. This is a significant improvement over UTMS.

5. Conclusions

Traffic congestion and emissions of harmful air pollutants are two consequences of intense automobile use. Although considerable gains have been made in reducing specific types of air pollutants over the past few decades (i.e., CO, NO_x, PM₁₀, SO₂ and VOC), the same

cannot be said for traffic congestion—that is, evidence continues to show that congestion is becoming much worse in Canadian and American cities of all sizes. It can be argued that the measures and tools available to policy makers for meeting the reduction challenge are responsible for this divergence in trends. On the one hand, policy makers continue to apply, with success, ever-tighter, legally-mandated emissions standards to incite improvements in vehicle technologies, which, in turn, reduce emissions. Conversely, their attempts at easing congestion through the application of various supply and demand strategies have, more often than not, failed to achieve desired results. The work contained in this paper for three specific strategies (i.e., roadway construction, jobs-housing balance and the compressed workweek) suggests the following reasons for this: failure to consider induced travel, failure to consider lateral or secondary effects and assuming that drivers are cost minimizers when they are, in fact, utility maximizers. To a large extent, these items have been overlooked by policy makers because of their reliance on UTMS for policy evaluation. The items are, however, accounted for in activity-based models, which represent the future of travel demanding modeling in North America. As such models become the norm, it is reasonable to expect that congestion-mitigation strategies will be scrutinized more rigorously and thus applied with fewer disappointing results.

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