THE JUSTICE OF URBAN CHANGE: ASSESSING THE SUSTAINABILITY AND DISTRIBUTIVE JUSTICE OF URBAN CHANGE USING AN INTEGRATED URBAN MODEL

THE JUSTICE OF URBAN CHANGE: ASSESSING THE SUSTAINABILITY AND DISTRIBUTIVE JUSTICE OF URBAN CHANGE USING AN INTEGRATED URBAN MODEL

By:
THOMAS A. LAVERY

A Thesis Submitted to the School of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree Master of Arts

McMaster University

MASTER OF ARTS (2012) McMaster University
(School of Geography and Earth Sciences) Hamilton, Ontario

TITLE:	The Justice of Urban Change: Assessing the Sustainability and Distributive Justice of Urban Change using an Integrated Urban Model
AUTHOR:	Thomas A. Lavery, B.A. Specializing in GIS (Trent University)
SUPERVISOR:	Dr. Pavlos S. Kanaroglou
NUMBER OF PAGES:	vii, 87

ABSTRACT

The importance of citizen's psychological need for community, amenities, and the feeling of equitable distribution of the varied impacts from urban change are gaining recognition as important factors in evaluating sustainable urban change. The inclusion of indicators that capture the equitable distribution of urban change impacts are a rare addition to the vast list of sustainability indicator sets available to researchers. Rarer still is the application of Integrated Urban Models (IUMs) and sustainability indicators in assessing the sustainability of land use and transportation policies which impact not only the form and structure of cities, but also the health and wellbeing of the city residents. Using three land use scenarios relevant to the study area: the City of Hamilton, scenarios which simulate alternative residential density patterns, the suburbanization of employment and the closure of elementary and secondary schools are projected into the medium term future using an integrated GIS-based model for simulating the consequences of demographic changes and population ageing on transportation (IMPACT), a sustainability indicator module and a set of indicators measuring the degree to which the urban change is just. The sustainability values generated from the use of IMPACT and SUSTAIN offer valuable insight to the literature related to each scenario. More importantly, the justice indicators add value information as to the impact of urban change on vulnerable population groups. The combination of IMPACT and SUSTAIN offers new avenue and method for future research on the sustainability of urban change.

Keywords: Integrated Urban Model, Distributed Justice, Residential Development, SMART growth, Sustainable Development, Job Sprawl, School Closures, Vulnerable Population, Land Use Policy, Transportation Policy

ACKNOWLEDGEMENTS

To my supervisor, Dr. Pavlos Kanaroglou, I would like to express my gratitude for providing your wisdom and guidance throughout the process of creating this work. Often I benefited from your advice towards producing quality research and reports. Advice which has profoundly impacted the way I view the world of academia and how to succeed in creating a meaningful role for myself in academic and private institutions.

The tool used to generate results for this research would not be here today if it were not for the contributions of Steve Spencer and Dr. Hanna Maoh who facilitated the use and customization of IMPACT and SUSTAIN through their hard work and timely advice.

The helpful advice provided by defense committee, Drs. Darren Scott and Niko Yiannakoulias was extremely helpful at improving the quality of this report. I appreciate and am thankful for the wisdom they offered during the defense of this thesis.

Finally, I would like to thank my colleagues in the Centre for Spatial Analysis for their assistance and company throughout my time at McMaster University. Their professional and personal support was appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES AND MAPS

1 INTRODUCTION

In 2001 the United Nations established a framework to assess and prevent extreme poverty, disease, hunger and illiteracy around the world in an effort to combat the inequitable distribution of both the positive and negative effects of globalization (United Nations 2011). Unequal access to wealth, education, food and medical care, in addition to unequal exposure to pollution and environmental degradation in cities around the world is a matter of justice. Without justice social instability can be manifested as disadvantaged groups seek more equitable treatment in their communities. Some recent examples of social instability around the world include the Arab Spring, protests against austerity measures in Europe and protests against tuition increases in Quebec. These events are evidence that the sustainability of a society rests in part on the just distribution of environmental, social and economic initiatives and policies which impact citizens.

Justice however, is a subjective concept. Should the consequences of change be distributed in a way that maximizes the benefits for all? Or should they be distributed equally among the population without regard of aggregate gains? This so called distributive justice is the focus of much literature on social and environmental justice. The theory of distributed justice, in the context of urban change, questions how a society should allocate the consequences of policy among individuals with different and often competing needs (Roemer 1996). This justice of distribution in the context of this research, relies on an understanding of vulnerability, a social condition which makes certain populations less resistant to change and which limits their ability to influence their physical and social environments (Cutter et al. 2003).

Certain age and socio-economic groups can be considered vulnerable based on their capacity to absorb changes in their physical and social environment. For example, children do not have the same ability as adults to absorb certain types of pollution without negative health implications because their body’s ability to detoxify and filter environmental hazards is not yet fully developed (Wild and Kleinjans 2003). Seniors also have a reduced capacity to cope with hazardous exposure to pollution as they metabolize toxins at a slower rate, often because of the reduced body mass which comes with age

(Schwartz et al. 2011). It is poverty though that represents the greatest risk to a citizen's health and well-being. Individuals in poverty are often exposed to more environmental hazards (Jerrett 2009) to which they often have less resistance due to nutritional deficiencies (Yassi 2001). Children, seniors and the poor are all identified as groups that also have unequal access to transportation which facilitates their inclusion in the community (Cass et al. 2005). Inadequate transportation supply and unjust population distribution are both responsible for creating socio-spatial exclusion among vulnerable groups of the population, negatively impacting social sustainability.

Unjust distribution of environmental and social stressors which negatively impact children, seniors and the poor reduces the social stability of the urban environment in which they live. Much early work related to distributive social and environmental justice utilizes race as the threshold defining vulnerable and non-vulnerable groups. This is because the study areas in much of this research were located in the United States, a nation which historically has suffered greatly from racial tensions (Pettigrew 1971; Bullard 1990; Jencks 1992). A broader definition of vulnerability is more suitable for a Canadian context however. Defining a vulnerable population as children, seniors and adults in poverty is based on recent literature regarding social exclusion and environmental justice (Cutter and Finch 2008; Miller et al. 2010). This analysis will offer insight on the distributive justice for a broader, and more inclusive vulnerable population to build on research relating race to social and environmental justice.

A sustainable urban social-ecological system has the ability to withstand social and environmental stressors that are created over time as the city changes. This ability also includes the system's ability to distribute stressors (and potential benefits) among the population in a just manner. Developed recently, the concept of a socio-ecological system recognizes that the distinction between social and environmental processes and the rules which govern the place in which people reside, should be considered together as one affects the other and vice versa (Adger 2006). The urban social-ecological system this research focuses on is the Census Metropolitan Area (CMA) of Hamilton, Ontario, a city region in which justice is a growing concern (DeLuca et al. 2012). In assessing the sustainability of urban environments, sustainability indicators are often used as a means to measure the degree to which a city is a sustainable urban social-ecological system.

According to Bossel (1999), in his comprehensive examination of sustainable development indicators, the psychological needs of citizens are important factors to be considered in evaluating sustainable urban development. Feelings of community, enjoyment of urban amenities, and a feeling of justice are key components to be considered when designing sustainable development indicators. Some researchers of sustainable urban change have included justice indicators which capture the important psychological factors that lead to social stability (European Commission 1998; Lautso et al. 2002; May et al. 2003; Minken et al. 2003; Lautso et al. 2004; Spiekermann and Wegener 2004).

Despite the potential negative consequences, as of yet there has been no effort in North America to project the sustainability of policies which seek to change urban socio-ecological systems. The literature on North American cities is rich with examinations of vulnerability and/or environmental and social justice as they relate to current or past time periods (Cole and Bowyer 1991; Lavalle and Coyle 1992; Jerrett et al. 2001; Buzzelli et al. 2002; Harner et al. 2002; Cutter et al. 2003; Apelberg et al. 2005; Buzzelli and Jerrett 2007; Cutter and Finch 2008; Havard et al. 2009; Shepard and Charles-Guzman 2009), yet lacking in research which seeks to test policies that impact the justice and sustainability cities *over time* and into the near future. To allow for the assessment of urban change over time, an Integrated Urban Model (IUM) can be used as a tool to project the impact of policies into future time periods. This research is an opportunity contribute to literature on using IUMs to assess sustainability (European Commission 1998; Lautso et al. 2002; May et al. 2003; Minken et al. 2003; Lautso et al. 2004; Spiekermann and Wegener 2004). As of now, this contribution is unique in the North American context, which only serves to add value to the results of this research.

A sustainability indicator module designed for the Hamilton CMA named SUSTAIN generates sustainability indicators that are focused on capturing the overall sustainability of urban change at an aggregate level of analysis (Maoh and Kanaroglou

2009). The indices are either measured as an aggregate of traffic analysis zones (TAZ) or the index values are generated for the entire CMA. Although the sustainability indicators measured by SUSTAIN capture the environmental, social and economic facets of urban sustainability, the module does not yield any information regarding the justice of pollution to the vulnerable. Instead, exposure to NOx and CO from mobile sources is calculated at a rate per 1,000 people. The population is therefore assumed to be homogeneous and distributed evenly throughout each grid cell. Indicators of social justice are impossible to measure using a homogeneous population as there is no way to assess the impact of urban change on more vulnerable individuals. This lack of functionality is due to the fact that SUSTAIN was originally developed for the Integrated Model for Urban Land Use, Transportation and Environmental Analysis (IMULATE) IUM, which does not project population cohorts with attributes; instead, households are treated as homogeneous (Anderson et al. 1994).

To assess the justice of urban change, the SUSTAIN module will be integrated to an IUM that projects not only the population for each TAZ, but also the composition of that population. IMPACT (An integrated GIS-based model for simulating the consequences of demographic changes and population ageing on transportation) is an IUM which facilitates this ability by projecting zonal populations in five-year age cohort groups (Maoh et al. 2007; Maoh et al. 2009), cohorts which can be used to organize the population into vulnerable and non-vulnerable groups.

One objective of this research is to assess the distributive justice of urban change using seven IMPACT scenarios which simulate land use policy initiatives related to residential development, employment suburbanization, and school closures. Sustainability indicators will measure the distributive justice of traffic pollution exposure, accessibility to services and the central business district (CBD), and the justice of access to hazardous industries, a set of indicators which capture the environmental and social aspects of urban justice.

The scope of this research does not include a detailed evaluation of the distributive justice of policies being tested nor does it include analysis on the sensitivity of certain types of distributive justice theory to policy, rather the results of these scenarios will be used to access the quality of IMPACT and SUSTAIN in generating sustainability indicators. A broad analysis of the results for each of these seven scenarios will offer evidence as to the value of using these tools in assessing social and environmental distributive justice. The objectives of this research are therefore to:

- Integrate SUSTAIN with IMPACT
- Draw conclusions on distributive social and environmental justice in the Hamilton CMA based on the disaggregation of the projected population into vulnerable and non-vulnerable groups.
- Evaluate the quality of SUSTAIN in generating indicators of sustainability based on the projected demographic, land use and transportation variables generated by IMPACT. Evidence of quality will be provided by assessing the logic of scenario results generated by IMPACT and SUSTAIN and by comparing the evidence gathered here to literature on the given land use policy.
- Determine if indicators of distributive justice add value to analysis regarding sustainable urban change.
- Recommend the types of scenarios IMPACT and SUSTAIN are best suited to simulate based on any weaknesses determined in analyzing simulation results.

2 SUSTAINABLE URBAN CHANGE

2.1 Defining Sustainable Urban Change

In assessing the sustainability of urban change, the term urban change itself is analogous to sustainable urban development and is used in its place because the definition of sustainable development is fiercely debated in the literature. Questions concerning the meaning of “development” have been raised by environmentalists and researchers, as public and private institutions often erroneously equate the “development” term to economic growth in particular, while devaluing the environmental and social aspects of sustainable development. Efforts at cataloguing the various definitions of sustainable development have been taken in the literature (Mebratu 1998), sparking debates over which approach to the definition is most appropriate between the three-pillar approach and the approach which emphasizes the human-nature relationship (Robinson 2004).

At a 1992 global conference, the Rio Earth Summit (United Nations 1992), 179 national governments agreed upon an agenda for urban change— and, importantly, also defined sustainable development in a way that encompassed factors other than environmental issues, which up until then had dominated discussions of urban sustainability. Previously, the definition of sustainable urban development was defined in the context of environmental or natural resources; for example, the UN Brundtland Commission (World Commission on Environment and Development 1987) defined sustainable development as “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs.” This process seeks a harmony between nature and the often conflicting aspirations of the different institutions and people which comprise a society. The report argued that environmental deterioration, human development and poverty had to be resolved simultaneously.

This research uses the Brandon and Lombardi (2011) definition of sustainable development while recognizing that defining “sustainable development” is subjective and is often suited to the authors’ unique political and philosophical outlook. In recognition of this idea, sustainable development of a built urban environment is defined by Brandon and Lombardi (2011) as “a process which aims to provide physical, social, and psychological environment in which the behaviour of human beings is harmoniously adjusted to address the integration with, and dependence upon, nature in order to improve, and not impact adversely, on present or future generations.” Due to the fact that the Brandon and Lombardi’s definition contains a psychological component, it is considered most appropriate for defining sustainable urban change, as the feeling of justice is a psychological need.

2.2 Comprehensive Sustainable Urban Change

Due to the complexity of urban environments, which consist of the built environment, the interaction of people, and the connection between built environment and human interaction, sustainable urban change is viewed in this research as three interconnected components: the environment, society and economy (Munasinghe 1993; World Bank 1996).

This definition has been challenged by Giddings et al. (2002) who argue that this three-dimension definition does not capture the fundamental relationships between those three dimensions. They argue that rather than researching the deeper issues of cause and effect between the dimensions, this definition assumes that trade-offs can be made freely between the sectors. The political reality, they insist, gives primacy to the economy over society and environment. Instead they suggest nesting the economy within the environment and society so that the economy is dependent on both. Despite these persuasive arguments, this research will use the traditional approach to defining sustainable change as built upon the three dimensions, because even Giddings et al. (2002) admit that the nested approach to defining sustainable change does not capture the full complexity of the relationships.

Sustainable urban change therefore consists of the environmental, societal and economic components identified by the World Bank (World Bank 1994). The environmental component consists of measuring pollution and the consumption of natural resources to determine the preservation of an ecological system's resilience and ability to absorb the negative environmental by products of urban environments (World Bank 1994).

The societal component refers to the mobility and health of the population and the economic opportunities offered by the urban environment. As part of the societal component, the justice of distribution for both the positive and negative effects of urban change refers to the degree to which these effects are distributed evenly among the population (United Nations 2011).

Based on the Hicks-Lindahl concept of maximizing the flow of income while maintaining the capital that produces this income, the economic component seeks to maximize the economic output of the city without compromising the capital of the urban environment in categories such as manufacturing, human, and natural (Solow 1986).

These pillars of sustainable urban change affect each other, since the positive or negative change in one component could have an impact on the others. Policies that seek to improve one pillar must therefore be tested with respect to the other components to ensure that the outcome is truly sustainable. SUSTAIN was designed with this intention, and this research seeks to improve upon this measurement tool with the addition of justice indicators that will address the psychological component of sustainable urban change.

2.3 Sustainability Indicators

To evaluate the sustainability of a proposed policy impacting urban change, it is necessary to have indicators that capture the components of sustainability in a measurable way. Indicators determine the present sustainability of a complex urban system and can be updated to reflect changes to sustainability over time. Traditionally, indicators are used in economics to determine progress in aggregate economic development. The recent popularity of sustainable development, or sustainable urban change, has prompted the creation of several indicators with different purposes and measured on different scales.

Since the Rio Earth Summit, more than 600 indicator sets are in use, designed for all spatial scales of analysis (Brandon and Lombardi 2011). The propagation of sustainability indicators underscores the importance of these systems in evaluating sustainable change. The indicators selected by the UN (United Nations 2007) are the most authoritative available. To measure progress towards the Millennium Development Goals, the Commission on Sustainable Development maintains and updates 50 indicators that capture all the components of sustainable change which the UN feels best represents sustainable development (United Nations 2011).

Some criticize the use of sustainability indicators in evaluating urban sustainable development due to a lack of consensus as to what constitutes urban sustainability

Table 1: SUSTAIN Indicators

Pillar	Theme	Indicator	Definition	Weight
Environment	Air Pollution	Greenhouse gases	Level of CO (kg) per 1000 people	0.083
		Acidifying gases	Level of NOx (kg) per 1000 people	0.143
		Volatile organic compounds	Level of HC (kg) per 1000 people	0.143
		Fine particulate < 2.5 µm	Level of PM2.5 (kg) per 1000 people	0.238
		Fine particulate < 10 µm	Level of PM10 (kg) per 1000 people	0.179
	Natural Resources	Energy use from fossil fuels	Litres of gas consumed per 1000 people	0.167
		Consumption of green space	Arable land area (sq. km) converted to urbanized land	0.048
Justice	Air Pollution	Justice of exposure to CO	Justice of exposure to harmful levels of CO	0.042
		Justice of exposure to NOx	Justice of exposure to harmful levels of NOx	0.167
	Accessibility	Justice of accessibility to services	Justice of accessibility to services represented as service employment	0.417
		Justice of accessibility to CBD	Justice of average travel times to CBD	0.333
	Industrial Pollution	Justice of hazards access	Justice of access to hazardous industries	0.042
Society	Health	Exposure to NOx from transport	Exposure to harmful levels of NOx per 1000 people	0.069
		Exposure to CO from transport	Exposure to harmful levels of CO per 1000 people	0.051
		Traffic Injuries	Traffic injuries per 1000 people	0.154
		Traffic Deaths	Traffic deaths per 1000 people	0.172
	Accessibility	Accessibility to CBD	Average travel times from all TAZs to CBD	0.129
		Accessibility to services	Average potential accessibility to services	0.137
	Commute	Vehicle km travelled	Total VKT per 1000 people	0.094
		Vehicle minutes travelled	Total VMT per 1000 people	0.103
	Mobility	Congestion Index	Average level of congestion in city	0.091
Economy		Transport investment costs	Dollars spent on maintaining roads	0.217
		Transport commuting costs	Overall cost of commuting	0.348
		Transport external costs	Dollars spent due to externalities associated with health	0.435

(Lundin et al. 2000; Lombardi and Cooper 2009). Some believe that they break up the problem of urban sustainability into ratios that do not reflect reality (Du Plessis 2009), and others contend that the selection of indicators merely reflects the interest of the authors (Adams 2006; Brandon and Lombardi 2011). The indicators for this research can be justified on the basis that a more participatory indicator selection that alleviates the critiques of centrally compiled indices has not yet been fully explored in the literature (Lombardi et al. 2010).

SUSTAIN (Maoh and Kanaroglou 2009) includes indicators based on the PROPOLIS and SPARTACUS sustainability evaluation systems (Lautso et al. 2004; Spiekermann and Wegener 2004) and Hatzopoulou and Miller's (2006) review of indicators of sustainable transport for integrated policy evaluation in Canada. These urban scale indicators (see Table 1) capture all three pillars of sustainable urban change as defined in this research. Similar to PROPOLIS, SUSTAIN aims to measure indicators based on the traditional three pillars of sustainability: environment, social, and economic. Themes measured in PROLPOLIS for each pillar include air pollution and natural resource consumption for the environment pillar, justice, health, opportunity, accessibility, commute and mobility for the social pillar, and cost for the economic pillar.

3 VULNERABILITY AND THE JUSTICE OF URBAN CHANGE

In addition to the aggregate measures of sustainable change developed originally by Maoh and Kanaroglou (2009) for IMULATE, justice indicators based on the disaggregation of the projected population into two vulnerability groups will be used to judge the distributive environmental and social justice of urban change based on two theories of justice, which have been quantified by the developers of PROPOLIS (Lautso et al. 2004; Spiekermann and Wegener 2004).

Using a comprehensive list of sustainability indicators, this research will determine if, and if so, to what degree, the urban change in the Hamilton CMA is sustainable. For the purposes of this research, sustainable urban change is considered to be urban change that maximizes the sustainability score for the three pillars of sustainability. Comparing the sustainability outcome of a scenario that simulates a policy initiative in future time periods with other scenarios will determine if the proposed land use policy is more or less sustainable compared to results from other simulations.

An important facet of the social pillar of sustainability indicators to be added to the original SUSTAIN is the set of indicators for environmental and social distributive justice. A just society and city will seek to distribute the positive and negative effects of urban change either in a way that maximizes the benefit of everyone or in a way which fairly distributes the impacts among different populations.

In assessing the "justice" of urban change, the term justice used in the context of environmental social justice literature relies on the theory of distributive justice. Defined as "how a society or group should allocate its scarce resources… among individuals with competing needs or claims" (Roemer 1996 pg. 1), distributive justice theory has long been discussed by philosophers and experts in other areas. The utilitarianism theory of distributive justice has been in the past, the default theory which determines what is just and what is not (Roemer 1996). In the context of urban change, the utilitarianism theory of distributive justice specifies that just allocation of the consequences of policies (both positive and negative) be allocated in a way which maximizes the total utility over the population. In response to this traditional stance on just distribution, Rawls (1971) introduced a view of justice which consists of the principles of egalitarianism. This concept of distributive justice relies on an understanding of equity between population groups. Rawls theory of justice introduced the "difference principle" which views the allocation of resources to the group of the population that is most vulnerable in a society as the most just distribution of resources.

3.1 Vulnerable Individuals

Certain individuals in society have a greater potential for unequal treatment and in many cases this population has a greater sensitivity to harm from environmental, social and economic stressors. This group of people are said to be more vulnerable than the bulk of the population and it is how this population is integrated and distributed in the CMA that partly determines how just a place is (Buzzelli et al. 2002).

Based on socio-economic and demographic factors, social vulnerability measures how resilient a population is to external stressors in the urban environment. However, this concept is difficult to define using a single variable, as it is often defined in the literature as multidimensional, generally consisting of ethnicity, socio-economic, gender, and age, specifically children and seniors (Cutter and Finch 2008). Regarding resilience to natural hazards, geophysical sciences and human ecology in particular, there are examples in the literature of efforts to characterize a vulnerable population using some of the above variables despite debates within academia as to a comprehensive definition (Eakin and Luers 2006; McLaughlin and Dietz 2008; Miller et al. 2010).

Vulnerability is not only the product of socio-economic and demographic variables, but can also be characterized by the built environment of the neighbourhood. Place vulnerability is affected by the level of urbanization or suburbanization, the economic vitality of the neighbourhood, and the demographic trends and population growth rates guiding the future composition of residents (Cutter et al. 2003). Vulnerable places, or places that cause the population some amount of external stress, are captured in this research as places that have high exposures to pollution from mobile sources and industry and places that lack accessibility to services and to the CBD.

