EVALUATION OF COMMUTE EFFICIENCY: DESIGN AND SIMULATION OF FUTURE URBAN FORM SCENARIOS IN WINDSOR, ONTARIO (2011 – 2031)

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1. Introduction

The development of the automobile led to the expansion of urban areas over the past century. The most traditional urban form–compact form–became history only existing in cities with long history or high density. Dispersed and multinuclear urban forms have emerged in many cities in North America and Western societies. Consequently, commuting patterns became more complex. Featuring a city where commuters mainly gravitate to the city centre is not the only observed pattern any more.

Urban form of Windsor, Ontario exhibits a sprawled pattern. Sprawl is a main characteristic of a dispersed city with land use development happening far from the urban core (Maoh *et al*., 2010). Dispersed cities are also characterized with patterns of low-density development, leapfrog patterns as well as commercial strip development and discontinuous residential development (Ewing, 1997; Weitz and Moore, 1998; Galster *et al*., 2001; Hess *et al*., 2001). Typically, a sprawled city is usually featured as having a high car-dependency and very high level of commute. Consequently, more gas is consumed; higher tailpipe emissions are emitted and commuters can face congestion in rush hours. Studying the future of urban growth and its relation to commuting patterns via scenario simulation can help promote sustainable futures in Windsor.

In this paper, different urban form scenarios pertaining to various spatial distributions of worker's place of residence and place of work will be simulated and evaluated. The evaluation will focus on commuting patterns, transportation system usage and performance, and sustainable indicators for the Census Metropolitan Area (CMA) of Windsor, over the time period 2011 to 2031. The analysis will determine the most sustainable and least sustainable urban form growth patterns, in order to guide the land use and transportation planning process in this Canadian city.

2. Background

Urban form, as Anderson *et al*. (1996) defined, is the spatial configuration of human activities within a city. It can be represented by the spatial distribution of jobs and residences in an urban area. The three main types of urban form are: monocentric/compact, polycentric/multinucleated, and dispersed/sprawled forms. Research on urban form should be related to transportation when one plans the future of cities. Anderson *et al*. (1996), Behan *et al*. (2008) and Farber *et al*. (2009) also considered the environment as a third element since urban form and travel have direct impact on the environment.

Recently, two important concepts – "sustainable transportation" and "smart growth" – have emerged in the literature. Sustainable transportation is a concept used to balance the requirements of travel while insuring environmental protection, meeting social needs and maintaining economic growth (Black 2010). Smart growth, on the other hand, aims to promote sustainable urban forms by channeling future development to central areas (Behan *et al*., 2008). The aim is to achieve mixed land uses and reduce commuting distances.

Evidence from the literature suggests that the nature of urban form influence people's decisions of travel modes, commuting distance and patterns. Giuliano and Narayan (2003) showed that US cities with low development densities, dispersed population and employment, and compact British cities differ in the level of car-dependence, travel pattern and traveled miles. Further proof of the effect of urban form on commuting patterns can be found in the work of Li (2010) for Guangzhou, China. Owing to the occurrence of suburbanization and evolving urban form, the author observes a convergence in commuting behavior between Guangzhou and cities in Western societies. Additionally, Sultana and Weber (2007) developed a study for Birmingham and Tuscaloosa metropolitan areas in the United States to investigate journey-to-work patterns. Their analysis showed that sprawl, as an explanatory variable of commuting distances, is more important in smaller metropolitan area (e.g. Tuscaloosa).

A way to disentangle and evaluate the relations between urban form, transportation and the environment for a number of growth scenarios is to rely on simulation models. The four-stage model or the Urban Transportation Modeling System (UTMS) is usually used to estimate trips and assign them on the road network of a city to determine traffic flows. Sustainable indicators can give a comprehensive assessment of a given land use scenario that is input into the simulation model. Examples of such work can be found in Spiekermann and Wegener (2003), Maoh and Kanaroglou (2009) and Farber *et al.* (2009). For instance, Maoh and Kanaroglou (2009) developed the SUSTAIN module to evaluate sustainable indicators based on the results obtained from an integrated land use, transport and environmental model for Hamilton, Ontario.