To assess the distributive justice of urban change, the distribution of the consequences of a particular policy alternative among different groups of the population needs to be considered. Based on vulnerability research, two population groups will be studied here: a vulnerable population and a non-vulnerable population. Seniors (individuals aged 65+), children (aged 19 and below) and adults in poverty are individuals which are defined in this research as vulnerable. This definition is based on a review of literature on environmental and social distributive justice. Defining the vulnerable population using seniors, children and adults in poverty is also more appropriate for the Hamilton CMA than a definition of vulnerability based on racial differences. In recognition of the subjective nature of what constitutes the just distribution of urban change to vulnerable and non-vulnerable individuals, two different theories of justice are used.

The adults in poverty sub-vulnerable population is based on the Statistics Canada poverty rate measure, which classifies a certain percentage of the population in a given census tract as below the poverty line. The poverty rate has long been critiqued as an index that does not accurately measure poverty increases or decreases over time. Sen (1976) suggests that quality indices of poverty should increase if there is a reduction income among the poor or if income is transferred from a poor household to any other household or individual that is richer. For example, the poverty rate would conceal if incomes of poor individuals or households has decreased from one time period to the next (Myles and Picot 2000). Regardless, the poverty rate as determined by Statistics Canada is used to generate adults in poverty because other, more quality measures of poverty are not available for past census years. Preferably a poverty index like the Sen (1976), Shorrocks (1995) and Thon (SST) method would be utilized based on the indexes ability to measure poverty rate, the poverty gap, and inequality, however the historic poverty rate is required for this research to establish trends of poverty over time, trends that are the basis of projected poverty into future time periods.

3.2 Theories of Distributive Justice

The distributive justice of urban change can be understood in relation to the concepts of equity and efficiency. Because aggregated justice indicators are inherently objective, two theories of justice will be used to represent the subjective nature of justice. To allow for variation between theories of distributive justice, SUSTAIN will have the ability to modify the weighting of each justice theory. Based on the PROPOLIS justice indicator system (Lautso et al. 2004; Spiekermann and Wegener 2004), values of justice will be calculated for two theories of justice: equal shares and the utilitarian approach. The selection of these particular theories of distributive justice represents newer understanding of justice based on equity and the traditional definition based on utility maximization. These represent the equity vs. efficiency debate on distributive justice.

The equal shares philosophy is the belief that positive and negative impacts on sustainable urban development should be shared equally among all members of the population (Miller 1976). It is the equal shares philosophy that requires differentiation between vulnerability groups, as the effects of urban change are assessed to be either equally or unequally distributed among the two vulnerability groups. Equal distribution of impacts results in a high equal shares justice score. This approach incorporates equity and distributive justice to represent "objective equity" (Cook and Hegtvedt 1983), which, problematically can lead to a situation where the consequences of urban change are distributed purposefully to non-vulnerable individuals to ensure that both population groups are impacted equally.

Rawls (1971) justifies this stance however by developing the notion of "natural liberty," which argues that everyone should be allowed to benefit or suffer from the resources available or lacking from birth. This is different than his notion of "liberal equality," which argues that individuals are allowed to benefit from their natural talents, and not by the resources they are born with. From these ideas, Rawls developed his difference principle, where inequality is justified if it is to the benefit of vulnerable members of society, as long as inequalities are not based on resources provided at birth, and as long as everyone is provided with basic liberty to take advantage of natural talents (Hochschild 1981). The exclusion of a Rawlsian understanding of what is just, is based on the limitations SUSTAIN, which is unable to determine if vulnerable adults in poverty are born vulnerable or not. Instead, all children (including the new born) are considered vulnerable because of their reduced capacity to absorb pollution without harm (Wild and Kleinjans 2003) and their lack of power to influence the society and the environment in which they live.

The opposing philosophy to equal shares would be the utilitarian theory of distributive justice which seeks to maximize the average positive impacts to the whole population without regard to the distribution among different population groups (Ryan 1997). If the urban change being measured is a negative factor (such as exposure to pollution), an increase in this factor will result in a lower justice score without regard to the distribution of this change among the population. At the same time positive urban change (such as an increase in total accessibility) will increase the justice score from the utilitarian perspective on justice theory.

SUSTAIN will include the ability to weigh justice theories that are used to generate results. The purpose of providing the ability to weigh justice theories is to allow future research regarding the sensitivity of justice indicators to policies influencing urban change. By quantitatively analyzing the sensitivity of the two weighted justice indicators it would be possible to characterize exactly what *type* of distributive justice is being achieved by the consequences of urban change. It will also provide a means to optimize the weights in future research.

3.3 Environmental Justice

Environmental justice is a relatively recent global movement that challenges the inequitable exposure to pollution and environmental degradation borne by individuals and communities more vulnerable than the general population. Often this literature is associated with activism aimed at curbing environmental stressors that disproportionately affect low income communities and communities that are racially segregated (Harner et al. 2002; Shepard and Charles-Guzman 2009).

Led by Bullard (2011) in the 1980s, the social justice and environmental movements were combined into a grassroots environmental justice movement based on the correlation between waste facility sites and demographic characteristics which specifically identified race as the variable which best predicted the location of new waste facilities (Commission for Racial Justice 1987). In 1991, delegates to the First National People of Color Environmental Leadership Summit drafted the principles of environmental justice that set forth a unified vision and set of values for the movement. As of 2004 the majority of U.S. states have official policies aimed at avoiding inequitable exposure to pollution and environmental degradation (Shepard and Charles-Guzman 2009). This policy development is a result of activism and academic studies (Cole and Bowyer 1991; Lavalle and Coyle 1992; Lee 1992) which strongly support the relationship between disadvantaged population groups and exposure to pollution.

The body of literature that connects social distributive justice and air pollution from traffic is small but growing globally (Jerrett 2009). Evidence of the unequal distribution of different types of traffic pollution by socio-economic status and race has been gathered for cities in the United States (Apelberg et al. 2005; Havard et al. 2009), New Zealand (Pearce et al. 2006), Britain (Brainard et al. 2002), Sweden (Chaix et al. 2006) and in Canada (Buzzelli and Jerrett 2007). Unlike most other cities, evidence from Toronto suggests that traffic pollution exposure is actually lower for racial minorities due to Toronto's role as a destination for highly-skilled immigrants with financial resources.

Significant literature exists regarding the distributive justice of exposure to traffic pollution for Hamilton, Ontario, primarily as a result of the work by Buzzelli and Jerrett (Jerrett et al. 2001; Buzzelli et al. 2002; Buzzelli et al. 2003; Buzzelli and Jerrett 2004). Results from their research suggest that the environmental justice of exposure to traffic pollution is related to socio-economic status and racial minorities, a similar situation to many U.S. cities. Low income, unemployment and racial minority statuses were significant predictors of exposure, though in contrast to American cities, Asian-Canadians in Hamilton were disproportionately impacted as opposed to the Latin population in American cities (Jerrett et al. 2004). In addition, higher acute mortality effects linked to air pollution exposure was found to be associated with Hamilton census tracts that have lower socio-economic status. There has been increased interest in recent years in the topic of inequality across Hamilton neighbourhoods, including a multi-part series in the local newspaper which won several awards for its reporting and analysis (DeLuca et al. 2012). Based on this literature, projecting the distributive justice of exposure to traffic pollution and access to hazardous industries in Hamilton CMA is an important addition to SUSTAIN.

3.4 Social and Economic Justice

Since Harvey's 1971 book "Social Justice and the City" (Harvey 2009), literature connecting social justice to the application of spatial and geographic principles in urban and regional planning has been present in geographic literature. Social and economic equality in urban environments has its foundation in distributive social justice defined as: "fairness in the apportionment of resources" (Dempsey et al. 2009). In the urban context, an equitable society is one in which there are no purposeful or accidental discriminatory practices or policies excluding individuals from the economic and social benefits of society (Ratcliffe 2000). Spatially, social inequality can be seen in areas where there are disadvantaged people and families who are living in a poor environment, who in some cases, lack access to a range of public services that other areas of the city enjoy (Macintyre et al. 1993).

Measures of social equity are reviewed in Dempsey et al. (2009). The most cited measure of social equity is accessibility to service facilities and transportation services (Barton 2000; Burton and Mitchell 2006) which is captured in several indicators within the society pillar of SUSTAIN. The justice of accessibility to services and to the CBD captures the effect of the built environment on accessibility. A just society must be one which maximizes social inclusion, in other words, a population's ability to participate in society. Accessibility to a space, which depends on the user's location and also the means they have available to navigate to that space, represents society's ability to provide all members with equitable access to space and activities. In providing the population with greater and more equitable accessibility through the provision of transportation supply, an urban area will increase social inclusion of all members positively affecting the sustainability of the urban environment (Farrington and Farrington 2005).

In this research accessibility is a function of space, in other words how far one must travel, and *time*, which is represented as the cost of travelling from one location to another. It is useful here to draw upon work by Miller (2005) in defining social exclusion using the space-time activity theory (STAT), which defines exclusion as constraints on an individual's ability to access or extend themselves to limited activity locations for limited durations of time. Different population groups will have different controls over their location in space and time which varies with respect to social factors such as socio-economic status, age and gender (Pas 1984; McNally 1998; Kwan 1999). The justice of this control, as determined by the equal shares and utilitarian theories of justice, is an important contributor to assessing the sustainable change of the Hamilton CMA.

4 SCENARIO LITERATURE

To determine if the addition of justice indicators to the SUSTAIN module is a useful addition to the sustainability indicators developed previously (Maoh and Kanaroglou 2009), a set of scenarios selected based on topical events in the Hamilton CMA will be simulated to the medium term future (the year 2026). The first simulations will test the theories of SMART growth which dictate, among other things, that denser, more walkable communities developed from scratch or through urban residential intensification (URI) discourage auto dependence and increases urban sustainability (Calthorpe 1993). The second scenario, alto related to literature on SMART growth, will simulate the effects of employment suburbanization, a phenomenon that the Hamilton CMA has experienced over the last two decades. The final scenario is a particularly topical issue, specifically for the City of Hamilton, which has seen elementary and secondary school enrolment decline as a result of rapidly-aging population. In response to this declining enrolment, the Hamilton-Wentworth District School Board (HWDSB) has decided to close a number of schools throughout the city in an effort to cut costs from the annual budget, a policy which has created significant controversy among residents of the city (Pecoskie 2012b).

4.1 Residential Development Patterns

Significant literature exists which links residential development with transportation variables that have a negative influence on mobile source air pollution, vehicle kilometers travelled, energy consumption and auto dependence. Specifically, it is a well-established fact that excessive spatial growth of residential and commercial land uses, also known as urban sprawl, is associated with these negative transportation impacts (Newman and Kenworthy 1989; Kanaroglou and South 1999; Behan et al. 2008; Farber et al. 2009).

This information lends evidence to researchers promoting the principles of SMART growth as a way of improving the sustainability of urban environments (Calthorpe 1993; Ewing 1999; Corrigan et al. 2004). The principles of SMART growth include: community planning, sustainable infrastructure, nature conservation, the promotion of land use mixes and increased density to name a few (see Corrigan et al.

2004 for more). A major component of SMART growth includes increasing residential population in the CBD and other previously developed residential tracts using three distinct strategies for the urban core (Williams et al. 1999):

- Redevelopment: The demolition of existing structures in favour of new residential developments.
- Infill: Underutilized properties within the urban core are developed or redeveloped.
- Conversion: Existing residential and other land uses are renovated or converted into residential units in the case of other land uses.

These strategies are the key strategies in URI, which has been found to improve the environment, and reduce urban sprawl, leading to reduced congestion, energy use, and mobile source air pollution (Filion and McSpurren 2007; Behan et al. 2008; Farber et al. 2009; Newman and Falconer 2010). In addition, other work links the density of residential development to reduced auto dependence (Newman and Kenworthy 1989; Holtzclaw 1994; Newman and Kenworthy 1999), improved public transportation service (Wiley 2009; Thompson et al. 2012) and quality of life (Jones 2003; Beatley 2004).

The initial SUSTAIN simulation results in Maoh and Kanaroglou (2009) did not replicate the extensive URI and SMART growth research which suggests these concepts and methods lead to positive environmental, social and economic impacts. Rather, their results suggested that sprawling land use development had a positive effect on the overall sustainability indicator, which meant that urban sprawl, instead of URI, was the alternative residential land use pattern which was more sustainable for the Hamilton CMA. Their URI simulation performed better compared to a reference scenario and a sprawl scenario in only the environmental pillar of indicators, while the sprawl scenario scored higher in the social and economic pillars. Given these surprising results, they identified some future research considerations related to SUSTAIN, including the ability to disaggregate the population in socio-economic groups according to age.

The three residential land use scenarios simulated here partly address this concern by adding vulnerability groups and justice indicators to the list of sustainability indicators. This research will also rely on a different system for designating which TAZs will see an increase in residential growth over projection time periods. Map 1 displays the different land use designations for the TAZs used for the URI, expansion and sprawl land use scenarios. Expansion TAZs are zones which are primarily composed of recently constructed residences (in the past 15 years) which also have space for further residential development. Sprawl zones are zones which are not composed of recently constructed residential units, and except for three zones, these are census tracts that have space for new development. Consideration is given to the Government of Ontario's *Greenbelt Plan 2005*, which limits the spatial growth of GTHA urban areas within protected a "belt" of conserved agricultural and green space (Government of Ontario 2012).

The zones that will receive a greater proportion of residential development in the URI scenario are those in the downtowns of the City of Burlington and Hamilton. The City of Hamilton is designated as a "place to grow" in the Government of Ontario's *Places to Grow Act* (Hemson Consulting 2005), so the addition of the CBD of Burlington to URI census tracts is at the discretion of the authors. The City of Hamilton also intends to promote URI in and around a future light rail transit line known as the B-Line corridor (City of Hamilton 2010; City of Hamilton 2012), part of the City's nodes and corridors strategy of URI (Dillon Consulting 2006). In each scenario, the URI, expansion and sprawl zones will have 40% of the CMA's new dwellings distributed to them respectively, with the remaining new residential development distributed to all other zones based on their land use classification.

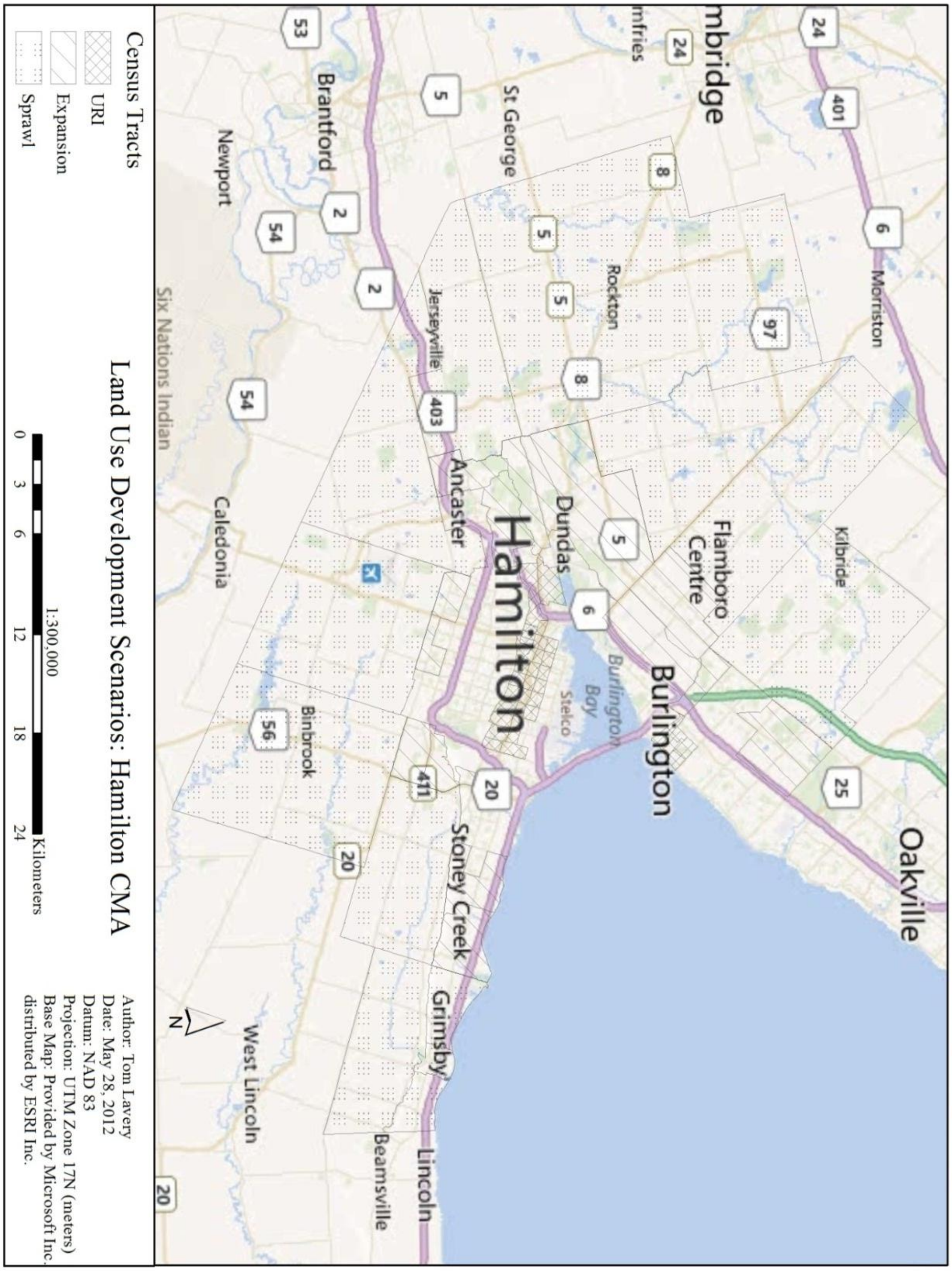
4.2 Suburbanization of Employment

The movement of people and jobs away from the CBD of the city is a long-standing trend in North American that dates back to the 1950s, when residential and commercial land use choices began favouring suburban locations over centrally located spaces. Over time this, land use development has tended to turn formerly monocentric cities into multinucleated cities containing well established peripheral centres based on existing transportation corridors and intersections (Anderson et al. 1996). This dispersed pattern of development, although not necessarily considered sprawl, has been linked with similar negative impacts on the environment, society and the economy of urban systems (Ewing et al. 2007; Newman and Falconer 2010).

When jobs and residences locate at a distance from the CBD, the changing spatial distribution of a city's jobs can impact its economic productivity, environmental sustainability, and social inclusion as the commute to work tends to make up the bulk of automobile trips generated in a city (Kneebone 2009). In most North American cities, the new predominant urban form under which development takes place is "edgeless," where employment congregates along transportation corridors. This development pattern has further distanced workers from their jobs, aggravating the historic increase in distance between residence and employment locations (Lang 2003).

In studies using 1990-2000 U.S. census data, Stoll (2005) and Holzer and Stoll (2007) identify an increasing spatial mismatch between workers, often less affluent and African American, and their place of employment. They identified trends that point to increased employment opportunities in the suburbs, and more specifically higher income suburbs, which forces residents from lower income inner suburbs to commute to increasingly distant places of work. Using data from 102 U.S. metropolitan regions, Stoll (2005) concluded that the spatial mismatch between workers and their place of work disproportionately affects low income residents and residents which are a visible minority. Employment decentralization has continued to occur in the U.S. where, by 2006, 97% of major metropolitan areas experienced a decrease in the share of jobs located within three miles of downtown. This trend is also widespread among industry groups, with almost every industry experiencing a shift in employment away from the CBD between 1998 to 2006 (Kneebone 2009).

There is evidence this U.S. literature that job sprawl has disproportionately impacted population groups that could be considered more vulnerable which means this "job sprawl" potentially decreases urban justice. More of the vulnerable residents bear a disproportionate amount of the negative consequences of urban change. The Hamilton CMA has seen a 48.3% increase in jobs located in the suburbs and rural areas and a 10.2% decrease in employment located in the urban cores of Hamilton and Burlington

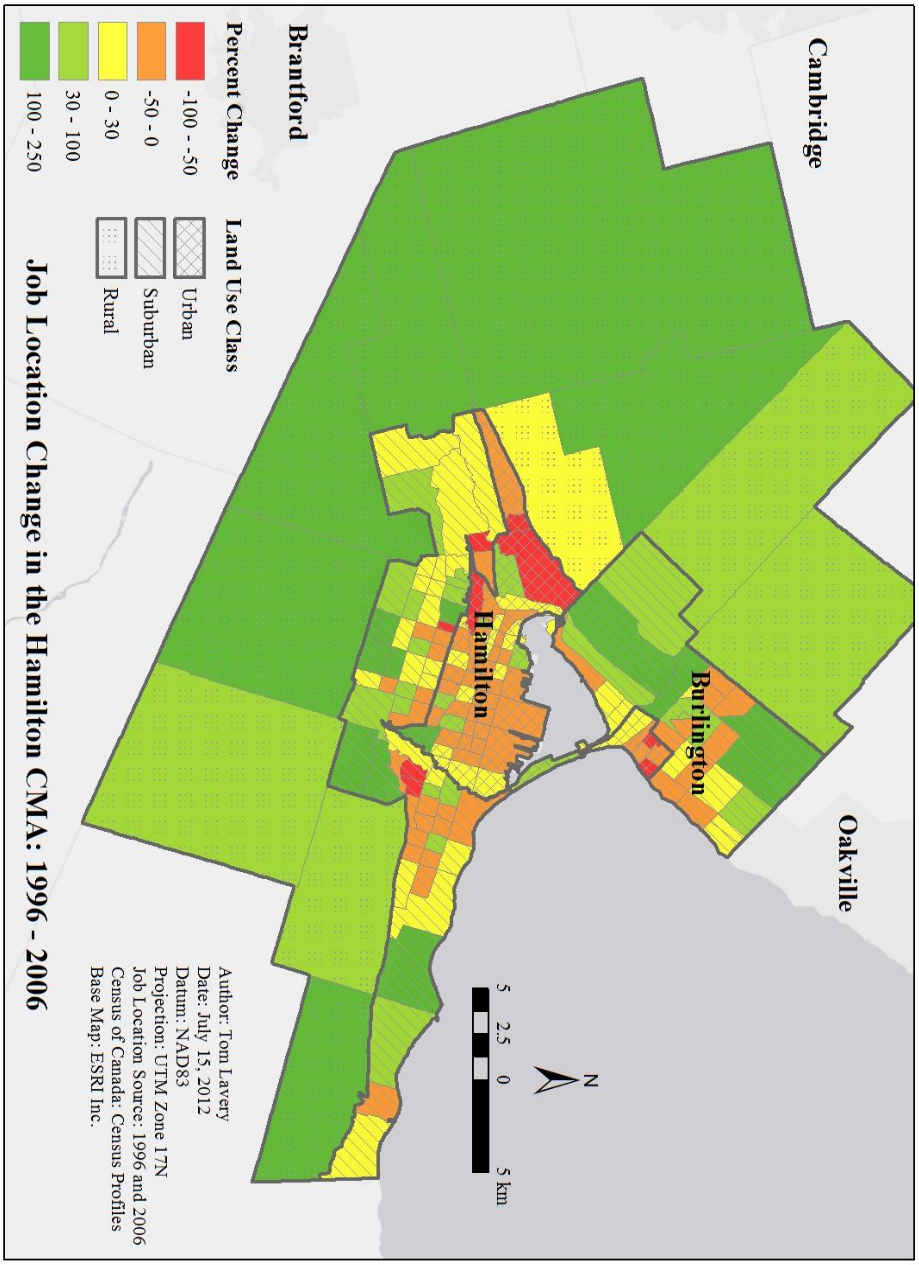


Map 1: Census Tracts by Designation

between 1996 and 2006 (see Map 2), a situation which up until now has never been associated with potential injustice.

Using a combination of kernel density surfaces, univariate and bivariate K-function estimations, Maoh and Kanaroglou (2010) compared and analyzed residential and commercial development in the City of Hamilton for the decades spanning from 1950-2003 to determine the current and future urban form and whether there is a spatial and interdependent relationship between residential and commercial development. They found that both residential and commercial floor space shifted away from the older part of the City of Hamilton (which was developed mainly pre-WWII), and towards the suburbs. Residential dispersal intensified from the 1970s onwards, and commercial dispersal started to intensify in the 1990s. The authors found that the distance between commercial and residential locations in the suburbs increased from the 1990s onwards. Despite this study being done on the City of Hamilton, the authors concluded that the same suburbanization of employment has taken place in The City of Burlington, as Burlington has a far greater proportion of its residents living in recently (last 15 years) constructed suburbs (90.7%) than does Hamilton (60%). The Hamilton CMA can be said to be undergoing two phenomena. First, it is experiencing the long and historic trend of job sprawl, where suburban residential and commercial floor space is becoming further disconnected. Second, considering the aforementioned research on the spatial mismatch between jobs and workers in the U.S. context, the job sprawl patterns in the Hamilton CMA potentially impacts more vulnerable population groups disproportionately – an outcome that SUSTAIN will measure with the addition of justice indicators.

The second set of land use scenarios simulates the sustainability and distributive justice effects of increased job sprawl and increased job centralization. From the time periods of 2001 to 2026, the number of jobs added to the suburbs will continue from historic trends in the job sprawl scenario, whereas the job centralization scenario would reverse past job sprawl, ensuring that the proportion of jobs in urban areas steadily increases over projection periods.



Map 2: Job Location Change

4.3 School Closures

The U.S. Environmental Protection Agency (EPA 2003) has identified demographic trends in the U.S. which have led to a decrease in the school-aged proportion of the population. This has meant that school boards have had to close older neighbourhood schools in favour of larger schools often located in the suburbs of cities, in part because of the volume of land required for such construction. This trend and has raised concerns over the lack of residential density and network connectivity in the areas where these new schools are being built which has resulted in a broad shift in travel mode choice for journey to school trips favouring the automobile (Ewing et al. 2004).

Relocating schools from neighbourhood locations acts to increase the distance students must travel, often prompting parents of students to drive their children to school. The new location of the school also changes the street network and urban form students must navigate in their daily journey to school, a change which also is recognized to increase auto dependence for the journey to school (EPA 2003). Not surprisingly, as distance increases, the likelihood of the student walking or cycling to school decreases, while those located within 1.6 kilometers from school are still most likely to walk (Ewing et al. 2004).

As schools become increasingly remote and disconnected from the residences of students and their families, the rate at which they commute to school using an active mode has declined from 90% in 1969 to 49% in the mid-1970s to 14% as of 2004 (Schlossberg et al. 2006). Urban form variables such as population density (Braza et al. 2004), quality of sidewalk infrastructure (Boarnet et al. 2005), network connectivity (Trapp et al. 2012) and accessibility from origin to destination (Ewing et al. 2004) in addition to household variables like car ownership (Ewing et al. 2004; Muller et al. 2008) and parental perceptions of heavy neighbourhood traffic (Timperio et al. 2004; Trapp et al. 2012) all impact journey-to-school mode choice. To exacerbate the negative environmental and health consequences for children, factors encouraging active modes of transportation to school tend to be more favourable in dense urban areas, where the bulk of schools are being closed. The potential impact on the sustainability of urban areas has yet to be tested despite the potential of the consequences to affect primarily children, a population which does not have control over the communities in which they live.

The Hamilton CMA, like most other city regions in North America, is characterized by an aging population and a decreasing demand for seats in elementary and primary schools. As the percentage of infant to 19 year olds in the CMA dropped from 26% in 2001 to 23.4% in 2011 (Statistics Canada 2012b; Statistics Canada 2012a), pressure has been placed on school boards with low or declining enrolment, to close in favour of amalgamating students to fewer, new or renovated facilities to save costs (Pecoskie 2012b). Closing a significant number of schools in the next five years is a unique situation faced by the Hamilton-Wentworth District School Board (HWDSB) within the Hamilton CMA, however (see Map 3). The public school board's Catholic counterpart has proactively closed 11 schools in the past decade to combat declining enrolment, resulting in only a handful of surplus seats compared with the HWDSB's 11,000 seat surplus (Pecoskie 2012b). The school boards which are responsible for the City of Burlington on the other hand, are not facing the same declining enrolment: the population has grown in the last ten years by 16% compared to the City of Hamilton's 6% which has impacted the population of school-aged children. Hamilton's school-aged (5 to 19 years old) population declined by 4.5% from 2001 to 2011 compared to Burlington's 7.7% increase in population for the same cohort.

To simulate the environmental consequences of increased reliance on automobiles that school closures are known to cause, a scenario which simulates the closure of 19 schools and construction of three new facilities in the City of Hamilton will be assessed. Schools which are slated to be closed in the next five to ten years will be removed from the simulation to assess the sustainability and distributive justice of policies related to closing schools.

5 THE HAMILTON CMA AND INTEGRATED URBAN MODELS

5.1 Hamilton Census Metropolitan Area

The Hamilton CMA is a key component of the Greater Toronto and Hamilton Area (GTHA), the largest urban region in Canada. Located equidistant from the City of Toronto and the U.S. border, the Hamilton CMA is a strategically placed as a transportation hub (MITL 2009) and is the ninth largest CMA in Canada with a population growing from 692,911 to 721,050 between the 2006 and 2011 censuses (Statistics Canada 2012b). The amalgamated City of Hamilton and the City of Burlington make up the majority of the Hamilton CMA, which also includes the smaller Town of Grimsby (see Map 4).

5.2 Integrated Urban Models

Starting with Alonso's bid rent curve, which recognized the transportation/land use interaction by suggesting that the value of transportation cost savings was reflected in land prices (Alonso 1964), significant, early work was done by Lowry (Lowry 1964) and McFadden (McFadden and Domencich 1975) to model the urban environment as a result of the interaction of transportation and land use. Since then, several IUMs have been calibrated for different cities around the world to test public policy impacts: DRAM/EMPAL (Putman 1991) IRPUD (Wegener et al. 1991), ITLUP (Putman 1991), ILUTE (Miller et al. 1998), MEPLAN (Echenique et al. 1990), MUSSA (Martinez 1991),TRANUS (de la Barra 1989), and UrbanSim (Waddel 2002). These IUMs are used to test policies such as property taxes, road tolls, or transit fares; regulatory policies such as zoning, parking provision, rules of the road; or the addition of infrastructure such as public housing, new roads, or new rail or parking facilities.

IUMs are tools that honour the land use/transportation relationship which makes them particularly useful in assessing urban change and the associated change to urban sustainability (Lautso et al. 2002; Miller et al. 2004; Spiekermann and Wegener 2004; Behan et al. 2008). To test the multi-dimensional nature of urban sustainable change, the ability to test the impacts of land use policy changes on transportation and the population is fundamental to generating meaningful results. IUMs have been used to assess sustainability in the European context with SPARTACUS (European Commission 1998), PROPOLIS (Lautso et al. 2002; Duchateau 2004; Lautso et al. 2004; Spiekermann and Wegener 2004), and PROSPECTS (May et al. 2003; Minken et al. 2003), all of which are sustainability modules that take the outputs of IUMs to generate corresponding sustainability indices.

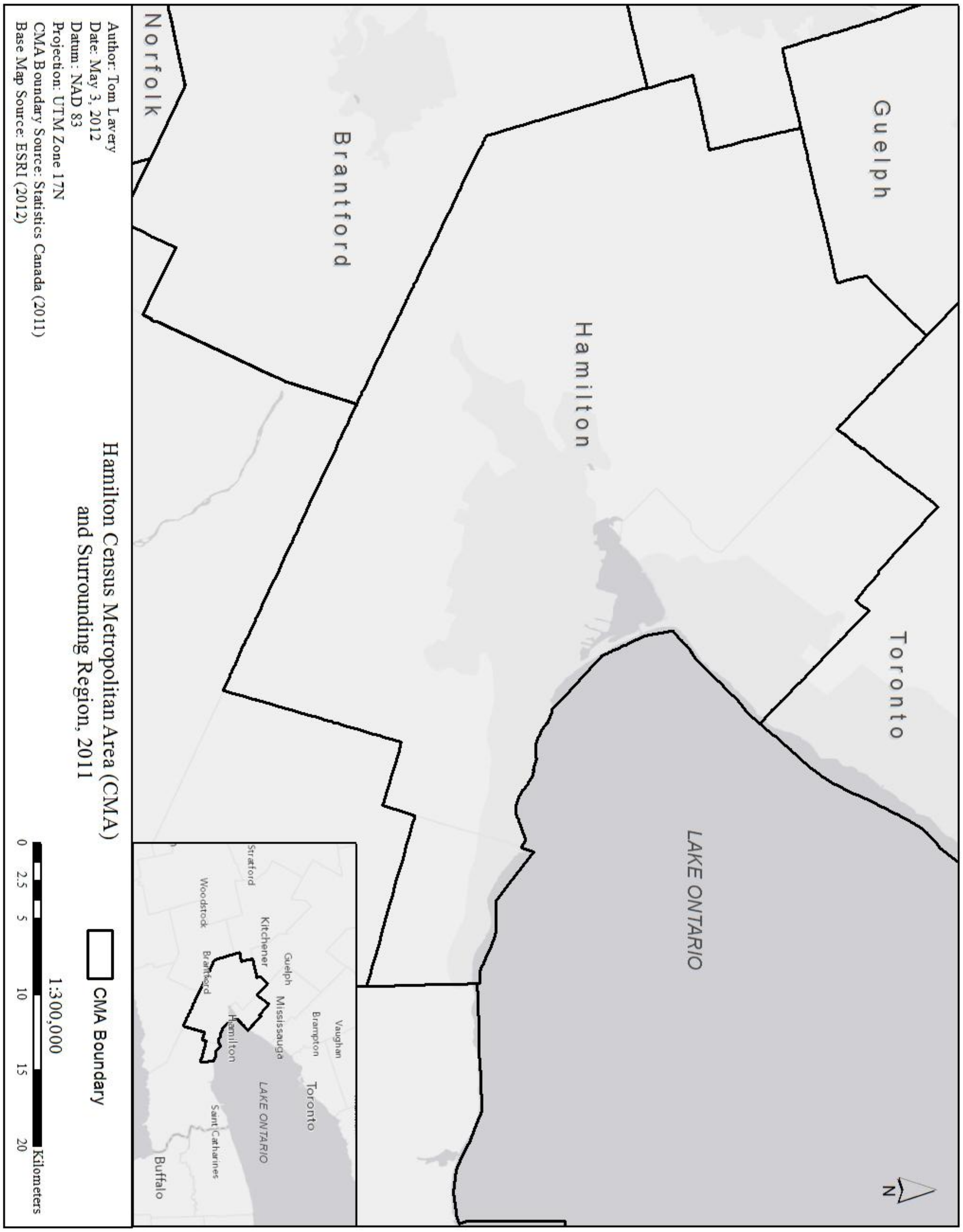
SUSTAIN was developed by Maoh and Kanaroglou (2009) as a module for IMULATE (Anderson et al. 1994), which has been used to assess commuting efficiency (Scott et al. 1997), energy use and consumption as a result of land use (Kanaroglou and South 1999; Behan et al. 2008), commercial vehicle emissions (Kanaroglou and Buliung 2008), the location of firms (Maoh et al. 2005), and for testing the impact of a light rail transit line (Lavery and Kanaroglou 2012) to name a few.

5.3 IMPACT System

IMPACT (see Figure 1) was developed to test the potential effects of an expanding elderly population and increased dependence on the automobile. This IUM uses three interconnected modules: demographic, transportation and environmental.

The demographic module relies on a Rogers multiregional demographic model and 1996 census data for age, mortality, sex-specific fertility rates and inter-municipal migration. Using an Aggregate Spatial Multinomial Logit (ASMNL) model the projected population is distributed to traffic analysis zones (TAZs), which are equivalent to census tracts for the Hamilton CMA. IMPACT uses census tract utilities for several variables, which are calibrated with an aggregated spatial multinomial logit model (Kanaroglou et al. 2009), and TAZ destination choice utilities from zonal revealed destination choices (Ferguson and Kanaroglou 1997; Kanaroglou and Ferguson 1998). In this way, the Rogers multiregional demographic model is extended to enable small area demographic projections using the ASMNL model. The transportation module of IMPACT assesses the travel for the driving population (aged 15 and over) and for the adult population

Map 3: School Closures



Map 4: Regional Context of the Hamilton CMA

(between 15 and 64 years old), where the difference between the two cohorts equals the elderly driving population (aged 65 and older). Using data from the 1996 Transportation Tomorrow Survey (TTS), eight trip generation models, sixteen trip distribution models, and sixteen modal split models were estimated by purpose and for four time periods throughout the day corresponding to morning, daytime, afternoon and night.

Based on personal, household and zonal variables, an ordered probit model predicts the changes of generating some number of trips (0, 1, 2, or 3+) (Paez et al. 2007). Personal attributes include the age cohort of the decision maker, gender, ownership status of a driver's license, if this person has a vehicle and/or transit pass, as well as employment status and access to free parking. Household variables are used to identify family structure and presence of children for the family to which the decision maker belongs. Finally, zonal attributes include the median income and the location of the TAZ in which the decision maker resides. Using the inter-zonal congested travel times and the attractiveness of potential destination zones, these generated trips are distributed to the TAZs through a production-constrained gravity model, based on Ortuzar and Willumsen (2001), that produces an origin-destination (OD) matrix of trips by purpose.

Again, using 1996 TTS data, the probability that a person belonging to a certain socio-economic category takes a certain mode for work or non-work purposes is estimated via a multinomial logit model (Train 2009). The utility of taking a particular mode is based on the utility that a person derives from using one of three modes in use in IMPACT: auto (driver), auto-passenger, and all other modes. The systematic utility is a linear combination of variables characterizing the mode choice between the given OD pair and the category in which the decision maker belongs. The trips are then assigned to the network using a stochastic user equilibrium model based on work by Sheffi (1984).

The environmental module, based on the approach in Anderson et al. (1996) and using the MOBILE6C emission model, uses link flows and average speeds from the traffic assignment routine to estimate carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOx) and particular matter (PM2.5 and PM10) emissions from traffic for each link.

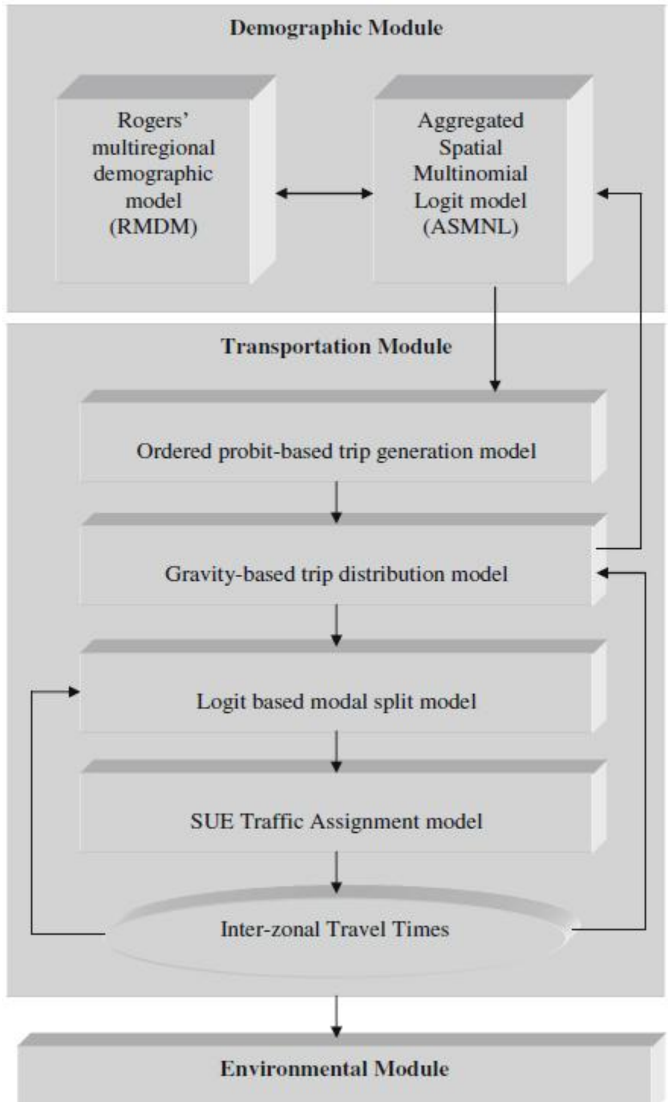


Figure 1: IMPACT Structure (Moah, Kanaroglou et al. 2009)

5.4 IMPACT Validation

Efforts have been taken recently to validate projected results generated using IMPACT, with actual, observed data. Using a reference scenario run to the 2001-2006 time period, Chen (2009) compared the results of the demographic and transportation modules to data collected in the 2006 Census of Canada and 2006 TTS. The results of this comparison verify that IMPACT is capable of accurately projecting demographics, population distribution and trip generation. She did however, find that the trip distribution model generated results that are less accurate than expected, which therefore affected the performance of the traffic assignment model.

The Rogers multiregional demographic model generated a simulated population that is only 1.52% less than the observed 2006 population in the Hamilton CMA. In terms of distributing the population to TAZs, the ASMNL predicts a population distribution with an R^2 value of 0.787 for males and 0.793 for the female population, indicating that the model is highly correlated to the actual, 2006 population distribution (Chen 2009).

For the transportation module of IMPACT, only the trip generation model performs as expected. For the morning, in the 2001-2006 time period, the trip generation model simulates only 3.86% and 2.47% more work trips and non-work trips respectively compared to observed traffic generated for each TAZ in 2006. The trip generation does not perform as well, simulating results with a R^2 value of 0.17 and 0.35 for morning, work and non-work trips respectively, indicating this model is less correlated to actual data than expected. Because the traffic assignment is based on the results of the trip distribution model and the modal split model (which at present has not yet been validated), the model assigned 37.91% less traffic to 91 random network links when compared with observed traffic flow on those links. With a R^2 value of 0.44, the traffic assigned to the Hamilton CMA links is less correlated with the observed traffic assignment than expected (Chen 2009).

Despite some of the inaccurate simulation results generated by the transportation module, IMPACT is the best available IUM calibrated for the Hamilton CMA that allows for the generation of the vulnerable population required in assessing the justice of urban change. The scenarios that are to be tested using IMPACT do not represent a "prediction" about actual impacts of land use and transportation policies in future time periods, instead the results of the various simulations are compared to each other to gain insight into the phenomenon being simulated. In this way IMPACT is a valid tool for the purposes of this research.

5.5 SUSTAIN Module

Table **1** displays the environmental, social and economic indicators used in SUSTAIN which are summarized here. With the exception of indicators created for this research, a more technical discussion of SUSTAIN indicators can be found in Maoh and Kanaroglou (2009).

Environmental indicators include five different types of traffic pollution normalized to a rate per 1,000 CMA residents, the consumption of gasoline per 1,000 people and an indicator for consumption of green space in the Hamilton CMA. The types of mobile source air pollution include greenhouse gases, acidifying gases, volatile organic compounds, and two sizes of particulate matter. As a representation of the consumption of non-renewable natural resources, consumption of fossil fuel is calculated using the parameters of the fuel consumption model developed for IMULATE (Anderson et al. 1994). The indicator for the conversion of green space and arable land to urban land uses calculates the total arable land converted to new residential land development during projection time periods in all census tracts.

Social indicators are generated for health, accessibility, commute, mobility and now justice themes. Exposure to unsafe levels of NOx and CO are calculated using regression models that are substitutes for a much more complex dispersion model (Maoh and Kanaroglou 2009). Two 2.5 km^2 raster surfaces (one for each traffic pollutant included) covering the Hamilton CMA are first created. The total population exposed to unsafe levels of pollution is then calculated based on the projected population in a given TAZ and the ratio of residential land in a given grid to the total residential land in the TAZ. For traffic accidents and injuries per 1,000 people, Transportation Canada incident rates per billion vehicle kilometres travelled (VKT) (669 for injuries and 9.3 for deaths) are used in place of more complex methods due to the difficulty in projecting accident and death rates associated with vehicle usage (Maoh and Kanaroglou 2009).

Accessibility is measured using the accessibility to the CBD and to services. Accessibility to the CBD is defined as the average travel time (in minutes) it takes to move from a TAZ to the CBD in congested traffic. Accessibility to service employment from one zone to another is found by dividing the number of service jobs in other zones divided by the travel times to those same zones.

The output of the traffic assignment routine is used to calculate the commute and mobility indicators. The total commuting VKT and vehicle minutes travelled (VMT) are normalized to a rate per 1,000 people. The mobility indicator is a reflection of the average congestion index for all links in the Hamilton CMA which is calculated for each link by dividing the projected flow for a given link by link's the capacity.

To capture the monetary costs that result from transportation, the economic indicators measure the cost to supply and maintain road infrastructure, the cost of commuting, and the external costs to society that result from transportation. Based on Transportation Canada estimates, the total cost of supplying and maintaining a kilometer of roadway is $0.027 per VKT and the cost of one minute of commute to the traveler is $0.114 (Maoh and Kanaroglou 2009). The final economic indicator uses a combination of other environmental and social indicators to reflect the cost of pollution exposure, injuries, and death based on Transport Canada and Ontario Medical Association figures which quantify the cost of transportation externalities (Maoh and Kanaroglou 2009).