3. Methods of Analysis

3.1 Study area and datasets

Windsor is the southernmost city of Canada. The metropolitan area has a population of 323,342 and a density of 301.1/km^2 (Wikipedia, 2010). As the capital of the Auto industry in Canada, Windsor also has a high car-dependency. The efficiency of commute directly affects air quality and resource consumption. In a sprawled city like Windsor, the level of commute is expected to be high leading to lower efficiency. The study area in this paper is the CMA of Windsor. The traffic analysis zones (TAZs) are based on the delineation of the 70 census tracts forming the CMA in 2006 (*Figure* 1).

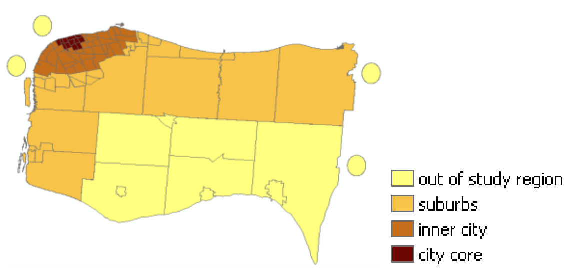

Figure 1 Map of TAZs in the CMA of Windsor and existing city core, inner city and suburbs

In order to estimate the status quo growth in population in future years, existing population information from the Canadian Census is used. The data include the following variables: increased population ΔP from 1996 to 2001, population size $P(t)$ and population density $D(t)$ of each census tract in 2001, and population growth $G(t+1)$ from 2001 to 2006 per census tract. Zonal population growth rate $G(t+1)$ for the period 2001 – 2006 is related to a composite variable $Z(t)$ that encompasses the rate of change in population size (derived from the difference in population size ΔP, where $\Delta P = P(t) - P(t-1)$, and population density $D(t)$ in the zone. After several experimentations, $Z(t)$ was calculated as follows:

$$Z(t) = \frac{\exp\left(\left(\frac{\Delta P}{P(t)}\right)^{\frac{1}{3}}\right)}{(D(t))^{0.05}}$$

Where t = 2001. Curve fitting using a third degree polynomial function is applied to establish a relationship between $Z(t)$ and $G(t+1)$ using the 1996, 2001 and 2006 data. The derived relationship is given as follows:

$$G(t+1) = 36.29Z^3(t) - 49.33Z^2(t) + 23.44Z(t) - 7.75$$

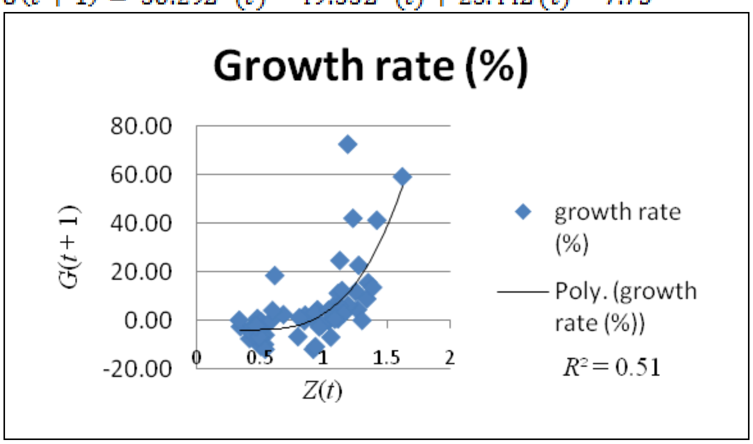

Figure 2 Population growth rate function

According to the derived growth function, higher population growth occurs in zones (census tracts) of low density but with higher rate of population growth in the previous time period. This is a pragmatic approach as it captures the effect of the ongoing sprawled development in the study area.

Using the existing census data and setting 2006 as the base year, the growth function is used to estimate the working population size of each census tract for the following future years: 2011, 2016, 2021, 2026 and 2031. The sum of zonal populations provides the CMA-wide worker population in each forecasted year (see *Table* 1). Since the working population corresponds to the existing jobs in the region, the forecasted number of jobs is the same as the forecasted number of workers at the CMA level. The ratio of jobs to workers in each zone is assumed to be the same over time. This allowed us to estimate the number of jobs in each zone in future years.