6 INTEGRATING JUSTICE INTO SUSTAIN

6.1 Generating Vulnerability Groups

Distributing the positive and negative effects of urban change in a way that encourages the perception of equality among residents can only be determined by establishing that there are two principles of justice residents are likely to use when considering the distributive justice of urban change. Measuring the distributive justice of impacts requires the generation of vulnerability groups that will be impacted differently, thus providing a basis for measuring justice. Two vulnerability groups will be generated from the detailed population projected from IMPACT. Using information from the population pyramid from each census tract and a projected poverty rate, children, seniors and adults in poverty will represent the high vulnerability group and the remaining population of adults not in poverty will represent the low vulnerability group.

The first two justice indicators that measure exposure to NOx and CO from mobile source emissions are based on the disaggregation of the population into 2.5 km^2 grid cells which are exposed to the pollution in question based on a simplified pollution dispersion model (Maoh and Kanaroglou 2009). In the original SUSTAIN the census tract population (*Pj*) was disaggregated into grid cells using the following formula:

$$P_g = P_j * \frac{RLU_g}{\sum_{g=1}^{jg} RLU_g} \tag{1}$$

Where *g* represents the grid cell being populated, *j* is the census tract(s) the population numbers are being pulled from and *RLU* is an acronym for residential land use. The population of grid cell *g* is therefore a product of the total population in *j* and the proportion of residential land use from *j* that is contained by *g*. The detailed population projections generated by the demographic module of IMPACT enables a further disaggregation, namely the ability to separate seniors and children from adults. The high vulnerability group (P_h) for each *g* is described by:

$$P_{hg} = CHILD_g + SENIOR_g + ADULTP_g, where: \tag{2}$$

$$CHILD_g = CHILD_j * \frac{RLU_g}{\sum_{g=1}^{j_g} RLU_g} \tag{3}$$

$$SENIOR_g = SENIOR_j * \frac{RLU_g}{\sum_{g=1}^{j_g} RLU_g} \tag{4}$$

$$ADULTP_g = ADULT_j * POVRATE_{j,t+n} * \frac{RLU_g}{\sum_{g=1}^{j_g} RLU_g} \tag{5}$$

The low vulnerability group (P_l) is simply the population of *g* minus the number of highly vulnerable people in the same grid cell.

The poverty rate (*POVRATE*) at time period t for zone j is provided exogenously and is based on current and past Statistics Canada data describing the poverty rate for each census tract in the Hamilton CMA. For projected time periods ($t+n$) the poverty rate for j_{t+n} is calculated based on the average five year change in the poverty rate from the 1991 census to the 2006 census. The projected poverty rates begin for the 2006-2011 time period and continue to the final projection period. The poverty rate statistics for each census tract at a given time period are the result of the cumulative rise or fall of the poverty rate calculated from the average five year poverty rate change from 1991-2006.

The remaining three justice indicators are not disaggregated to grid cells. These indicators require that the population for zone j be grouped into high and low vulnerability groups based on the demographic module outputs from IMPACT. The high vulnerability group for j is therefore the sum of the children, seniors and adults in poverty residing in j while the low vulnerability group is calculated by subtracting the high vulnerability group from the total population of j.

6.2 Representing the Theories of Justice

For the five justice indicators to be comparable and compatible with previously-established sustainability indicators, they are standardized and weighted according to the justice theory weights provided exogenously.

The equal shares philosophy is the belief that positive and negative impacts on sustainable urban change should be shared equally among all members of the population. The formula used to achieve this is a variation on the equal shares formula used by the authors of PROPOLIS (Lautso et al. 2004). The equal shares theory of justice is represented in this research as:

$$ES_i = \frac{(P_{hi,t} * |\Delta_{ai} - \Delta_{hi}|) + (P_{li,t} * |\Delta_{ai} - \Delta_{li}|)}{P_{ai,t}} \tag{6}$$

The justice indicator being assessed for zone i (grid or census tract) is the sum of two weighted population groups (P_{hi} = high vulnerability and P_{li} = low vulnerability) divided by the total population (P_{ai}). The weights for each population group are based on the change in raw levels of a given variable (γ) from the base time period (t =1996,) to the projected time period ($t+n$). Δ_{ai} represents the change in γ from 1996 to the projected time period for the total population, Δ_{hi} is the change for highly vulnerable and Δ_{li} is the change for the low vulnerability group. Since γ equals exposure to mobile source pollution (NOx or CO), γ_{t+1} will, in most cases, be different from t. For accessibility to the CBD and services, γ will also change from t to $t+n$ based on the amount of congestion and distance between i and destination zones (See equations (13) and (14)). Because of the immobility industrial capital investments (large factories), the exposure to industrial pollution is an exogenous variable used in the IMULATE which does not change over time, as a result access to hazardous industries represents the number of people (and type) benefiting from a i with low access to hazardous industries. Change in variables for each population group is solved with the following formula:

$$\Delta_{ai} = \left(P_{ai(t+n)} * \gamma_{i(t+n)}\right) - \left(P_{ai(t)} * \gamma_{i(t)}\right) \tag{7}$$

$$\Delta_{hi} = \left(P_{hi(t+n)} * \gamma_{i(t+n)}\right) - \left(P_{hi(t)} * \gamma_{i(t)}\right) \tag{8}$$

$$\Delta_{li} = \left(P_{li(t+n)} * \gamma_{i(t+n)}\right) - \left(P_{li(t)} * \gamma_{i(t)}\right) \tag{9}$$

The utilitarian justice theory, contrary to the equal shares philosophy, would value an overall positive change for a neighbourhood without regard to whether that change was shared equally between groups. The utilitarian justice theory (U_i) is therefore represented as:

$$U_i = \Delta_{ai} \tag{10}$$

This formula is used when increases in γ are linked with negative outcomes for the population. Exposure to mobile source pollution and hazardous industries are examples of negative outcomes as a result of an increase in γ. Therefore if Δ_{ai} has a high value, the justice score will decrease as a result of the urban change that negatively affects the population of *i*. The opposite is true of the distributive justice of accessibility, which increases as γ increases, reflecting the fact that an increase in total accessibility has potential positive effects on the population. This contradiction of U_i contributing to justice in one indicator and to injustice in another is resolved in the standardization procedure described below (See equations (15**)** and (16)).

6.3 Generating Raw Justice Indicator Values

6.3.1 Justice of Exposure to Mobile Source Emissions

The raw values for the first two justice indicators are measures of exposure to mobile source emissions calculated for each vulnerability group. In these cases Hamilton CMA is divided into a set of 2.5 km^2 grid cells (*g*). The exposure index is modified from the original formula (Maoh and Kanaroglou 2009) as follows:

$$EXP_g = P_{ag}\delta_g, where \tag{11}$$

$$\delta_g = \begin{cases} 1, & CON_g > \tau \\ 0, & CON_g \le \tau \end{cases} \tag{12}$$

CON_g represents the concentration of the pollutant (either NOx or CO) in *g*, τ is a threshold which represents the level at which the concentration of the pollutant is harmful to humans used in the dummy variable (δ). When CON_g is greater than the threshold value determined by the user, then δ_g is equal to 1 and EXP_g for each vulnerability group is calculated. If CON_g is equal to 0 then the value of EXP_g is 0 for each vulnerability group indicating that no one in grid cell *g* is exposed to harmful levels of mobile source emissions. The U.S. Environmental Protection Agency (EPA) CO and NOx standards for unsafe 1 hour exposure to ambient air pollution are used as the threshold value for both pollution exposure indicators (U.S. EPA 1993; EPA 2000).

The change in total exposure (EXP_g) from t to $t+n$ for the total population and high/low vulnerability groups is used in the formulation of Δ_{ai}, Δ_{hi} and Δ_{ai} respectively, which are in turn integrated into the two justice theories. In equations (7), (8) and (9) EXP_g is integrated in the given formula as γ_i which would read as γ_g.

6.3.2 Justice of Accessibility to Services and CBD

Both justice of accessibility measures are generated using travel times (C) between zones in a congested traffic situation. When travel times between zones increase, the congestion and travel time increase, reducing accessibility both to services and the CBD. Accessibility to services is measured by averaging the potential access to service employment (SE) from i to all census tracts in Hamilton CMA ($j = 1,2,3 \ldots n$) each of which is divided by the inter-zone travel time (C_{ij}) squared. For the accessibility to services indicator C_{ij} is squared to increase the denominator which makes the final accessibility score a smaller, more manageable number. The accessibility to services from the origin census tract ($A_{services,i}$) is calculated using (Maoh and Kanaroglou 2009):

$$A_{serices,i} = \sum_{j=1}^{n} SE_j / C_{ij}^2 \tag{13}$$

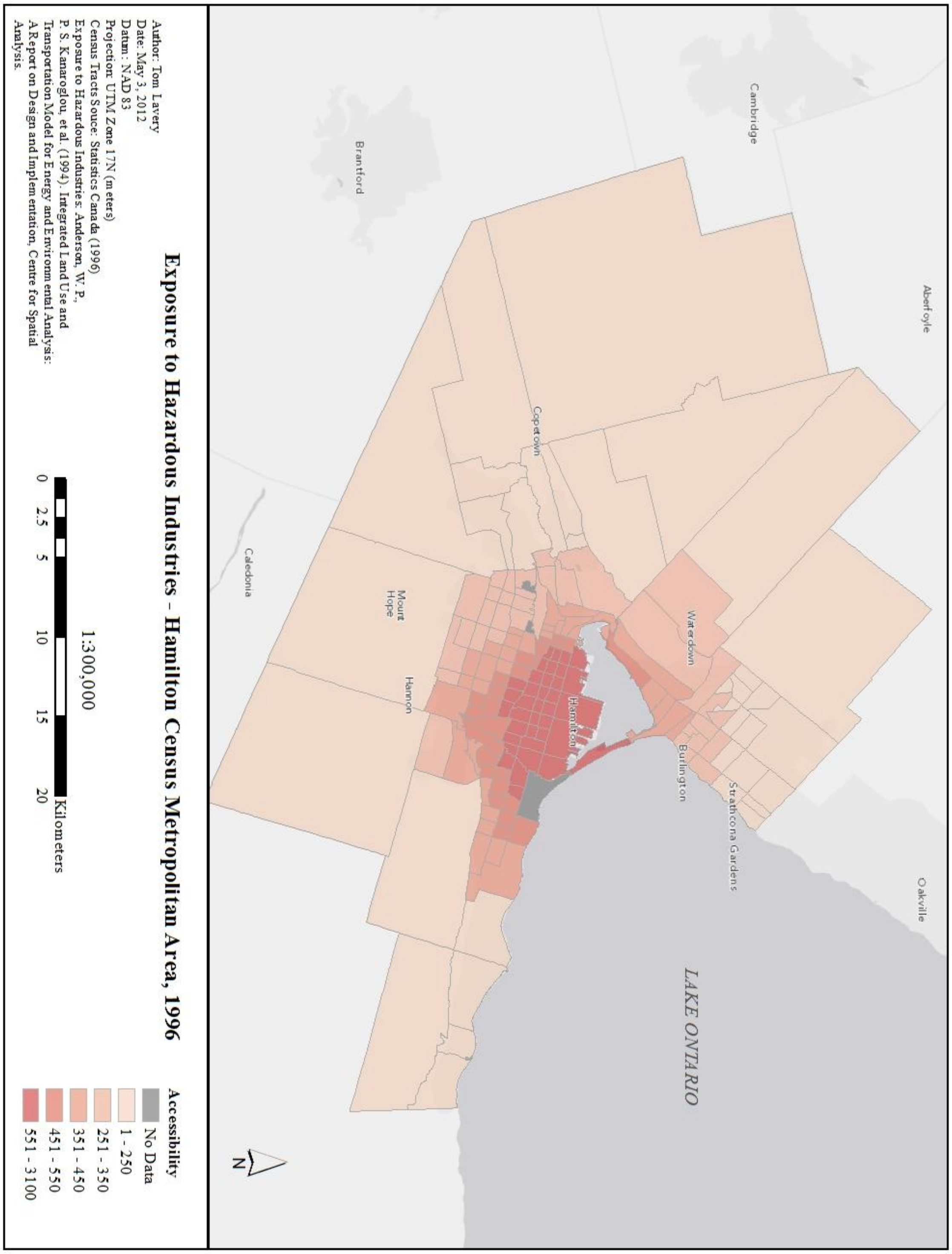
Accessibility to the City of Hamilton's CBD (A_{cbd}) is defined as the travel time that is required to move from zone i to the census tract defined as a CBD zone (j). As travel times to the CBD under congested conditions increase (C_{ij}), the accessibility to the CBD score will decrease, reflecting the reduced accessibility.

$$A_{cbd,i} = C_{ij} \tag{14}$$

Both accessibility measures are generated for each zone and integrated into Δ_{ai}, Δ_{hi} and Δ_{ai} formulas as γ_i at t and $t+n$ time periods. The change in accessibility for all population groups are then used to calculate the justice indicators for equal shares and utilitarian theories of justice.

6.3.3 Justice of Access to Hazardous Industries

The variable for access to hazardous industries for each census tract is a variable used in the location choice module of IMULATE (POPMOB). For the location choice model of POPMOB, access to hazardous industries is a disutility for census tracts with high access to hazardous industries, reflecting the significant external costs associated with pollution from heavy industry (Anderson et al. 1994). Because the location of heavy industry is relatively fixed in the Hamilton CMA due to existing infrastructure, the use of this statistic from the older IMULATE model can be justified. As the location of the industrial firms is assumed to remain static throughout the projection time periods (see Map 5), the exposure in census tract i will be the same at t and $t+n$. Any changes in the amount of exposure to the different vulnerability groups will be as a result of population mobility alone. If highly vulnerable people are attracted to zones with high relative to the low vulnerability, it is likely that a lower justice score will be the result. The exposure per zone is therefore equal to γ in the Δ formulas for all $t+n$.



Map 5: Exposure to Industrial Pollution

6.4 Standardizing and Weighing Justice Indicators

Before the justice indicators are standardized and integrated with other sustainability indicators, the raw justice values are themselves standardized using a different method which captures the fact that two of these indicators are a benefit to the population and three have the potential to cost the population in a given grid cell or census tract. Each justice indicator is therefore standardized twice. The first is weighted according to the exogenous weights for the equal shares theory (W_{es}) and the utilitarian perspective on justice (W_u). The second standardization integrates each indicator into the three pillars of sustainability indicators.

This research utilizes a linear scale transformation of values to first standardize the raw justice indicators generated by the equal shares and utilitarian justice functions. Standardizing the raw indicators allows for differentiation between benefit criteria, as represented by the accessibility measures, and cost criteria, which represent the exposure to NOx, CO and proximity to hazardous industries. The benefit and cost criteria are standardized to a value between 0 and 1 using the following formulas:

Benefit Criteria: $$X_i' = \left(x_i - x_i^{min}\right) / \left(x_i^{max} - x_i^{min}\right) \tag{15}$$

Cost Criteria: $$X_i' = 1 - \left(x_i - x_i^{min}\right) / \left(x_i^{max} - x_i^{min}\right) \tag{16}$$

Where X_i' is the criterion score for justice variable i, x_i represents the raw justice indicator value and x_i^{max} is the maximum raw justice indicator value generated by SUSTAIN. This software generates three values for each indicator representing the actual raw indicator and a hypothetical minimum and maximum value as determined by the Transportation Problem. In calculating the x_i^{max} and x_i^{min} values, SUSTAIN relies on the underlying premises of the Transportation Problem which determines the theoretical minimum and maximum values of an indicator based on the optimal distribution of trips for all OD pairs (minimum) and the least optimal distribution of trips (maximum). Generating the optimal trip distribution minimizes the distance that each individual travels in their journey to work (from origin to destination), while the least optimal distribution of trips places individuals as far away from work as possible within the CMA limits (Maoh and Kanaroglou 2009). Unlike the original SUSTAIN which generated these values based on a population migration (POPMOB) and employment location (EMPLOC) (Anderson et al. 1994), the new version of SUSTAIN utilizes zonal variables used in the production-constrained gravity model of IMPACT. The population of the origin zone and the percentage of non-residential land uses in the destination zone are used to find the most (x_i^{min}) and least optimal (x_i^{max}) OD pairings.

Justice theory values of $X_i'$are weighed by a value between 0 and 1 where W_{es} + W_u = 1. The weighted criteria score for justice variable for the given variable is integrated into the social pillar of sustainability indicators using the same method outlined in Maoh and Kanaroglou (2009) which again utilizes the x_i^{max} and x_i^{min} generated by the Transportation Problem.

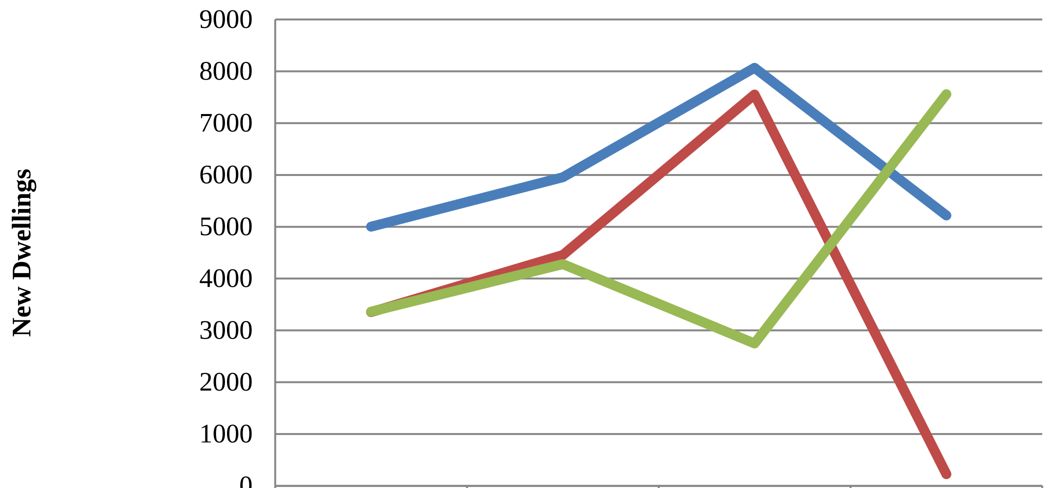
7 INTEGRATING SCENARIOS

7.1 Residential Development

Residential development scenarios will be simulated using the new dwellings exogenous variable which lists the total number of new dwellings per TAZ that is expected to be built for each projection period. For the four, 5 year projection periods from 2006 to 2026 the number of new dwellings expected to be developed is 12523, 14875, 20159 and 13027 new residential units respectively. These residential development projections were obtained from City of Hamilton estimates and distributed to individual census tracts in Kanaroglou et al. (2009). For each scenario, 40% of these new dwellings will added to URI, expansion and sprawl census tracts in their respective residential development scenarios (see Map 1). For each TAZ receiving extra new dwellings in simulation, they will receive an equal share. If the scenario census tracts already contain 40% or greater of the new residential development, then no new dwellings are added for that projection period (see Tables 2, 3 and 5).

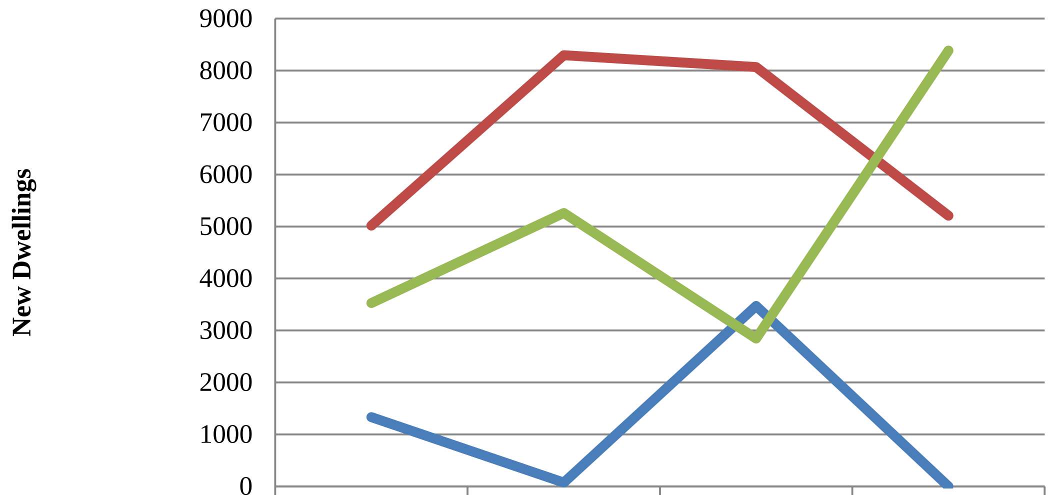
Deciding which zones (i) to remove new dwellings from will follow three rules. First, the total dwellings added in each projection period (t) for each development scenario ($NEWD_{i,t}$) will equal the total original new dwelling totals ($NEWD_{i,orig}$) regardless of the new distribution (See equation (17)). Second, zones that were originally projected to receive no new dwellings ($NODWELL_i$) in a given projection period will not have any dwellings removed (See equation (18)). Finally, these scenarios intend to change the development patterns of large developers and not small, private developers who, individually, are responsible for a smaller share of new residential development. To represent this rule, equation (18) shows that only those zones which have a greater or equal to average number of new dwellings being constructed for the projection period (μ_t) will be subtracted from.

Table 2: New Dwellings in URI Scenario



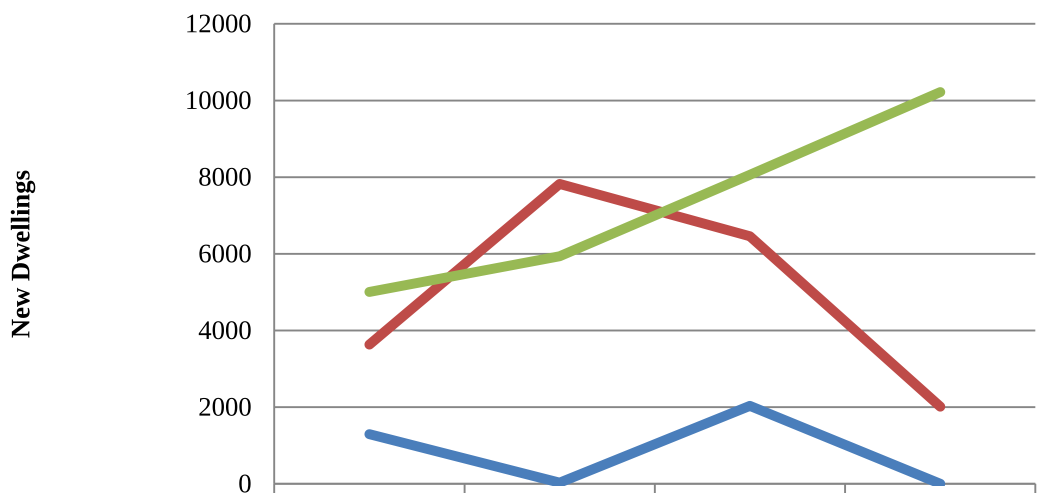
	2006-11	2011-16	2016-21	2021-26
URI Tracts	5002	5956	8067	5217
Expansion Tracts	3353	4456	7553	225
Sprawl Tracts	3363	4280	2746	7558

Table 3: New Dwellings in Expansion Scenario



	2006-11	2011-16	2016-21	2021-26
URI Tracts	1332	73	3472	0
Expansion Tracts	5016	8296	8069	5208
Sprawl Tracts	3527	5262	2844	8386

Table 4: New Dwellings in Sprawl Scenario



	2006-11	2011-16	2016-21	2021-26
URI Tracts	1297	30	2036	0
Expansion Tracts	3634	7823	6458	2012
Sprawl Tracts	5005	5938	8060	10218

$$\sum_{i=n}^{n} NEWD_{i,t} = \sum_{i=n}^{n} NEWD_{i,orig} \tag{17}$$

$$GRT_{i,t} = NODWELL_{i,t} \geq 0, and\ NODWELL_{i,t} \geq \mu_t \tag{18}$$

$$\beta_t = {D_{sub,t}}/{GRT_t} \tag{19}$$

Where $NODWELL_{i,t}$ represents the original new dwellings of zones that are not to receive new dwellings in a given scenario at a given projection period. $GRT_{i,}$ represent $NODWELL_{i,t}$ that are greater than 0 and μ_t. β_t is the number of dwellings that have to be removed ($D_{sub,t}$) from each zone that meets the criteria of the second and third rule (GRT_t).