Table 1 Employment estimates in forecasted years

	2006	2011	2016	2021	2026	2031
Base Emp.	152990	159919	166000	170538	180986	192703
Forecasted Emp.		6929	6081	6538	8448	11717
Growth Rate (%)	5.0	4.5	3.8	3.9	5.0	6.5

The second datasets used in the analysis is the observed 24-hour Journey to Work (JTW) Origin-Destination (OD) matrix in the CMA of Windsor for 2006. We also used hourly work trip proportions that were available from the City of Hamilton, Ontario. Our analysis focuses on the morning rush hours (i.e. 6 am, 7 am, and 8 am). It should be noted that according to the Hamilton figures, work trips constitute more than 80% of the total morning peak period trips. Hence, the analysis of JTW for the morning peak period can effectively reflect the bulk of traffic on the road network in that period.

3.2 Scenarios

1) **Base Scenario**: In the base scenario, population of each census tract in each future year is calculated using the above growth rate function. As we can see from *Figure* 3, new jobs are distributed dispersedly following the current trend, while the residential location of new workers exhibits a sprawled (outward) pattern in the CMA.

2) **Compact Scenario**: 80%, 15% and 5% of the forecasted number of workers and jobs are assigned to the city core, inner city and suburbs respectively (*Figure* 4). In each year, the ratio of zonal new workers to city-core-wide total new workers is held constant.

3) **Worker Sprawl Scenario**: 5%, 15% and 80% of the forecasted workers are assigned in the city core, inner city and suburbs respectively (*Figure* 5). This scenario has the same job distribution as the compact scenario. The figure shows that job growth is concentrated in the city core, while new workers are allocated in the suburbs

4) **Combined Sprawl Scenario**: the distributions of forecasted workers and jobs reflect a sprawled trend in this scenario (*Figure* 6). Here, 5%, 15% and 80% of workers and jobs are assigned to the city core, inner city and suburbs.

5) **Polycentric Scenario:** According to the population density of each census tract in 2006 (*Figure* 7), the circled regions are the two major centers in the CMA. The west center is the existing city center, while the eastern centre is a potentially growing area. The existing population density of the tracts in the east centre is relatively high. Also, there is a proper distance between the west and east centers. Furthermore, as a newly growing area, the tracts in the east centre have the potential to accommodate new development in the future. 40% and 50% of new workers and jobs are assigned to tracts in the west and east centers respectively, while the remaining 10% are added in non-city center zones (*Figure* 8).

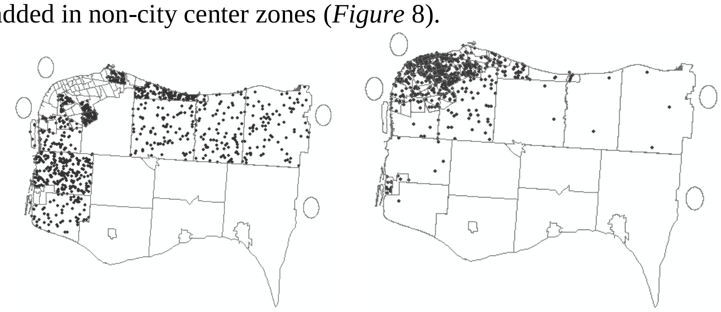

Figure 3 New workers (left) and jobs (right) distribution trends in base scenario

Figure 4 New workers (left) and jobs (right) distribution trends in compact scenario

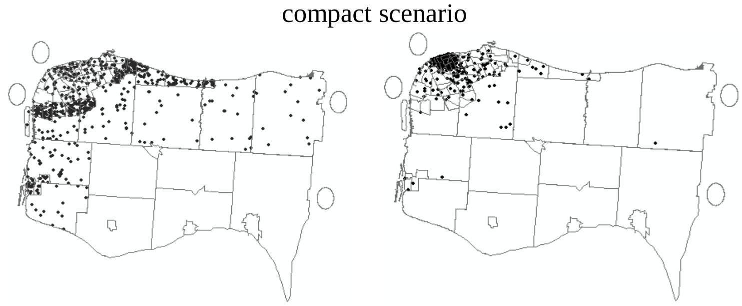

Figure 5 New workers (left) and jobs (right) distribution trends in worker sprawl scenario