The increase of new dwellings in scenario zones and the corresponding decrease in other zones, which originally were to have significant new dwellings, is expected to attract residents to the scenario zones in IMPACTs residential choice model. In the demographic module, the utility of moving to a particular zone, given that the resident is moving, increases as the number of new dwellings increase. Increasing the proportion of new residential units being developed in particular census tracts therefore increases the probability of selecting those census tracts as a place of residence (Kanaroglou et al. 2009). It is expected that zones receiving a greater proportion of new dwellings will see an increase in total population as these zones become more attractive. If the proponents of SMART growth are correct in their assertion that URI creates more walkable and sustainable communities, than the URI scenario is expected to score the highest sustainability score as a greater number of people relocate to the urban cores of the Hamilton CMA.

The degree to which people rely on the automobile for travel should also be reduced as individuals and families move to core zones better serviced by public transportation. To demonstrate that SMART growth concepts can be tested using

IMPACT and SUSTAIN, the URI scenario should generate the least amount of automobile traffic over all census tracts in the CMA and specifically, the census tracts which will be attracting new residents.

7.2 Suburbanization of Employment

To simulate the effects and sustainability of job centralization and sprawl on the Hamilton CMA, the zone specific variable that represents the total number of jobs present in each census tract measured in the 1996 TTS, will increase or decrease over the projection periods. From 1996 to 2006 urban census tracts (as defined in Map 2) saw an average job loss rate of 5% while suburban tracts saw an average job increase of 10%. In other scenarios the number of jobs in each census tract remains the same throughout projection periods based on information from 1996. In these scenarios, the reference scenario will reflect this historic trend in job suburbanization by increasing employment opportunities in suburban zones 10% for each of the 5 projection periods from 2001 to 2026.

To simulate a return of jobs to older neighbourhoods in the Hamilton CMA, the urban census tracts job counts will increase 5% per projection period while at the same time reducing the number of jobs in suburban tracts by 10%. In both scenarios the total number of jobs in the Hamilton CMA will not change, only the distribution of the employment. In the job centralization scenario it was necessary to add a small amount of jobs to rural regions in order to maintain the total CMA jobs while still distributing the jobs based on scenario parameters. Adding jobs to the rural regions of the Hamilton CMA is representative of reality, as rural census tract jobs almost doubled from 1996 to 2006.

These scenarios define urban, suburban and rural tracts in a way which will best represent the residential and employment structure of the CMA. Urban census tracts are defined as zones in which the majority of residential and commercial development took place before 1970, the year identified by Maoh and Kanaroglou (2010) as the year in residential dispersal began intensifying followed in the 1990s by commercial dispersal. At this time, commercial and industrial firms relocated closer to rapidly growing residential areas for better access to customers and employees. Suburban census tracts are therefore defined as zones which began to develop in the 1970s as residential choice preferences came to favour less dense, larger neighbourhoods (Maoh et al. 2010).

The different distribution of jobs in the Hamilton CMA will affect the *Aj* term used to represent the attractiveness of zone *j* for work trips in a constrained gravity model. Non-work trips will not be affected by these job distribution scenarios as the term used to define the attractiveness of zone *j* is a compound measure of the population and non-residential land use in *j*. The trip distribution model used in IMPACT is defined by Maoh et al. (2009) as:

$$T_{ij}^{w} = T_{i}^{w} * {A_j exp(-\beta t_{ij})} \Big/ {\sum_k A_k exp(-\beta t_{ik})} \qquad (20)$$

An OD trip matrix T_{ij} for work trips (*w*) is generated as a reflection of the number of jobs in the destination zone (A_j) and the inter-zonal congested travel time (t_{ij}). Because the β coefficient is negative, any increase in inter-zonal travel times will reduce the attractiveness of *j* compared to all other zones (*k*). An increase in the number of jobs in *j* on the other hand increases the attractiveness of *j* relative to other zones.

The effect of adding jobs to urban zones is expected to mildly decrease VKT, VMT and energy consumption, increasing the overall sustainability indicators modestly compared to the job sprawl scenario. Centralizing jobs in urban zones is not expected to increase the environmental and social distributive justice indicators to a significant degree as the zones with a greater share of highly vulnerable population tend to be located in urban zones which will likely see increased emissions and traffic, thereby negatively affecting justice of exposure to NOx, CO and the justice of accessibility indicators. The relationship between high attractiveness and traffic is expected to balance out the positive and negative effects, the net effect being a negligible increase in overall sustainability. Because the location of employment is a factor only in the trip generation model, the location of jobs does not influence the population distribution.

7.3 School Closures

The closure of 9 high schools and 8 elementary schools in the City of Hamilton (see Map 3) will be simulated by decreasing the number of schools present in the census tracts in which the closing schools are located. The exogenous variable that represents the number of schools in each census tract will be modified from the 2011-16 projection period onwards to 2021-26 to represent the announced school closures as well as schools which are currently at below 50% enrollment capacity as reported by the local newspaper (Pecoskie 2012b). There are also three high schools that will be added to zones which represent the planned location of the new schools (Pecoskie 2012c; Pecoskie 2012a). These new facilities will be added to the 2016-21 projection period onwards in the approximate spot discussed by the school board (Pecoskie 2012c). One will be located in the downtown core on King St. East between the closing high schools of Delta, Parkview and Sir John A. MacDonald, the will also be one school added near the closing Parkside High School and one near the closing Lincoln Alexander School. These new schools represent the school boards effort in amalgamating smaller neighbourhood schools into larger schools which serve a broader region.

The number of schools variable is used in the demographic sub module as a parameter of migrant location choice, given the individual has chosen to relocate. The number of schools is combined with the population cohort of individuals between the age of 5 and 19 to create a composite variable which was estimated to be a positive coefficient (Kanaroglou et al. 2009). In the choice of location, if the decision maker is between the age of 5 and 19 the presence of schools in zone *j* is factor which attracts that individual to that zone.

Equation (21) describes the location choice for a decision maker that has already made the choice to leave zone *i* for a sub-region (see Kanaroglou et al., 2009 for more detail), which is this case, will be assumed to be within the Hamilton CMA. Other regional and sub-regional choices are detailed in Ferguson and Kanaroglou (1997).

$$P_{ij} = \exp(V_{ij}) \Big/ \sum_k \exp(V_{ik}) \tag{21}$$

V_{ij} is the linear combination of personal and zonal variables that represent the systematic utility of moving from i to j as the destination. As the number of schools decrease in certain zones, those zones become a less attractive destination for the 5 to 19 age cohort.

School closures will also affect the trip distribution model for non-work trips (which include school trips) and the modal split for these same trips. As noted in equation (20), the attractiveness of zone j (A_j) combined with the expected travel time between zone i and j in congested traffic are factors which determine the OD matrix of work trips in the Hamilton CMA. For non-work trips the A_j term is set to $P_j^{\gamma} F_j^{\theta}$, where P_j represents the population of zone j and F_j represents the proportion of non-residential land uses in j (Maoh et al. 2009). To simulate the school closures, the proportion of land that is non-residential will be reduced or increased based on school closures and openings. The area of the new schools will reflect the average plot size of existing schools (7.8 km^2) where the proportion of non-residential land use in a given census tract will adjust based on the census tract area. For zones with a reduced proportion of non-residential land use, the non-work trips destined to that zone will be reduced as well, has non-work trips will be attracted to a greater degree elsewhere.

As the population distribution and congestion changes through the projection periods, it is expected that the modal choice model will also be impacted. According to Ewing et al. (2004), the increased time and distance for the journey to school are major factors in mode selection. IMPACT measures the journey to school trips as non-work trips. Equation (22) represents the mode choice model of each O/D pairing used in IMPACT (Maoh et al. 2009).

$$ {}^{m}T_{ij}^{w} = T_{ij}^{w} \sum_{c} P_{c/i} * P_{m.w/ijc} \tag{22} $$

Where m is the mode choice for w purpose between the O/D (T_{ij}^{w}) pair ij. In the MNL choice model, the probability of selecting a particular mode (P) is affected the utility of that mode which is calculated using a linear combination of household, personal and zonal attributes are used to determine modal split of *ij* trips for unique socio-economic groups (*c*) (see Maoh et al. 2009 for list of variables). Of particular importance is cost of travel between zones, which in IMPACT is a function of the in-vehicle congested travel time and the Euclidean distance between origin and destination (Anderson et al. 1994). As children and school trips become attracted to zones which do not have schools set to close, the increased travel distance, time and congestion will impact the mode choice model.

8 RESULTS AND DISCUSSION

The following sections report on the results of a reference, and a set of residential development, suburbanization of employment and school closure scenarios. The reference scenario is intended to assess the new features of SUSTAIN, namely the subdivision of the population into vulnerable and non-vulnerable groups, the migration of these groups from the over the projection time period, the difference in exposure to mobile source emissions and the difference in accessibility to hazardous industries between the two population groups. This reference scenario is also used to compare and contrast results from the school closures scenario.

For all scenarios reported here, the projection time period is the 2021-26 time period which ensures that the policy alternatives tested here have sufficient time to impact the urban socio-ecological environment. Depending on the scenario, the base time period will change to reflect the best possible simulation of real world policy alternatives, some of which have already been implemented while others are planned for the future.

For the purpose of analysis, census tracts are separated into zones with “high” and “low” proportions of vulnerable population. Zones with a high proportion of vulnerable individuals are defined as zones which have a proportion of vulnerable individuals that is greater than one standard deviation from the mean vulnerable proportion for all zones. The opposite is true for zones with a low proportion of vulnerable population, defined as zones which have a proportion of vulnerable individuals that more than one standard deviation less than the mean vulnerable proportion for all zones.

As part of the essential design of IMPACT, it is possible to report on results from the whole population or seniors for different parts of the day. As this research is focused on the development of SUSTAIN in particular, only results for the vulnerable and non-vulnerable populations during the morning (6am – 9am) are reported. The senior population is therefore integrated into the vulnerable population. The morning day period is selected because the great bulk of work related trips are made during this time of the day. In the case of the school closures scenario, where non-work trips are of interest, morning results are still appropriate, as this coincides with the beginning of the school day.

The weighting of the indicators to reflect their importance towards attaining a more sustainable urban environment were determined using the ratio estimation method of weighting (Malczewski 1999). Each indicator, for each separate sustainability pillar is weighted according to this method so that weights within each sustainability pillar equal one. Table 1 displays the weights that are multiplied by the standardized sustainability indicators to generate an overall score for each sustainability theme. One more set of weights are applied only to the justice indicators to represent the relative importance of the theories of justice. In all scenarios, a weight of 30% is applied to the equal shares theory and 70% is applied to the utilitarian justice theory. To test the sensitivity of SUSTAIN and the degree to which the conclusions reached for each scenario are related to unequal distribution, the weights are reversed so that the 30%/70% split is applied to the utilitarian and equal shares justice theories respectively. If the overall justice indicator increases by reversing the weights, it can be concluded that it is the distribution of the effects of urban change that is primarily responsible for raising or lowering justice indicator values.

8.1 Vulnerable Population Trends

8.1.1 Population Distribution

Using the land use classification methodology suggested for the suburbanization of employment scenario (represented in Map 1), the reference simulation shows slight increase of the suburban vulnerable and a decrease in the urban vulnerable from the base time period (1996-2001) to the projection time period (2021-26). Over this time, the total vulnerable population in the Hamilton CMA increased by 61,965 and the vulnerable population proportion increased slightly from 43.3% in 1996-2001 to 47.4% in the projection time period (see Figure 2). The composition of the vulnerable population is projected to get older as well, with the proportion of seniors representing the vulnerable population projected to increase from 33.2% to 53.9% from 2001 to 2026.

The whole population is also projected to increasingly be attracted to urban areas at the cost of the suburbs over time, as evidenced by a 3% increase in the proportion of urban population over the projection period, and a matching 3% drop in the total proportion of suburban population. In total it is projected that there will be 131,604 vulnerable individuals in urban areas, 202,780 in the suburbs, and 25,753 in the rural areas by the end of 2026. For census tracts designated as urban, the average proportion of vulnerable people present increases slightly from 43.3% in the base time period to 44.1% in the projected time period and over the same time, the proportion of the vulnerable population living in the suburbs increases from 57.7% to 68%. Rural census tracts are projected to have an increasing number and proportion, of the vulnerable population. From the base time period the proportion of the vulnerable population living in rural areas increased from 6.4% to 8.6% by 2026.

Provided exogenously, there is projected to be significantly more new dwellings added to suburban areas over projection time periods, a positive coefficient for the residential choice model which should attract people to the suburbs in simulation. Despite this fact and the fact that the suburbs have an increased distance to the CBD (also positive coefficient), urban areas are still projected to attract a greater share of the non-vulnerable population than the suburbs. The increase in the proportion of suburban vulnerable population is as a result of increasingly older suburbs specifically, and more generally, the increasingly older CMA. The increasing age of the suburbs is a well-known phenomenon that is a result primarily of the increasing mobility of seniors compared with previous senior cohorts (Newbold et al. 2005; Paez et al. 2007; Spinney et al. 2009).

Current and future seniors are selecting suburban residential locations or are choosing to stay in the suburbs more often due to their increased mobility. Increased mobility allows them to locate further from public transit supply, other services and further from the CBD. The relationship between increasing mobility and the residential location choice of seniors is demonstrated by the parameters for the residential choice model used in IMPACT. When the parameters of the choice model were estimated, it was found that seniors, unlike young adults, are attracted to suburban locations more so than urban areas (Kanaroglou et al. 2009). This fact and the fact that the senior population is projected to represent a progressively higher proportion of the vulnerable population demonstrate, clearly, why the vulnerable population in the Hamilton CMA is projected to be increasingly suburban and rural.

8.1.2 Exposure to Mobile Source Pollution

Over the projection period the overall exposure to unsafe levels of NOx is projected to increase by 31.7% while CO exposure remained unchanged at zero for the Hamilton CMA. As noted in Maoh and Kanaroglou (2009), mobile source CO emissions are usually low enough that harmful exposure to each 2.5 km^2 grid cell is below the EPA threshold of 25 million part per million exposure for 1 hour (EPA 2000).

Different land use types of the Hamilton CMA (as classified in Map 1) experienced different dangerous levels of NOx exposure (threshold value in equation (12)) growth rates from the base to projection year. Urban grid cells experienced a 16.3% growth in NOx exposure whereas suburban and rural grids experienced much higher growth rates in dangerous NOx levels of 36.1% and 42.6% respectively. Of the 209 grid cells which intersect the urban areas of the CMA, 39 grids (or 18.7%) had a decrease in NOx pollution over the projection period compared with only 6% of the suburban cells and 3% of rural cells. The higher NOx pollution growth rate in the suburbs is as a result of increased traffic in the Eastern suburbs of Burlington close to Oakville and in Ancaster, a suburb of the City of Hamilton (see Map 4). The rate of pollution increase in rural grid cells is as a result of increased traffic on Highway 403, the western portion of which is primarily located in rural areas of the CMA (see Map 4).

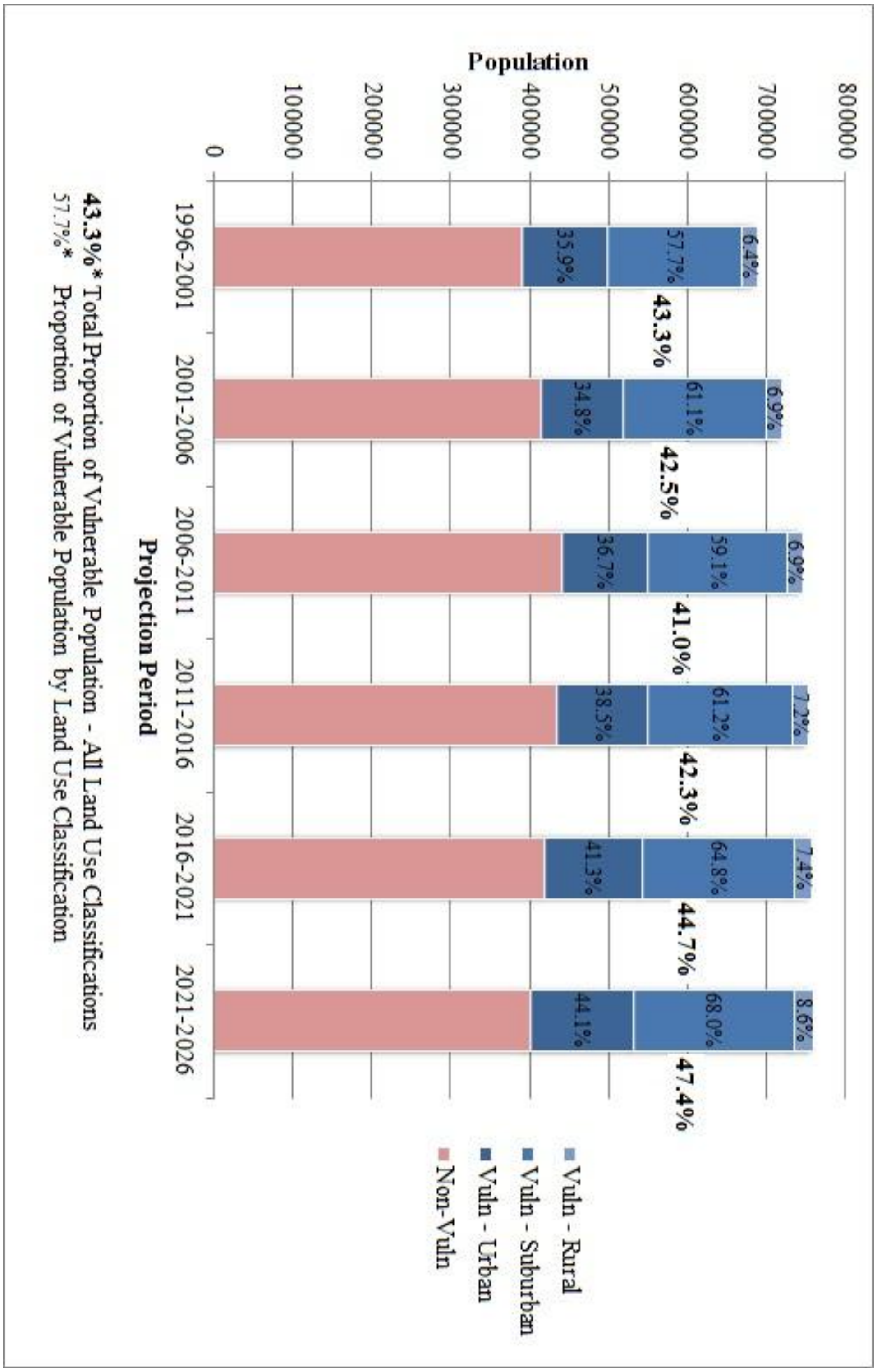


Figure 2: Vulnerable Population Proportions in the Hamilton CMA - Total, and by Land Use Classifications

Overall, the total exposure to dangerous levels of NOx is greater for the vulnerable population in the base and projected time periods compared with the rest of the population even though the rate of growth in exposure to dangerous levels of NOx over the projection period rose 2.6% less for the vulnerable population compared to the non-vulnerable population. As noted above, the vulnerable population is projected to become more suburban, yet the location choice of this vulnerable suburban population in 2026 primarily favours the Eastern suburbs of the CMA in Stoney Creek (see Map 4), an area of the CMA which did not see significant increases in NOx pollution. Overall the vulnerable suburban population is projected to have an increase in NOx exposure of 5% over the projection period compared to a 21.6% increase for non-vulnerable individuals. This pattern of exposure is also present in the rural areas where the vulnerable population is projected to experience a 10% increase compared to a 50.5% increase for the non-vulnerable residents. The opposite is true of the urban grid cells, where the vulnerable population will have a 67.7% increase in NOx exposure compared to a still significant 39.9% increase for the urban non-vulnerable individuals. The vulnerable population who stay or relocate in urban census tracts are distributed to cells within the tracts which experience higher levels of NOx pollution. Even though the rate of growth in exposure to dangerous amounts of NOx pollution is less for the vulnerable population overall and in suburban and rural grid cells, the vulnerable population maintains a higher rate of exposure during the projection time periods.

These results are supportive of the work done by other researchers on pollution in the Hamilton CMA (Jerrett et al. 2001; Buzzelli et al. 2002; Buzzelli et al. 2003; Buzzelli and Jerrett 2004) that establishes a link between vulnerability and pollution exposure. The strength of this previous research is the range of different methods used to generate results. The major weaknesses are the range of pollutants studied (limited to suspended particulate matter) and that the fact that this research does not project pollution or location choice into the future in linking pollution to justice. Because the simulation results are based on the future projection of NOx and CO exposure and the relationship of pollution to the future residential choices of vulnerable individuals, these results add valuable knowledge to the literature on environmental justice.

Within the broader scope of distributive justice, the unjust distribution of exposure to harmful levels of pollution to residents of the Hamilton CMA offers evidence which can be used environmental justice advocates in North America. This research utilizes a unique methodology within the literature on environmental justice to reach the similar conclusion as earlier environmental justice research which identified the inequitable exposure to environmental degradation present in many cities around the world (Bullard 2011). Other literature within this discipline has historically connected levels of pollution exposure visible minority populations (Harner et al. 2002; Shepard and Charles-Guzman 2009). Here though, vulnerability consists of socio-economic and demographic factors that are known to influence an individual's ability to safely absorb a certain amount of pollution without negative health consequences. This broader definition of a vulnerable population adds valuable knowledge and insight to our understanding of distributive justice and pollution exposure.

8.1.3 Accessibility

Accessibility to services in the Hamilton CMA is projected to become more accessible over time, as the sustainability indicators for the accessibility services increased from the base to the projection time period. On the other hand, accessibility to CBD reduced slightly despite decreased travel time to access the downtown. The total population residing in urban areas increased causing decreased accessibility to the CBD for more residents of the Hamilton. Interestingly, despite increased travel times to access services, the growing urban population would also enjoy greater accessibility to services because of the higher service employment that urban census tracts offer compared to suburban and rural zones.

For the projected time period, zones with a high proportion of vulnerable individuals are simulated to have an average accessibility to services that is almost three times greater than zones with a low proportion of vulnerable individuals. For the same time period, the travel time to the CBD for census tracts with a higher proportion of vulnerable individuals was on average 4.5 minutes less compared to zones with a lower proportion of vulnerable individuals.

Despite literature on social exclusion which suggests there are certain vulnerable groups of the population that are at risk at being isolated from their community because of a lack of accessibility (Kwan 1999; Church et al. 2000), the results of the reference scenario simulation suggest that the vulnerable population in the Hamilton CMA actually enjoy increased accessibility compared to the non-vulnerable population in the projection period. Contrary to expectations, based on the increased population of vulnerable residents in suburban locations, the vulnerable population is projected to have higher accessibility to services and the CBD compared to the non-vulnerable population. While not attracted to urban regions of the city to the same degree as the non-vulnerable population, these results indicate that in a reference scenario, the vulnerable population tends to live in or relocate to zones that offer a higher degree of accessibility even if those census tracts are suburban.

The results of this reference scenario support the conclusion made by Scott and Horner (2008) in their investigation of accessibility and social exclusion in the seven counties of the Louisville, Kentucky-Indiana metropolitan statistical area (MSA). While not explicitly defining the characteristics of a vulnerability group, the socio-economic groups considered in this study included individuals living in low income households, individuals living in rural communities, the elderly, women and persons living in a single person or single parent household. They found that vulnerable individuals in the Louisville, Kentucky-Indiana MSA were not particularly disadvantaged by a lack of accessibility to popular destinations in the study area, excluding vulnerable rural residents who suffered from low accessibility due to their remote location.

The Hamilton CMA is projected to distribute transportation supply in a manner which serves vulnerable individuals, facilitating their access to activities throughout the city region. Accessibility is apportioned in a fair manner to children, seniors and the adults in poverty, contributing to the social equality, and therefore sustainability of this urban environment. Using IMPACT, the socio-economic and demographic factors which have been identified as factors contributing to a person's ability to control their location in time and space (Pas 1984; McNally 1998; Kwan 1999), are successfully projected into the near future, meaning the results from this simulation offer valuable and trustworthy evidence towards better understanding the justice of accessibility in the urban environment.

8.1.4 Access to Hazardous Industries

Map 5 displays clearly that the census tracts which have the greatest access to heavy industry firms (and therefore exposure to industrial pollution) are located primarily in urban areas which have an average access to heavy industry score of 673.2 compared to 336.6 in suburban locations and 157.5 in rural census tracts. From the base to the projected time period, the amount of industrial access/pollution in the Hamilton CMA increased 11.4%. This is as a result of the projected increase in urban residents over the projection period.

Census tracts with a heavy industrial access value of over 1,000 and census tracts (n = 8) did not lose a significant amount of population. Zones with an access to heavy industry value of between 500 and 1000 (n = 37) lost 2% of their population and zones with a value of less than 500 (n = 118) saw a 15.4% increase in population. Increased population in zones with a relatively low accessibility to heavy industrial facilities are responsible for the increased industrial pollution indicator despite the fact that population growth is projected to occur in zones with a low exposure to industrial pollution.

Unlike IMULATE, access to industrial firms is not a factor in the residential location choice model so it cannot be said that individuals are attracted to zones with lower access, yet unexpectedly, individuals were attracted to zones with less access to industrial firms and away from zones with higher access to heavy industry. Because this indicator is not a factor in residential choice, no conclusions related to location choice can be drawn from the results of this reference simulation.

8.2 Residential Development

8.2.1 Impact on Population Distribution

Adjusting the exogenous new dwelling variable to simulate alternative residential development policy successfully influences the residential choice of individuals. The base time period for these scenarios is defined as the 2006-11 period and the simulation was run to the projected time period, 2021-26.

As expected, adjusting the location of new dwellings over the projection time period attracts residents to those zones which receive 40% of the new residential development taking place in the Hamilton CMA. For the base time period, the URI scenario attracted residents to URI zones, for the expansion scenario population is attracted to expansion zones and for the sprawl scenario residents are attracted to sprawl zones (as defined in Map 1). In each case, the scenario zones attracted residents to the intended zones. The most effective policy at attracting residents to the intended zones is the sprawl land use development policy. Sprawl zones attracted 8.1% and 7.7% more residents in the sprawl scenario compared to the URI and expansion scenarios respectively.

The distribution of the vulnerable population follows the same logic. The vulnerable population is attracted to the intended zones to the same degree as the non-vulnerable population. Sprawl zones in the sprawl scenario are projected to have the greatest the increase in the proportion of vulnerable, growing from 38% in the base time period to 47.6% in the projection period.

8.2.2 Impact on Transportation

Based on literature related to SMART growth, as expected the URI scenario is projected to have the least amount of vehicle kilometers traveled (VKT), vehicle minutes traveled (VMT) and energy consumed as a result of an increasing urban population closer to services and the CBD (see Table 5). Overall, these results support the theory that SMART growth can support more environmentally friendly cities by reducing energy consumption, travel distance and time, leading to decreased mobile source emissions

(Filion and McSpurren 2007; Behan et al. 2008; Farber et al. 2009; Newman and Falconer 2010).

Table 5: Summary Statistics 2021-2026: Land Use Scenarios

	URI	**Expansion**	**Sprawl**	**Units**
Vehicle Kilometres Travelled (VKT)	247,646	248,781	251,542	km
Vehicle Minutes Travelled (VMT)	235,880	236,811	238,868	minutes
Total Energy Consumed	19,849	19,940	20,161	litres of gasoline
Congested Vehicle Speeds				
Average	63.41	63.44	63.52	km/hr

What did not happen in the URI scenario, or any other residential land use scenario for that matter, is a decreased reliance on the automobile. In all scenarios, the use of public transit and other active modes in URI census tracts is projected to decrease slightly from the base to projection time period. This result supports the conclusion reached recently by Thompson et al. (2012) who reported factors which made the Broward County, FL bus transit system, the United States' most efficient from a cost per passenger-kilometer perspective in 2004. This county's land use planning and transportation network would normally lend itself to a transit-unfriendly environment. They found that the selection of transit by residents had little to do with land use and much more to do with the travel time from origin to destination. Despite an intensification of residential development in the Hamilton and Burlington CBDs, transit ridership and active travel modes are not positively affected by URI land use policies, a finding at odds with research that connects high population density with lower auto dependence (Newman and Kenworthy 1989; Kenworthy and Laube 1996).

An interesting and unexpected result which impacts the sustainability score of the URI scenario is that the average speed of vehicles in congested traffic is lowest in the URI scenario and highest in the sprawl scenario (see Table 5). Roads that intersect with URI zones are projected to have the highest amount of traffic in the URI scenario compared with the other scenarios. The same is true for links intersecting with expansion zones in the expansion scenario and for links intersecting sprawl zones in the sprawl scenario. The increased traffic assigned to downtown links in the URI scenario increased congestion for those links, unlike other scenarios where the increased traffic did not affect congestion or travel speeds significantly due to excess transportation supply.

8.2.3 Sustainability Assessment

The result of the indicators generated by the new version of SUSTAIN are similar to the values generated by Maoh and Kanaroglou (2009), who found that a URI strategy to residential land development generated the lowest sustainability indicators (see Figure 3). The URI scenario has the lowest overall sustainability indicator value of the three residential land use scenarios with the highest being the expansion scenario. Of the four indicator themes, a high indicator for environmental sustainability is the value which is primarily responsible for producing the highest overall sustainability indicator value in the expansion scenario. The mobile source pollution and the farm land converted to other land use indicators were the primary indicators which favour a policy strategy to residential development which promotes expansion.

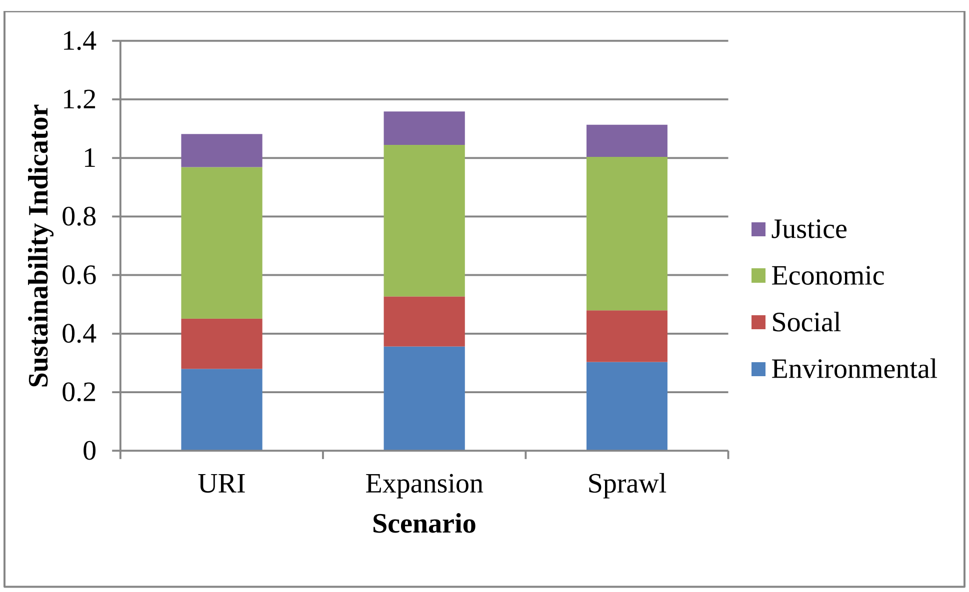


Figure 3: Overall Sustainability Indicators 2021-26: Residential Development

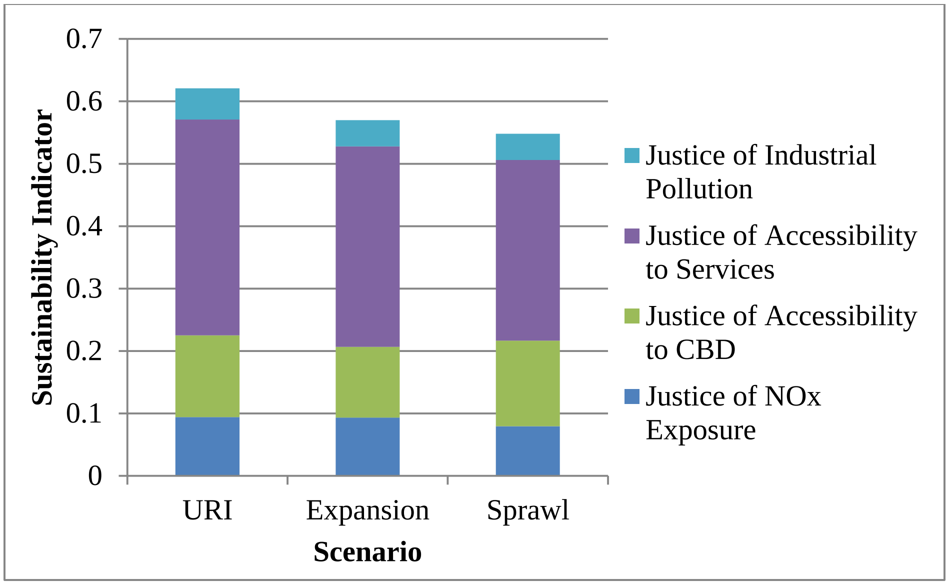


Figure 4: Justice Indicators 2021-26: Residential Development

Despite the justice indicator being higher for the URI scenario than the other scenarios (see Figure 4), the higher environmental indicator for the expansion scenario was the difference in obtaining the highest overall sustainability indicator. Excluding the justice of CO exposure, which was zero in all scenarios, and the justice of accessibility to the CBD, the URI scenario produced the highest indicator values for three of the five justice indicators measured resulting in the highest justice indicator value. The lower justice of accessibility to the CBD indicator generated by the URI scenario is a result of the increased congestion on URI links, congestion which is not projected to impact the accessibility to services to the same degree. The location of services is distributed throughout all census tracts whereas the CBD is defined as one zone which means that links used to access services from zone *i*, in many cases, will include only suburban and rural links with low congestion, unlike many links located near the CBD.

Adjusting the justice theory weights so that the equal shares theory has 70% and utilitarian 30% increases the overall justice indicator values for all scenarios, especially for the expansion scenario whose justice indicators score increased by 12.7% compared to 10.7% for the sprawl scenario and only 0.03% for the URI scenario. This indicates that the impacts of urban change for the expansion scenario are more justly shared among the population compared with the URI scenario, a result which counters the literature on residential development patterns favouring SMART growth.

As predicted by proponents of SMART growth (Calthorpe 1993; Ewing 1999; Corrigan et al. 2004) encouraging urban densification using strategies outlined by Williams et al.(1999), resulted in lower summary statistics that initially would seem to favour the sustainability indicators of the URI scenario. Results from this research indicate that increased congestion in URI zones is an important negative consequence that must be considered when evaluating the sustainability and distributive justice of SMART growth policies.

8.3 Suburbanization of Employment

Simulating the trend of job suburbanization in the Hamilton CMA is accomplished by using two scenarios which represent two distinct employment distributions seen in figure 5. The scenario known as the “centralize” scenario represents policy initiatives that would encourage firms and therefore employment, to reverse the current trend of employment suburbanization by locating in urban census tracts, effectively reversing the observed trends over the last 10 years (see Map 2). In the centralize scenario, urban jobs represent the minority of jobs in the 2001-06 base time period which increases to represent almost half of jobs in the Hamilton CMA for the 2021-26 projection time period. For the projected time period, the simulated “current trends” scenario projects that the suburbs will be the location of almost half of all jobs in the CMA. Job location does not affect the location choice of workers in IMPACT so the population distribution is virtually identical to the reference scenario.

8.3.1 Impact on Transportation

The summary statistics of the two scenarios for the projected time period reveal results that are unexpected (see Table 6). The current trend of employment suburbanization generates lower VKT, VMT, total energy consumed and congestion. The current trend of employment suburbanization reduces the distance and time spent by residents on the network in addition to causing to making residents’ trip to work more efficient. This job sprawl scenario simulated slightly more, but shorter, total trips than the centralize scenario.

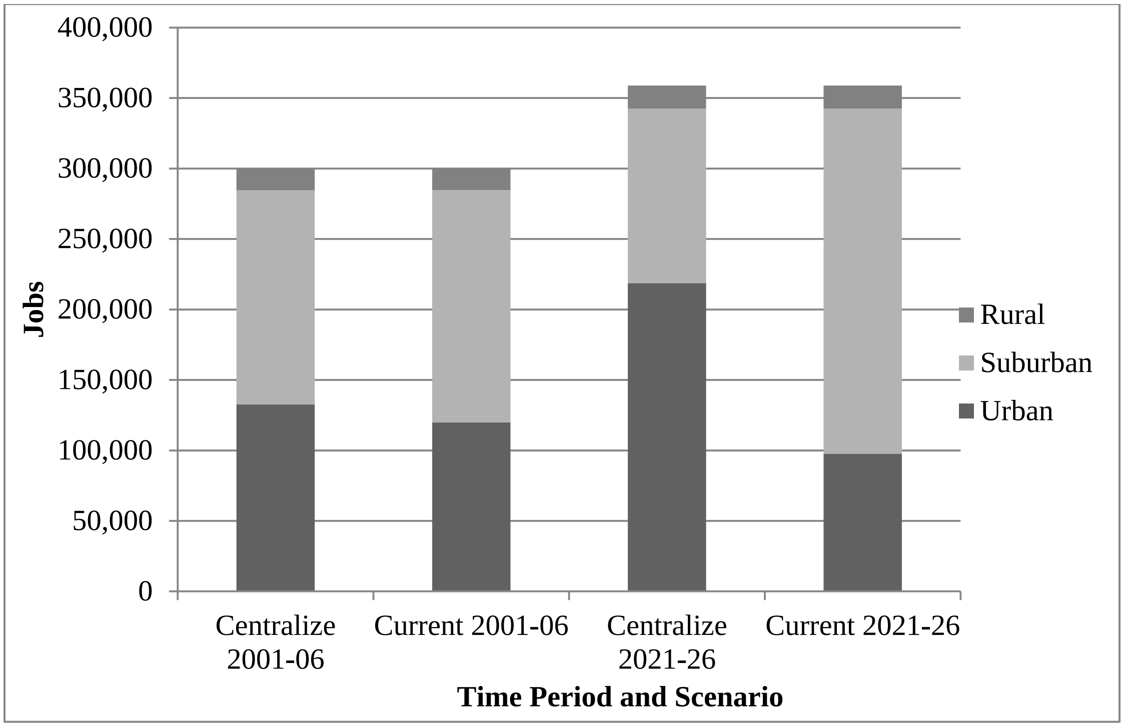


Figure 5: Job Count by Land Use Type

Table 6: Summary Statistics 2021-2026: Job Suburbanization Scenarios

	Centralize	**Current**	**Units**
Vehicle Kilometres Travelled (VKT)	251,276	249,737	km
Vehicle Minutes Travelled (VMT)	238,824	237,211	minutes
Total Energy Consumed	20,140	20,016	litres of gasoline
Congested Vehicle Speeds			
Average	63.47	63.54	km/hr

Suburban zones contained 62.4% of the labour force in the Hamilton CMA in the base time period, despite being projected to contain only 56% of the total population. Because the location labour force in the Hamilton CMA is concentrated in suburban locations, the suburbanization of employment reduces the time and distance that the bulk of the labour force must travel to access their jobs.

Overall, the population benefits from the increased suburban jobs as more working individuals live in the suburbs than do in urban zones. Rather than counter employment suburbanization literature which argues that employment suburbanization can reduce urban sustainability (Stoll 2005), these results indicate that there will be an increasing spatial mismatch between residents of urban zones and the location of their employment.

8.3.2 Sustainability Assessment

The distribution of employment into the suburbs does not impact the population of the Hamilton CMA equally. Non-vulnerable individuals are projected to benefit more from employment suburbanization than the vulnerable despite the increasingly suburban vulnerable population. Zones with a high proportion of vulnerable population benefit from the centralize scenario, in terms of employment location and accessibility, whereas zones with a low proportion of vulnerable individuals benefits from the current trends scenario. These results impact the overall sustainability and justice indicators (see Figure 6 and Figure 7 respectively). Policies which encourage centralization of employment are more sustainable overall in the projected time period compared to the current trend of employment suburbanization.

The centralize scenario is projected to have higher sustainability indicator values for only the justice themed indicators. The justice of accessibility to services and to the CBD in particular, favour the centralize scenario to employment distribution. Compared to the current trends scenario, the centralize scenario had lower indicator values for the environmental, social and economic pillars of sustainability due to favourable summary statistics simulated for the current trends scenario. These summary statistics impact the economic indicators, as well as the amount of mobile source pollution and congestion, variables used in the environmental and social indicators.

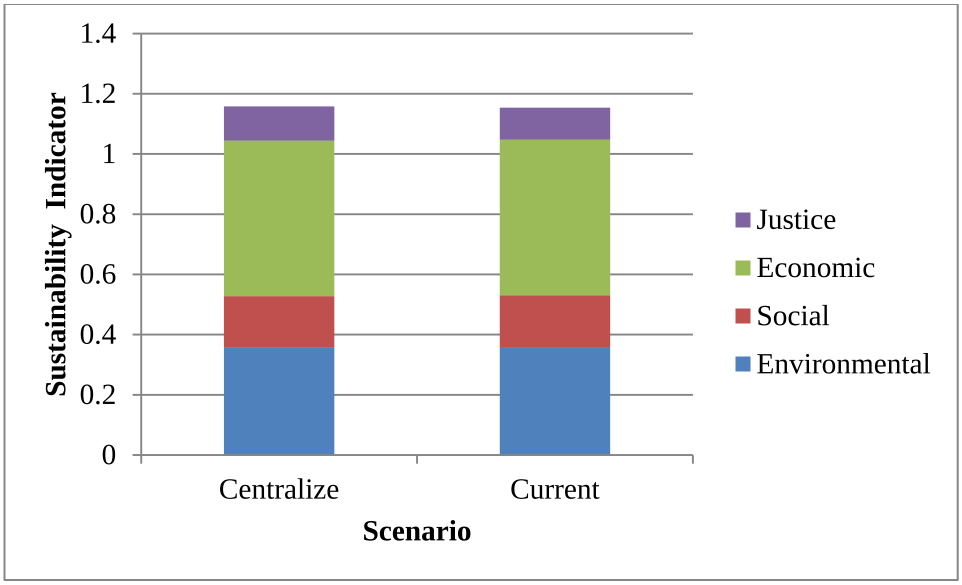


Figure 6: Overall Sustainability Indicators 2021-2026: Employment Suburbanization

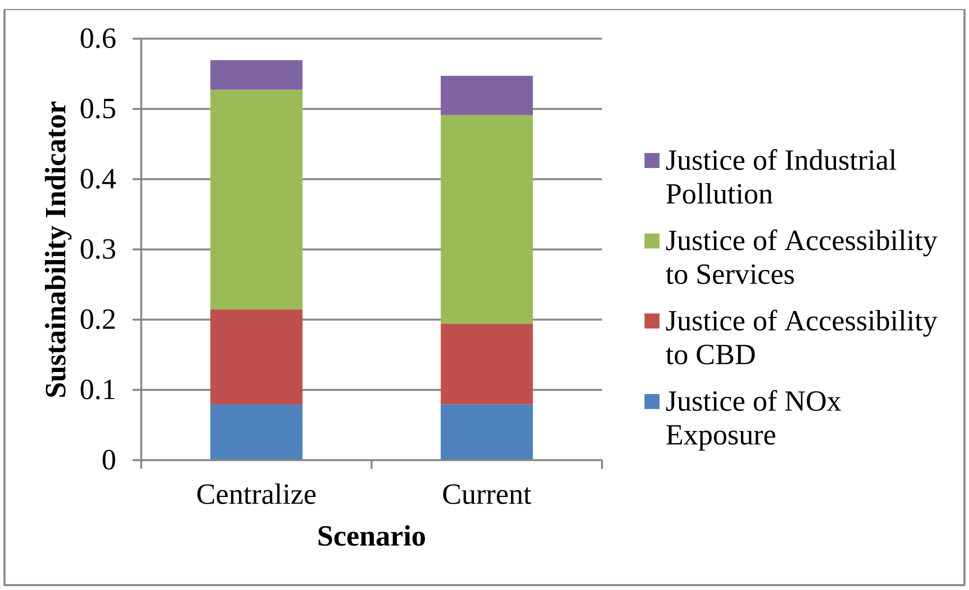


Figure 7: Justice Indicators 2021-2026: Employment Suburbanization

The fact that census tracts with a high proportion of vulnerable population benefit from increased accessibility to employment in the centralize scenario suggests an increasing spatial mismatch between vulnerable residents and their jobs in the Hamilton CMA. Kneebone (2009) and Holzer and Stoll (2007), using data from the U.S., link a pattern of spatial mismatch between increasing employment in wealthy suburbs and the location of vulnerable populations, a pattern which is present in the simulation results for the Hamilton CMA.