Figure 6 New workers (left) and jobs (right) distribution trends in combined sprawl scenario

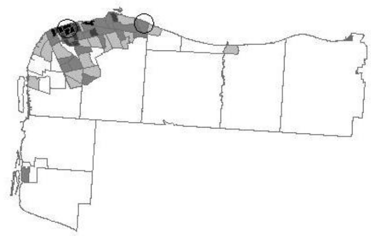

Figure 7 2006 population density in each tract

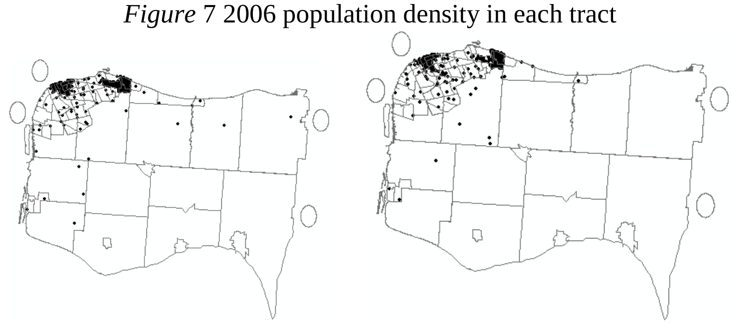

Figure 8 New workers (left) and jobs (right) distribution trends in polycentric scenario

3.3 Methods

The process of analysis consists of two steps: 1) evaluation of transportation system usage and performance measures, and 2) comparison of overall sustainability scores among all five scenarios. In the first step, CMA-wide total vehicle kilometer traveled (VKT), total vehicle minutes traveled (VMT), energy consumption (i.e. liters of gasoline used), and environmental tailpipe emissions for several pollutants (i.e. HC, CO, and NOx) are compared. The input data includes base O-D matrices for the peak hours (i.e. 6 am, 7 am, and 8 am) and the distribution of workers and jobs in each TAZ for each scenario. The fratar method is used to update the base O-D matrices pertaining to the peak hours for each future year and under each scenario. The estimated O-D matrices are then fed into stochastic user equilibrium (SUE) traffic assignment routine to determine network traffic flows. Based on the length, flow, and congested average speed for each link, emissions for several pollutants were estimated via mobile6C.

In the second step, sustainability indicator scores pertaining to the environment, society and economy are calculated and assessed. The indicators cover a range of themes including: air pollution and natural resources, commuting cost, mobility, urban expansion requirement, saving potential and efficiency.

4. Results

4.1 System usage in morning peak hours

The results from simulating the scenarios indicate that the compact scenario will produce the lowest number of VKT over time. This is expected since workers do not have to travel too long when their place of residence is in the same areas as their place of work (i.e. core of the city). The base scenario, on the other hand, generates the highest number of total VKT over time. Again, this is no surprise since the base scenario reflects a sprawled developmental pattern that follows the current trends of development in Windsor. These results are consistent with earlier findings in the literature. Total VKT in the polycentric scenario is the second lowest after the compact scenario. Two centers in the CMA will require higher level of commute compared to a city with only one center. However, the overall commute as discerned from the estimated VKTs is lower compared to the two sprawled scenarios.

When comparing the two sprawled scenarios, we found that the total VKT is smaller in the combined sprawl scenario. In the latter, workers and jobs are allocated in suburban areas. This will provide more possibilities for commuting within the suburbs. This in turn will reduce commute between the city core and suburbs. However, the values in both scenarios are very close although the patterns of jobs and workers distribution are not all the same. An explanation of this similarity could be traced to the current dispersed jobs distribution. The results for VMTs and energy consumption (i.e. liters of gas used follow the same patterns as VKTs over time and across scenarios.

4.2 System performance in morning peak hours

Overall link emissions of HC, CO, and NO_x are used to assess transportation system performance. Here, we report on the levels of emissions from HC during the morning rush hours for the winter season. The emission trends for the other two pollutants are very similar to HC over time and across scenarios.

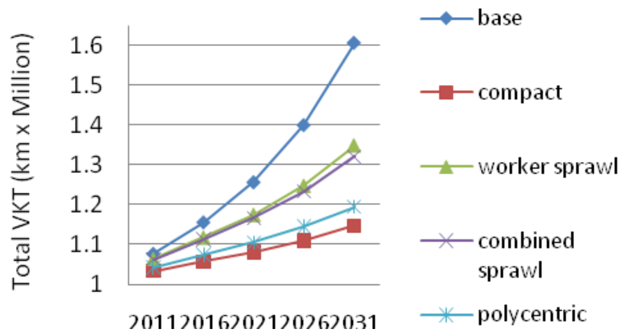

Figure 9 CMA-wide total VKT in 2011 – 2031

As shown in Figure 10, HC emissions in the worker sprawl scenario are almost the same as those in base scenario over time. The value of these emissions in the polycentric case is even higher than that in the combined sprawl scenario. The compact scenario still performs the best, but the curve is very close to the curve of the combined sprawl scenario. It should be noted that the estimation of emissions depends not only on the length of the link travelled but also the congested average speeds on that link. *Figure* 11 shows the congested average speed for the different scenarios. When driving speed is low, the emission factors are high resulting in higher emission levels. Therefore, avoiding congestion conditions is a precursor for reducing harmful emissions.

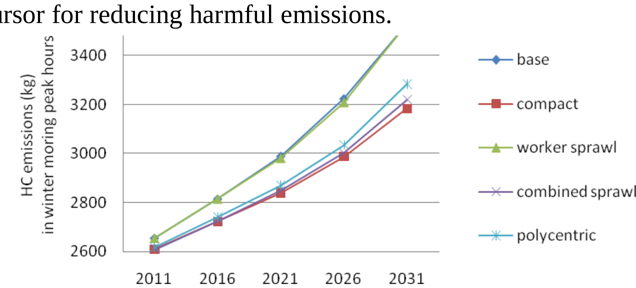

Figure 10 CMA-wide HC emissions in winter in 2011 – 2031

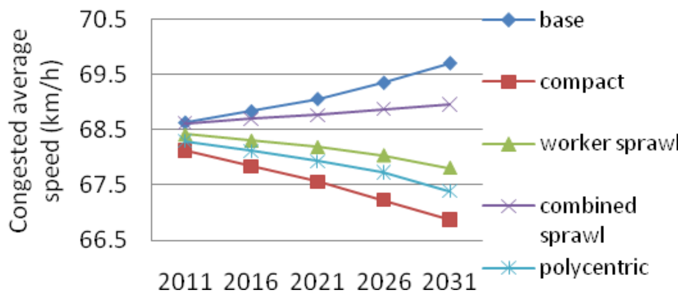

Figure 11 CMA-wide congested average speed in 2011 – 2031

4.3 Sustainable indicators

The sustainable indicators used in the evaluation are listed in Table 2. For brevity, the indicators are assessed for only the year 2031. Indicators: greenhouse gases, acidifying gases, volatile organic compounds, energy use from fossil fuels, total VKT, total VMT, congestion index, and congested average speed can be extracted directly from the results in section 4.1 and 4.2. Consumption of land resources is reflected by the areas of all tracts with density (either of workers or jobs) higher than 1000/km^2. Distribution width is defined as the largest Euclidean distance between any two tracts with density higher than 1800/km^2. As noted earlier, the expansion of a city is a trend characterizing modern cities. The distribution width is introduced as a new indicator to capture the effect of city expansion. Here, 1800/km^2 is chosen after many tests. This density value effectively distinguishes one scenario from the others and reflects how much the city is likely to expand under each scenario. Minimum commuting cost is the lowest cost that can occur when all workers move their residence close to their workplaces based on the nature of urban form. Minimum commuting cost is determined by minimizing the total average commute for each scenario (see White, 1988 for the method of optimizing total average commute). The minimum commuting cost used here is presented in terms of commuting distance per trip.

Since there is no specific emphasis on any theme in our modeling exercise, every indicator shares the same weight in all 11 indicators. These 11 indicators are compared and summed up using dimensionless scores. The Base scenario is used as a benchmark. All the scores of indicators are listed in *Table* 2.