In the current trends scenario, it is projected that the spatial mismatch of employment and residential location burdens vulnerable individuals' more than non-vulnerable individuals. Like the U.S. case studies used by Stoll (2005), the Hamilton CMA has seen increasing suburbanization of employment leading, not only to a decrease in the overall accessibility, but also the justice of accessibility. This current trend of job sprawl projected to the 2021-2026 time period, positively impacts the general population, but disproportionately decreases accessibility to employment, services and the CBD for vulnerable individuals. Reversing the justice theory weights to 70% for equal shares and 30% for the utilitarian theory of justice increases the difference in justice indicator values for the job centralization scenario compared to the current trends scenario. This offers further evidence that employment suburbanization negatively impacts the accessibility of the vulnerable compared to the non-vulnerable population and is therefore an example of unjust urban change.

8.4 School Closures

8.4.1 Impact on Population Distribution

By decreasing the number of schools in the Hamilton CMA starting at the base time period of 2011-16, specifically schools administered by the HWDSB based on announced closures (Pecoskie 2012b), the 15 census tracts that are simulated to lose schools also see a reduction in the number of children compared to the reference scenario. As expected, the reduced number of schools in certain zones impacted the residential location choice for the 5 to 19 year old cohort. In the reference scenario, the 15 zones which had schools closed lost 4.7% of their school-aged population from the base to the projection time period compared to a projected increase of 6% in the school closure scenario. In addition, the Hamilton CMA as a whole is projected to have 505 less children in the school closure scenario compared to the reference. Not only did the utility decrease for school closure zones, but the Hamilton CMA also became slightly less attractive to families with children compared to other locations in Ontario and beyond.

The vulnerable population distribution to urban, suburban and rural census tracts is not significantly impacted by school closures. It is projected however, that the closure of 19 schools will cause the vulnerable population to become more dispersed throughout the CMA. Evidence of this can be seen in a reduction of the standard deviation of vulnerable population proportion per zone and by a reduced number of vulnerable individuals living in low and high proportioned census tracts. As the location of schools change to favour larger, suburban locations, the vulnerable population is projected to relocate to census tracts that are less socio-economically segregated.

8.4.2 Impact on Transportation

Table 7 displays the projection time period summary statistics for the two scenarios. The reference scenario is projected to be slightly more efficient as the VKT, VMT and total energy consumed are all higher than the school closure scenario. By decreasing the proportion of non-residential land in the 15 zones which contain the closing schools, non-work trips normally attracted to these zones were attracted to census tracts which did not lose schools. The increased distance and time that some would be forced to endure in their journey to school is balanced by the residential location choice model which attracted children to locations close to school. By negating the effects of increased traffic and therefore mobile source air pollution, the difference in summary statistics between the reference and school closure scenarios is less than expected based on previous literature which warns of increased traffic and pollution as a result of children being farther away from their schools (EPA 2003).

Overall, there is projected to be a negligible change in the modal split as a result of school closures, which would also be affected by the balancing of the residential location choice model and the trip distribution model. As school-aged children (and their families) relocate closer to census tracts with more schools, the journey to school and therefore the non-work trip modal choice remain relatively unaffected. The fact that the modal split did not change significantly, in addition to the fact that the all zones and zones with schools closing are projected to have only a slight decrease in non-work trips generated (147 and 20 trips respectively), is evidence that the residential location choice model negated the negative transportation related consequences anticipated as a result of school closures.

Table 7: Summary Statistics 2021-2026: School Closures Scenario

	Reference	**School Closures**	**Units**
Vehicle Kilometres Travelled (VKT)	250,512	250,932	km
Vehicle Minutes Travelled (VMT)	238,074	238,422	minutes
Total Energy Consumed	20,078	20,112	litres of gasoline
Congested Vehicle Speeds			
Average	63.49	63.5	km/hr

The results generated by IMPACT for this scenario do not replicate the literature on the effect of school closures on traffic and mode choice as IMPACT does not account for the detailed decision making process or variables relevant to school trips in particular. The factors important in the mode choice for the journey to school that IMPACT does account for indirectly are distance, travel time (Ewing et al. 2004) and car ownership (Muller et al. 2008). These variables are not specific to school trips; instead they are part of the modal choice model for all types of non-work trips for the morning only. The mode choice model used in IMPACT therefore fails to fully capture the complexity of the school trip mode choice as described in the literature.

8.4.3 Sustainability Assessment

Overall there is projected to be little difference in the environmental, social and economic themed sustainability indicators at the projection time period between the reference and school closure scenarios (see Figure 8). Taking only these indicator themes into account, closing schools has no appreciable effect on urban sustainability, a result which runs counter to literature which warns of the negative impacts of school closures on attaining a sustainable transport system (Docherty and Shaw 2003).

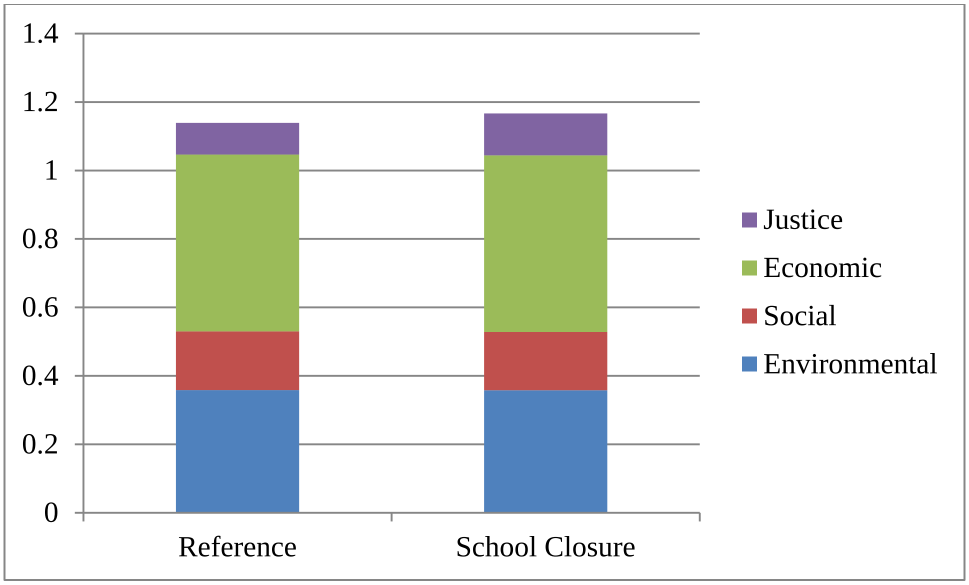


Figure 8: Overall Sustainability Indicators 2021-2026: School Closure Scenario

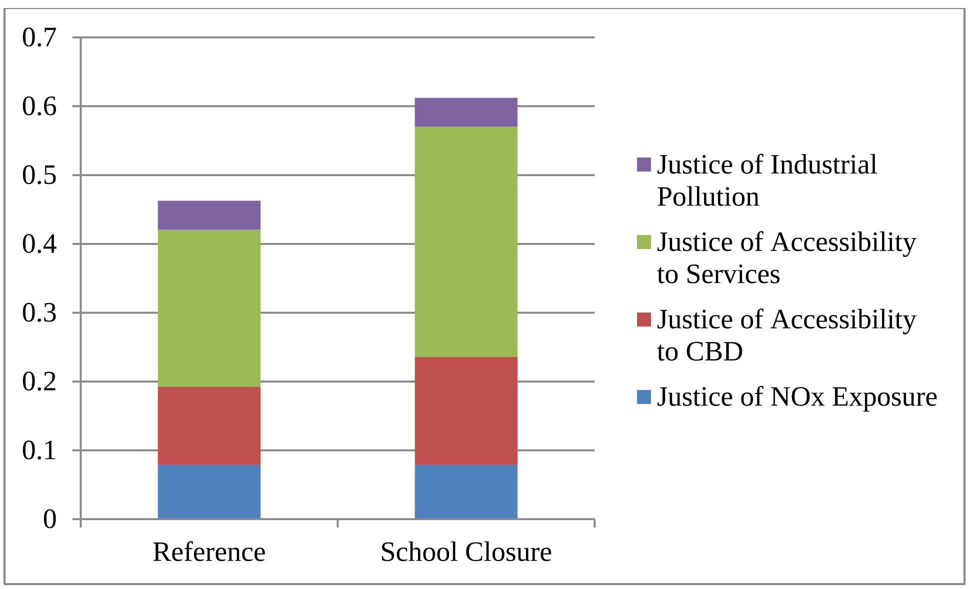


Figure 9: Justice Indicators 2021-2026: School Closure Scenario

An interesting result of the vulnerable population becoming more dispersed throughout the Hamilton CMA is that the vulnerable population is projected to have more just accessibility to services and the CBD in the school closure scenario compared to the reference scenario (see Figure 9). As both the vulnerable and non-vulnerable population groups seek locations that have schools close at hand, increased accessibility is shared in more just manner compared to the simulation where the population did not have to adjust to the closure of schools. Because the literature on the impact of school closures references children as the main subjects of interest, the sub-vulnerable population group of children is a critical point of interest.

To measure the accessibility of school-aged children in particular, a composite statistic which captures the accessibility to services and the CBD for each zone and the degree to which these accessibility measures apply to the children in each zone is needed. This accessibility measure (A_c) is represented in equation (**23**) as:

$$A_c = \sum_{i=1}^{n} P_{c,i} A_{services,i} + P_{c,i} A_{cbd,i} \tag{23}$$

Where P_c is the proportion of children present in zone i and $A_{services}$ and A_{cbd} are the accessibility measures for accessibility to services and the CBD respectively.

Children in particular did not share in the increased values for the justice of accessibility indicators. From the base to projected time period, the accessibility measure for children (A_c) did not change much in the reference scenario compared to the school closures scenario where overall accessibility decreased by 7.2%. In the census tracts which lost schools, the accessibility measure for children decreased by 4.7% in the reference scenario compared with a 6% decrease in the school closure scenario. The same formula, when applied to just the senior and adults in poverty sub-vulnerable population (which in equation (23) would mean replacing c with o to represent an "other" sub-vulnerable group) reinforces these results. The sub-vulnerable group excluding children has an increased accessibility measure from the base to projected time period in the school closure scenario of 18.9% compared to the 6% decrease for children. Although the vulnerable population benefits from increased justice of accessibility overall, children in particular do not benefit from increased accessibility as a result of school closures. As a result of school closures, children run the risk of being socially excluded which as the potential to hinder their ability to participate fully in society.

The functionality of the new SUSTAIN sub-module enabled this more detailed look at the results which offers a more refined view of the effects of school closures on different population groups in the Hamilton CMA. Decreased accessibility for children could very well lead to some of the negative health outcomes that the EPA (2003) believes may be a direct consequence of school relocations. There is however, no direct evidence from the results of this simulation that can be used to support the notion that school closures lead to modal shifts for the journey to school which would impact air quality as a result of increased auto dependence (Ewing et al. 2004; Schlossberg et al. 2006). The environmental sustainability indicators were not greatly affected by school closures as a result of the very minimal impact that closing these schools has on the summary statistics and mode selection. Because of the aforementioned weaknesses in how IMPACT treats the journey to school, no significant conclusions can be made related to modal split, environmental consequences or the health impact on children. The insight that children suffer from decreased accessibility as a result of school closures on the other hand, offers a unique insight that could be used to inform new research more focused on children's accessibility.

9 CONCLUSIONS

Policies which support the sustainability of urban systems are important to maintaining a complex urban socio-ecology. The impacts of land use and transportation policies must be ones which the urban socio-ecology system can absorb and can maintain for future generations in order for the change to be sustainable. This research leverages IMPACT and SUSTAIN to evaluate the sustainability and distributive justice of urban change in three scenario themes, testing seven separate policy alternatives. In the context of North America, there has been a lack of effort to measure the sustainability and distributive justice of urban change over time and into the near future, which up until this point has left a significant gap in the literature on urban sustainability.

To measure urban sustainability and distributive justice, a detailed list of indicators for environment, social, economic and justice themes where generated by

SUSTAIN based on the outputs of IMPACT. IMPACTs ability to project changes in land use, transportation, population distribution, and demographics, in addition to permitting the generation of a vulnerable population, makes the IUM a suitable platform with which policy scenarios can be run. By adding justice indicators to SUSTAIN, assessing the sustainability of urban change now simulates and measures citizen's psychological needs for a just society.

Literature on distributive environmental and social justice has often focused on the racial component of vulnerability to the exclusion of other important factors which can limit an individual's power and their ability to absorb stressors that are the result of urban change. This research contributes to distributive justice literature by applying the concept of vulnerability to three groups of the population who are often at higher risk of suffering illness and hardship brought on by exposure to air pollution. New insights on the potentially inequitable distribution of pollution and accessibility on a broader population of vulnerable individuals provides a means to better understand how urban change affects individual cohorts.

By running a reference scenario to test SUSTAINs ability to generate vulnerable individuals for grid cells and census tracts, it can be concluded that this task is successfully completed by SUSTAIN. Analysis of the exposure to pollution and accessibility that are distributed to the vulnerable population allows analysis on the distributive justice present in the Hamilton CMA. Even without analysis of the justice indicators, the ability to access distributive justice is a valuable contribution which opens up new avenues of research on the topic.

Testing alternative residential development policies using an IUM was appropriate given that residential development impacts traffic and vice versa. As IUMs are premised on the integration of land use and transportation variables, IMPACT is particularly well suited to testing land use policies. SUSTAIN generated results similar to previous research which simulated the effectiveness of URI (Maoh and Kanaroglou 2009). The addition of justice indicators added valuable insight into how URI in particular, has the potential to be the most just policy option regarding residential development patterns despite the lower sustainability indicators for other sustainability indicators. Based on these results, a new argument supporting URI can be made. Previous SMART growth literature has not promoted distributive justice as a potential positive outcome of URI; rather the focus has primarily been to describe the reduced auto dependence occurring because of the more walkable and transit friendly urban form. While the results of the IMPACT and SUSTAIN simulation do not lend evidence to URI reducing auto dependence, it does suggest that land use densification promotes just accessibility to activities and space in an urban environment.

The benefit of having justice indicators integrated into other sustainability indicators is also evident in the scenarios testing the current suburbanization of employment and an alternative policy encourage firms and employment back to the CBD. The current trend relocates jobs closer to the bulk of the Hamilton CMA's labour force which resulted in lower total VKT, VMT, energy use and pollution for the region. Though job suburbanization positively impacts the region's overall sustainability compared to centralizing the CMA's employment, the distribution of increased accessibility to jobs disproportionately benefits the non-vulnerable population over the vulnerable. In this result, it is clear that the addition of justice indicators to SUSTAIN adds valuable information that compliments other indices based on the three traditional sustainability pillars. Without an indicator measuring the justice of accessibility to services, results from IMPACT would have countered other literature on this topic erroneously. Instead, indicators of distributive justice allowed for a more nuanced conclusion to be made regarding the sustainability job sprawl.

With respect to the school closures scenario, IMPACT and SUSTAIN were unable to produce results that can answer research questions related to the literature on school closures. The modal split model used in IMPACT does not specify public or active modes of transportation, nor does is explicitly generate results specific to the journey to school making it impossible to draw any conclusions about the possible modal changes children and parents would be making to adjust to schools further away. Some interesting conclusions with regards to accessibility were possible but the validity of those conclusions remains questionable given the purpose and design of IMPACT. IMULATE is a better research tool for this purpose, as mode choice for school trips is modeled as a separate type of journey. The downside of using the older IUM IMPACT is that no conclusions can be drawn about the distributive justice of urban change with regards to the vulnerable population or children in particular. This type of analysis would be essential to answering important questions related to sustainable urban change.

The results of the seven scenarios simulated here would not have been as insightful or interesting without a discussion on how urban changes are distributed among the population. In a few cases, the scenario which had the highest overall sustainability indicator value had a low justice indicator value, prompting further analysis as to why this is the case. Scrutinizing the sustainability and justice indicators by analyzing the raw results of IMPACT, provides evidence which suggests the results generated by SUSTAIN are logical which means future research based on the results of SUSTAIN is valid. Despite the interesting new dimension to sustainability indicators created here, justice indicators are not often included in other indices. Evidence from the results of this research promotes not only a definition of sustainable urban change which includes a psychological component, but the addition of justice indicators in assessing sustainable urban change.

The one type of urban change that IMPACT cannot adequately measure is mode choice changes over time. Modal shifts anticipated in the residential development and school closures scenarios were not measured in enough detail due to the fact that IMPACTs mode choice set groups public transit and active modes of transportation into an “other” transportation mode. There is also a lack of travel purposes in the trip generation model which generates only work and non-work trips. Conclusions regarding modal shifts as a result of policy cannot be made using this IMPACT.

Future research using IMPACT can now include:

- Analysis of land use and transportation policy which has the potential inequitably impact a sub-vulnerable population group of children, seniors or adults struggling with poverty. Analysis done on the impact of school closures on children was undertaken here, but this represents only a small portion of the potential new research questions which can now be answered using the new features of IMPACT and SUSTAIN.

- Questions related to the impact of demographic and transportation policies on the sustainability of the urban environment can now be explored using this new set of tools. For example, alternative policies encouraging young adults to have more children or policies that would extend the life of seniors could be assessed for sustainability and distributive justice.
- Analysis of polices which would affect the time of day, as SUSTAIN generates indicators for four time periods including morning, day, evening and night.
- Comparing the difference of the consequences of urban change between the City of Hamilton and the City of Burlington. Two cities which are fundamentally different in their urban structure and form.
- Research which would quantify the relationship between justice and different types of policies. Using the distributive justice theory weights provides a means of analyzing the type of distributive justice and the sensitivity of distributive justice indicators resulting from urban change.
- Linking distributive justice of urban change to health outcomes for different cohorts projected by IMPACT.
- An effort to integrate more theories of justice which would make conclusions on the justice of urban change even more meaningful.
- Measurement of a greater variety of mobile source air pollution. The exclusion of exposure to CO and inclusion of exposure to particulate matter of different sizes in particular, would allow for comparisons to be made on past distributive justice research done on the Hamilton CMA.

The results of this research provide interesting new insights on how overall positive urban change can in some cases is an example of unjust urban change. More importantly, these results offer researchers an example of how sustainable urban change can be assessed in the near future using an IUM. The definition of sustainability used in this research implies that sustainable urban change cannot inhibit future generation's ability to seek sustainable urban change themselves. Using justice indicators and the near-term projected results from an IUM offers a methodology for researchers to better assess sustainable and just urban change with respect to current and future generations.

10 REFERENCES

Adams, W. (2006). The future of sustainability: Rethinking the environment and development in the twenty-first century. Report of the IUCN Renowned Thinkers Meeting.

Adger, W. N. (2006). "Vulnerability." *Global Environmental Change-Human and Policy Dimensions* **16**(3): 268-281.

Alonso, W. (1964). Location and Land use. Massachusetts, Harvard University Press.

Anderson, W. P., P. Kanaroglou, E. Miller and R. N. Buliung (1996). "Simulating automobile emissions in an integrated urban model." *Transportation Research Record* **1520**: 71-80.

Anderson, W. P., P. S. Kanaroglou and E. J. Miller (1994). Integrated Land Use and Transportation Model for Energy and Environmental Analysis: A Report on Design and Implementation, Centre for Spatial Analysis.

Apelberg, B. J., T. J. Buckley and R. H. White (2005). "Socioeconomic and racial disparities in cancer risk from air toxics in Maryland." *Environmental Health Perspectives* **113**(6): 693-699.

Barton, H. (2000). The neighbourhood as ecosystem. Sustainable communities : the potential for eco-neighbourhoods. H. Barton. London, Earthscan**:** xix, 305 p.

Beatley, T. (2004). Native to Nowhere: Sustaining Home and Community in a Global Age. Washington, D.C., Island Press.

Behan, K., H. Maoh and P. C. Kanaroglou (2008). "Smart growth stategies, transporation and urban sprawl: simulated futures for Hamilton, Ontario." *Canadian Geographer* **52**(3): 291-308.

Boarnet, M. G., C. L. Anderson, K. Day, T. McMillan and M. Alfonzo (2005). "Evaluation of the California Safe Routes to School legislation: urban form changes and children's active transportation to school." *Am J Prev Med* **28**(2 Suppl 2): 134-140.

Bossel, H. (1999). Indicators for sustainable development: Theory, method, applications. Winnipeg, Canada, The International Institute for Sustainable Development.

Brainard, J. S., A. P. Jones, I. J. Bateman and A. A. Lovett (2002). "Modelling environmental equity: access to air quality in Birmingham, England." *Environment and Planning A* **34**(4): 695-716.

Brandon, P. S. and P. L. Lombardi (2011). Evaluating sustainable development in the built environment. Chichester, West Sussex ; Ames, Iowa, Wiley-Blackwell.

Braza, M., W. Shoemaker and A. Seeley (2004). "Neighborhood design and rates of walking and biking to elementary school in 34 California communities." *Am J Health Promot* **19**(2): 128-136.

Bullard, R. D. (1990). Dumping in Dixie : race, class, and environmental quality. Boulder, Westview Press.

Bullard, R. D. (2011). "Environmental Justice in the 21st Century." Retrieved December 6, 2011, from http://www.ejrc.cau.edu/ejinthe21century.htm.

Burton, E. and L. Mitchell (2006). Inclusive urban design : streets for life. Oxford ; Burlington, MA, Architectural Press.

Buzzelli, M. and M. Jerrett (2004). "Racial gradients of ambient air pollution exposure in Hamilton, Canada." *Environment and Planning A* **36**(10): 1855-1876.

Buzzelli, M. and M. Jerrett (2007). "Geographies of susceptibility and exposure in the city: environmental inequity of traffic-related air pollution in Toronto." *Canadian Journal of Regional Science* **30**: 195-210.