Table 2 Sustainable indicator scores

	Indicators		Base	Compact	Worker sprawl	Combined sprawl	Polycentric
	Environment	**Total**	**5**	**4.344**	**5.104**	**4.829**	**4.468**
1	Greenhouse gases		1	0.891	0.991	0.908	0.911
2	Acidifying gases		1	0.878	0.976	0.903	0.892
3	Volatile organic compounds		1	0.901	1.000	0.911	0.929
4	Energy consumption		1	0.715	0.840	0.823	0.744
5	Land consumption		1	0.959	1.297	1.284	0.992
	Society	**Total**	**3.2**	**2.783**	**2.704**	**2.596**	**2.469**
6	total VKT		1	0.714	0.840	0.823	0.744
7	total VMT		1	0.754	0.877	0.855	0.814
8	Congestion index		1	0.915	0.987	0.918	0.911
9	Distribution width		0.2	0.4	0	0	0
	Economy	**Total**	**2**	**1.477**	**1.785**	**1.511**	**1.464**
10	min. commuting cost		1	0.439	0.755	0.499	0.421
11	Congested avg. speed		1	1.038	1.030	1.012	1.043
	Overall		**10.2**	**8.604**	**9.593**	**8.936**	**8.401**

The results in Table 2 suggest that the adoption of a polycentric growth pattern will produce the most sustainable outcome. The overall score for the polycentric scenario (8.401) stands as the lowest among all scenarios. The compact scenario is the second best compared to all scenarios. From an environmental point of view, the polycentric scenario ranks second behind the compact scenario. However from a social perspective the polycentric scenario ranks first. It seems that the development of the east part of the city will lessen the concentration of traffic on certain busy corridors leading to a slight reduction in overall congestion. As for the economic benefits, the polycentric scenario prevails over the compact scenario. The existence of multiple centers will lead workers to live closer to their place of work. This in turn will reduce commuting distance and increase economic efficiency. The base scenario appears to provide the worse sustainability outcomes. This is followed by the worker sprawl scenario. Evidently, the current pattern of development, being sprawl, is not sustainable. In summary, the polycentric scenario offers the best overall outcomes despite the fact that it is ranking second in terms of its environmental score.

5. Conclusion

This paper proposed, simulated, and evaluated a number of scenarios of urban form growth patterns for the CMA of Windsor, Ontario. The assessment of these scenarios considered three main aspects: transportation system usage, system performance and sustainable indicators. When it comes to the first two aspects, the compact scenario performs the best as far as the lowest values of total VKT, total VMT, energy consumption and pollutant emissions. Although the polycentric scenario ranks second when considering raw measures of usage and performance, it becomes the most efficient scenario from a sustainability perspective. Given that the expansion of cities nowadays can hardly be avoided, the polycentric urban form provides an advantage over the compact form.

In order to promote polycentricism, the most direct and effective way is to develop a second city center. Nice residential and commercial buildings with more job opportunities and more service accessibility to the city center will attract people to move close to or into the city center. Also reliable transit infrastructure and road networks connecting the developed centers may increase the utility of these centers in the future. Consequently, a new polycentric city can evolve in the right direction.

Meanwhile, it is important to avoid highly sprawled urban form growth patterns. Irregular jobs and workers distribution as in the case of the base scenario should be avoided at all costs. Insufficient levels of land use mixing of jobs and workers within zones due to sprawl will degrade transportation efficiency. A useful method to curb sprawl could be to restrict the private usage of green land. Also, proper increment of land price in the suburbs will discourage uncontrolled suburban development. Also, policies directed to provide a reliable alternative to the private vehicle for journey to work (for example, a rapid and frequent transit system) may lessen the use of cars and indirectly could control the increasing outward growth of cities.

The research in this paper paves the road for future research. First because of the lack of data, indicators related to health, accessibility to services, quality of open space, residential amenities, costs on transport investment, accidents, noise, and economic benefits from transport were not evaluated in this study. Furthermore, surveys to assess the importance of different indicators should be done when possible. Additionally, this study only considered work trips during the morning peak hours and for a typical weekday. How the transport system performs in other periods such as the afternoon rush hour and on weekends remains an important task to explore. Since non-work trips like leisure trips are also part of people's daily travel, there is a need to conduct research that will focus on these trips in the future. Finally, the relation between urban form and commercial vehicle movement in cities is also an important aspect that should be studied in future research.

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