Buzzelli, M., M. Jerrett, R. Burnett and N. Finkelstein (2002). "Environmental justice and ambient health risks: A GIS approach to outdoor air pollution exposure in Hamilton, 1986-1996." *Epidemiology* **13**(4): S211-S211.

Buzzelli, M., M. Jerrett, R. Burnett and N. Finklestein (2003). "Spatiotemporal perspectives on air pollution and environmental justice in Hamilton, Canada, 1985-1996." *Annals of the Association of American Geographers* **93**(3): 557-573.

Calthorpe, P. (1993). The next American metropolis : ecology, community, and the American dream. New York, N.Y., Princeton Architectural Press.

Cass, N., E. Shove and J. Urry (2005). "Social exclusion, mobility and access." *Sociological Review* **53**(3): 539-555.

Chaix, B., S. Gustafsson, M. Jerrett, H. Kristersson, T. Lithman, A. Boalt and J. Merlo (2006). "Children's exposure to nitrogen dioxide in Sweden: investigating environmental injustice in an egalitarian country." *Journal of Epidemiology and Community Health* **60**(3): 234-241.

Chen, G. (2009). Validation and Evaluation of Integrated Urban Models. School of Geography and Earth Sciences. Hamilton, McMaster University.

Church, A., M. Frost and K. Sullivan (2000). "Transport and social exclusion in London." *Transport Policy* **7**: 195-205.

City of Hamilton (2010). B-Line Draft Design, City of Hamilton.

City of Hamilton (2012). Main King Queenston Corridor Strategy Study: Phase 1 - Corridor Options. Hamilton, Ontario, City of Hamilton.

Cole, L. and S. Bowyer (1991). "Pesticides and the Poor in California." *Race Poverty and the Environment 2* **1**.

Commission for Racial Justice (1987). Toxic Wastes and Race in the United States. New York.

Cook, K. S. and K. A. Hegtvedt (1983). "Distributive Justice, Equity, and Equality." *Annual Review of Sociology* **9**: 217-241.

Corrigan, M. B., R. Dunphy, N. M. Gabel, R. L. Levitt, E. T. McMahon and M. Pawlukiewicz (2004). Ten Principles for Smart Growth on the Suburban Fringe. Washington, D.C., The Urban Land Institute.

Cutter, S. L., B. J. Boruff and W. L. Shirley (2003). "Social vulnerability to environmental hazards." *Social Science Quarterly* **84**(2): 242-261.

Cutter, S. L. and C. Finch (2008). "Temporal and spatial changes in social vulnerability to natural hazards." *Proceedings of the National Academy of Sciences of the United States of America* **105**(7): 2301-2306.

de la Barra, T. (1989). Integrated land use and transport modelling. Cambridge, Cambridge University Press.

DeLuca, P. F., S. Buist and N. Johnson (2012). "The Code Red Project: Engaging Communities in Health System Change in Hamilton, Canada." *Social Indicators Research* **(accepted)**.

Dempsey, N., G. Bramley, S. Power and C. Brown (2009). "The Social Dimension of Sustainable Development: Defi ning Urban Social Sustainability." *Sustainable Development* **19**: 289-300.

Dillon Consulting (2006). Growth Related Integrated Development Strategy: Growth Report, City of Hamilton.

Docherty, I. and J. Shaw (2003). A new deal for transport? : the UK's struggle with the sustainable transport agenda. Malden, MA ; Oxford, England, Blackwell Pub. Ltd.

Du Plessis, C. (2009). An approach to studying urban sustainability from within an ecological worldview. School of the Built Environment. Salford, University of Salford.

Duchateau, H. (2004). "Policy Testing Results in Case Studies: Brussels."

Eakin, H. and A. L. Luers (2006). "Assessing the vulnerability of social-environmental systems." *Annual Review of Environment and Resources* **31**: 365-394.

Echenique, M. H., A. Flowerdew, J. D. Hunt and D. C. Simmonds (1990). "The MEPLAN models of Bilbao, Leeds and Dortmund." *Transport Review* **10**: 309-322.

EPA (2000). Air Quality Criteria for Carbon Monoxide. Washington, D.C., United States Environmental Protection Agency.

EPA (2003). Travel and environmental implications of school siting. Washington, D.C., U.S. Environmental Protection Agency.

European Commission (1998). SPARTACUS: System for Planning and Research in Town and Cities for Urban Sustainability - Final Report. Helsinki, Finland, EC Environment and Climate Research Program.

Ewing, R. (1999). Pedestrian and Transit Friendly Design: A Primer for Smart Growth, American Planning Association.

Ewing, R., K. Bartholomew, S. Winkelman, J. Walters and D. Chen (2007). Growing Cooler: The Evidence on Urban Development and Climate Change. Washington, D.C., Urban Land Institute.

Ewing, R., W. Schroeder and W. Greene (2004). "School Location and Student Travel." *Transportation Res.Rec.* **1895**: 55-63.

Farber, S., H. Maoh and P. Kanaroglou (2009). "The impacts of urban growth policies on transportation system usage and performance: a simulation approach." *Canadian Journal of Transportation* **3**(1): 1-25.

Farrington, J. and C. Farrington (2005). "Rural accessibility, social inclusion and social justice: towards conceptualisation." *Journal of Transport Geography* **13**: 1-12.

Ferguson, M. R. and P. S. Kanaroglou (1997). "An empirical evaluation of the aggregated spatial choice model." *International Regional Science Review* **20**(1-2): 53-75.

Filion, P. and K. McSpurren (2007). "Smart growth and development reality: The difficult co-ordination of land use and transport objectives." *Urban Studies* **44**(3): 501-523.

Giddings, B., B. Hopwood and G. O'Brien (2002). "Environment, economy and society: Fitting them together into sustainable development." *Sustainable Development* **10**(4): 187-196.

Government of Ontario. (2012). "Greenbelt Plan Area." Retrieved May 29, 2012, from http://greenbelt.ca/maps/greenbelt-plan-area.

Harner, J., K. Warner, J. Pierce and T. Huber (2002). "Urban environmental justice indices." *Professional Geographer* **54**(3): 318-331.

Harvey, D. (2009). Social justice and the city. Athens, University of Georgia Press.

Hatzopoulou, M. and E. Miller (2006). *Indicators of Sustainable Transport for Integrated Policy Appraisal: Linking Sustainable Transport Plans with Decision-Making in the Greater Toronto Area (GTA)*. Proceedings of New Scholars Conference on Sustainable Transportation, Bloomington, Indiana, May 15-16.

Havard, S., S. Deguen, D. Zmirou-Navier, C. Schillinger and D. Bard (2009). "Traffic-related air pollution and socioeconomic status: a spatial autocorrelation study to assess environmental equity on a small-area scale." *Epidemiology* **20**(2): 223-230.

Hemson Consulting (2005). The Growth Outlook for the Greater Golden Horseshoe, Government of Ontario.

Hochschild, J. L. (1981). What's fair? : American beliefs about distributive justice. Cambridge, Mass., Harvard University Press.

Holtzclaw, H. F. (1994). Using Residential Patterns and Transit to Decrease Auto Dependence and Costs. San Francisco, National Resources Defense Council.

Holzer, H. J. and M. A. Stoll (2007). Where Workers Go, Do Jobs Follow? Metro Economy. Washington, D.C., The Brookings Institution.

Jencks, C. (1992). Rethinking social policy : race, poverty, and the underclass. Cambridge, Mass., Harvard University Press.

Jerrett, M. (2009). "Global Geographies of Injustice in Traffic-Related Air Pollution Exposure." *Epidemiology* **20**(2): 231-233.

Jerrett, M., R. T. Burnett, J. Brook, P. Kanaroglou, C. Giovis, N. Finkelstein and B. Hutchison (2004). "Do socioeconomic characteristics modify the short term association between air pollution and mortality? Evidence from a zonal time series in Hamilton, Canada." *Journal of Epidemiology and Community Health* **58**(1): 31-40.

Jerrett, M., R. T. Burnett, P. Kanaroglou, J. Eyles, N. Finkelstein, C. Giovis and J. R. Brook (2001). "A GIS - environmental justice analysis of particulate air pollution in Hamilton, Canada." *Environment and Planning A* **33**(6): 955-973.

Jones, E. (2003). Walkable towns: the Liveable Neighbourhood strategy. Sustainable transport : planning for walking and cycling in urban environments. R. S. Tolley. Cambridge, England, Woodhead Publishing Limited**:** 314-325.

Kanaroglou, P. and R. South (1999). "Can Urban Form Affect Transportation Energy Use and Emissions." *Energy Issues Review* **9**(2): 22-40.

Kanaroglou, P. S. and R. N. Buliung (2008). "Estimating the contribution of commercial vehicle movement to mobile emissions in urban areas." *Transportation Research Part E* **44**: 260-276.

Kanaroglou, P. S. and M. R. Ferguson (1998). "The aggregated spatial choice model vs. the multinomial logit: An empirical comparison using migration microdata." *Canadian Geographer-Geographe Canadien* **42**(3): 218-231.

Kanaroglou, P. S., H. F. Maoh, B. Newbold, D. M. Scott and A. Paez (2009). "A demographic model for small area population projections: an application to the Census Metropolitan Area of Hamilton in Ontario, Canada." *Environment and Planning A* **41**(4): 964-979.

Kenworthy, J. R. and F. B. Laube (1996). "Automobile Dependence in Cities: An International Comparison of Urban Transport and Land Use Patterns with Implications for Sustainability." *Environmental Impact Assessment Review* **16**: 279-308.

Kneebone, E. (2009). Job Sprawl Revisited: The Changing Geography of Metropolitan Employment. Metro Economy. Washington, D.C., The Brookings Institution.

Kwan, M. P. (1999). "Gender and individual access to urban opportunities: A study using space-time measures." *Professional Geographer* **51**(2): 210-227.

Lang, R. (2003). Edgeless cities : exploring the elusive metropolis. Washington, D.C., Brookings Institution Press.

Lautso, K., C. E. Spiekermann and M. Wegener (2002). Modelling Policies for Urban Sustainability. 42nd Congress of the European Regional Science Association. Dortmund.

Lautso, K., K. Spiekermann and M. Wegener (2004). PROPOLIS Final Report, European Commision.

Lavalle, M. and M. Coyle (1992). "Unequal Protection: The Racial Divide in Environmental Law." *National Law Journal* **15**: S1-S12.

Lavery, T. A. and P. Kanaroglou (2012). "Assessing the Real Estate Demand and Transit Ridership Impacts of a Light Rail Transit Line using an Integrated Urban Model: Hamilton, Ontario Case Study." *Accepted for publication in Transportation Letters*.

Lee, C. (1992). "Environmental Justice: Building a Unified Vision of Health and the Environment." *Environmental Health Perspectives* **2**: 141-144.

Lombardi, P. L. and I. Cooper (2009). "The challenge of the eAgora metrics: The social construction of meaningful measurements." *International Journal of Sustainable Development* **12**(2): 210-222.

Lombardi, P. L., P. Huovila and M. Sunikka-Blank (2010). The potential of e-participation in sustainable development evaluation - Evidence from case studies. Politics, Democracy and E-Government. C. G. Reddick. Hershey, PA, IGI Global Books.

Lowry, I. (1964). A Model of Metropolis, RAND Corportation.

Lundin, M., M. Bengtsson and S. Molander (2000). "Life cycle assessment of wastewater systems: Influence of system boundaries and scale on calculated environmental loads." *Environmental Science & Technology* **34**(1): 180-186.

Macintyre, S., S. Maciver and A. Sooman (1993). "Area, Class and Health - Should We Be Focusing on Places or People." *Journal of Social Policy* **22**: 213-234.

Malczewski, J. (1999). GIS and multicriteria decision analysis. New York, J. Wiley & Sons.

Maoh, H., P. Kanaroglou and R. N. Buliung (2005). Modeling the Location of Firms within an Integrated Transportation and Land-use Model for Hamilton, Ontario. Working Paper Series. Hamilton, Canada, Centre for Spatial Analysis, McMaster University.

Maoh, H., P. Kanaroglou, D. Scott, A. Paez and B. Newbold (2007). IMPACT: An Integrated GIS-Based Model for Population Aging Consequences on Transportation. Working Paper Series, Centre for Spatial Analysis, McMaster University.

Maoh, H., P. Kanaroglou, D. Scott, A. Paez and B. Newbold (2009). "IMPACT: An integrated GIS-based model for simulating the consequences of demographic changes and population ageing on transportation." *Computers Environment and Urban Systems* **33**(3): 200-210.

Maoh, H. and P. C. Kanaroglou (2009). "A tool for evaluating urban sustainability via integrated transportation and land use simulation models." *Urban Environment* **3**: 28-49.

Maoh, H., M. Koronios and P. C. Kanaroglou (2010). "Exploring the land development process and its impact on urban form in Hamilton, Ontario." *Canadian Geographer* **54**(1): 68-86.

Martinez, F. J. (1991). "The bid-choice land use model: an integrated economic framework." *Environment and Planning Part A* **24**: 885-871.

May, A., A. Karlstrom, N. Marler, A. Minken, A. Monzon, M. Page, P. Pfaffenbickler and S. Shepard (2003). A decision makers guidebook. Deliverable 15 of the PROSPECTS project. Leeds, U.K., Institute for Transportation Studies, University of Leeds.

McFadden, D. and T. A. Domencich (1975). Urban Travel Demand: A Behavioural Analysis, North-Holland Publishing Co.

McLaughlin, P. and T. Dietz (2008). "Structure, agency and environment: Toward an integrated perspective on vulnerability." *Global Environmental Change-Human and Policy Dimensions* **18**(1): 99-111.

McNally, M. G. (1998). "Activity-based forecasting models integrating GIS." *Geographical Systems* **5**(1-2): 163-187.

Mebratu, D. (1998). "Sustainability and sustainable development: historical and conceptual view." *Environmental Impact Assessment Review* **18**: 493-520.

Miller, D. (1976). Social justice. Oxford, Clarendon Press.

Miller, E., J. D. Hunt, J. E. Abraham and P. Salvini (2004). "Microsimulating urban systems." *Computers, environment and urban systems* **28**: 9-44.

Miller, E. J., J. D. Hunt, D. S. Kriger and D. A. Badoe (1998). Integrated urban models for simulation of transit and land use policies. Toronto, University of Toronto.

Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. van der Leeuw, J. Rockstrom, J. Hinkel, T. Downing, C. Folke and D. Nelson (2010). "Resilience and Vulnerability: Complementary or Conflicting Concepts?" *Ecology and Society* **15**(3).

Miller, H. J. (2005). Social Exclusion in Space and Time, University of Utah.

Minken, A., R. Johsson, S. Shepherd, T. Jarvi, A. May, A. Page, A. Pearman, P. Pfaffenbickler, P. Timms and A. Vold (2003). A methodological guidebook. Deliverable 14 of PROSPECTS project. Oslo, Norway, Institute of Transport Economics.

MITL (2009). A Sustainable Strategy for Developing Hamilton as a Gateway. Hamilton, Ontario, McMaster Institute for Transportation and Logistics.

Muller, S., S. Tscharaktschiew and K. Haase (2008). "Travel-to-school mode choice modelling and patterns of school choice in urban areas." *Journal of Transport Geography* **16**(5): 342-357.

Munasinghe, M. (1993). Environmental Economics and Sustainable Development. World Bank Environment Paper No. 3. Washington, D.C., World Bank.

Myles, J. and G. Picot (2000). "Poverty indices and policy analysis." *Review of Income and Wealth*(2): 161-179.

Newbold, B. K., D. M. Scott, J. E. L. Spinney, P. S. Kanaroglou and A. Paez (2005). "Travel behaviour within Canada's older population: a cohort analysis." *Journal of Transportation Geography* **13**: 340-351.

Newman, P. and R. Falconer (2010). "Is practice aligned with principles? Implementing New Urbanism in Perth, Western Australia." *Transport Policy* **17**: 287-294.

Newman, P. and J. R. Kenworthy (1989). Cities and automobile dependence: An international sourcebook. Aldershot, U.K., Gower.

Newman, P. and J. R. Kenworthy (1999). Sustainability and cities: Overcoming automobile dependence. Washington, D.C., Island Press.

Ortúzar S, J. d. D. and L. G. Willumsen (2001). Modelling transport. Chichester ; New York, J. Wiley.

Paez, A., D. Scott, D. Potoglou, P. Kanaroglou and K. B. Newbold (2007). "Elderly mobility: Demographic and spatial analysis of trip making in the Hamilton CMA, Canada." *Urban Studies* **44**(1): 123-146.

Pas, E. I. (1984). "The Effect of Selected Sociodemographic Characteristics on Daily Travel-Activity Behavior." *Environment and Planning A* **16**(5): 571-581.

Pearce, J., S. Kingham and P. Zawar-Reza (2006). "Every breath you take? Environmental justice and air pollution in Christchurch, New Zealand." *Environment and Planning A* **38**(5): 919-938.

Pecoskie, T. (2012a). Board will close Barton, Hill Park and Mountain high schools. The Hamilton Spectator Hamilton, ON.

Pecoskie, T. (2012b). School's out ... forever? The Hamilton Spectator Hamilton, ON.

Pecoskie, T. (2012c). Spectre of 'education desert' in lower city. The Hamilton Spectator Hamilton, ON.

Pettigrew, T. F. (1971). Racially separate or together? New York,, McGraw-Hill.

Putman, S. J. (1991). Integrated urban models 2. New Research and applications of optimization dynamics. London, Pion.

Ratcliffe, P. (2000). Is the assertion of minority identity compatible with the idea of a socially inclusive society? Social Inclusion: Possibilities and Tensions. P. Askonas and A. Stewart. Basingstoke, MacMillan.

Rawls, J. (1971). A theory of justice. Cambridge, Mass.,, Belknap Press of Harvard University Press.

Robinson, J. (2004). "Squaring the circle? Some thoughts on the idea of sustainable development." *Ecological Economics* **48**(4): 369-384.

Roemer, J. E. (1996). Theories of distributive justice. Cambridge, Mass, Harvard University Press.

Ryan, A. (1997). Justice and the City. Cities in Our Future. R. Geddes. Washington, D.C., Island Press.

Schlossberg, M., J. Greene, P. P. Phillips, B. Johnson and B. Parker (2006). "School trips - Effects of urban form and distance on travel mode." *Journal of the American Planning Association* **72**(3): 337-346.

Schwartz, J., D. Bellinger and T. Glass (2011). "Exploring potential sources of differential vulnerability and susceptibility in risk from environmental hazards to expand the scope of risk assessment." *Am J Public Health* **101 Suppl 1**: S94-101.

Scott, D. and M. W. Horner (2008). "The role of urban form in shaping access to opportunities." *Journal of Transport and Land Use* **1**(2): 89-119.

Scott, D. M., P. C. Kanaroglou and W. P. Anderson (1997). "Impacts of Commuting Efficiency on Congestion and Emissions: Case of the Hamilton CMA, Canada." *Tranportation Research Part D* **2**(4): 245-257.

Sen, A. (1976). "Poverty - Ordinal Approach to Measurement." *Econometrica* **44**(2): 219-231.

Sheffi, Y. (1984). Urban transportation networks : equilibrium analysis with mathematical programming methods. Englewood Cliffs, N.J., Prentice-Hall.

Shepard, P. M. and K. Charles-Guzman (2009). The Roots of Environmental Justice. Breakthrough communities : sustainability and justice in the next American metropolis. M. P. Pavel. Cambridge, Mass., MIT Press**:** xli, 446 p.

Shorrocks, A. F. (1995). "Revisiting the Sen Poverty Index." *Econometrica* **63**(5): 1225-1230.

Solow, R. M. (1986). "On the Intergenerational Allocation of Natural-Resources." *Scandinavian Journal of Economics* **88**(1): 141-149.

Spiekermann, K. and M. Wegener (2004). "Evaluating Urban Sustainability Using Land-Use Transport Interaction Models." *European Journal of Transport and Infrastructure Research* **4**(3): 251-272.

Spinney, J. E. L., D. M. Scott and K. B. Newbold (2009). "Transport mobility benefits and quality of life: A time-use perspective of elderly Canadians." *Transport Policy* **16**(1): 1-11.

Statistics Canada. (2012a). "Hamilton CMA Age and Population Profile, 2001." 2001 Census Retrieved May 25, 2012, from http://dc1.chass.utoronto.ca/census/2001_ct_as.html.

Statistics Canada (2012b). Hamilton, Ontario and Ontario Census Profile. Ottawa. **Statistics Canada Catalogue no. 98-316-XWE**.

Stoll, M. A. (2005). Job Sprawl and the Spatial Mismatch between Blacks and Jobs. Metro Economy. Washington, D.C., The Brookings Institution.

Thompson, G., J. Brown and T. Bhattacharya (2012). "What Really Matters for Increasing Transit Ridership: Understanding the Determinants of Transit Ridership Demand in Broward County, Florida." *Urban Studies*: 1-19.

Timperio, A., D. Crawford, A. Telford and J. Salmon (2004). "Perceptions about the local neighborhood and walking and cycling among children." *Preventive Medicine* **38**(1): 39-47.

Train, K. (2009). The Discrete Choice Process. New York, Cambridge University Press. **Second Edition**.

Trapp, G. S. A., B. Giles-Corti, H. E. Christian, M. Bulsara, A. F. Timperio, G. R. McCormack and K. P. Villaneuva (2012). "Increasing Children's Physical Activity: Individual, Social, and Environmental Factors Associated With Walking to and From School." *Health Education & Behavior* **39**(2): 172-182.

U.S. EPA (1993). Air Quality Criteria for Oxides of Nitrogen. Washington, D.C., United States Environmental Protection Agency.

United Nations (1992). Agenda 21. Rio de Janeiro, Brazil, UN Department of Economic and Social Affairs.

United Nations (2007). Indicators of Sustainable Development: Guidelines and Methodologies. New York, United Nations.

United Nations (2011). The Millennium Development Goals Report. New York, United Nations.

Waddel, P. (2002). "UrbanSim: modeling urban development for land use, transportation and envrionmental planning." *Journal of the American Planning Association* **68**: 297-314.

Wegener, M., R. Mackett and D. C. Simmonds (1991). "One city, three models: comparison of land use/transport policy simulation models for Dortmund." *Transport Review* **11**: 107-129.

Wild, C. P. and J. Kleinjans (2003). "Children and increased susceptibility to environmental carcinogens: evidence or empathy?" *Cancer Epidemiol Biomarkers Prev* **12**(12): 1389-1394.

Wiley, K., L. (2009). Exploring and Modeling the Level of Service of Public Transity in Urban Areas: An Application to the Greater Toronto and Hamilton Area (GTHA), Canada, McMaster University.

Williams, K., M. Jenks and E. Burton (1999). "How much is too much? Urban intensification, social capacity and sustainable development." *Open House International* **24**(1): 17-25.

World Bank (1994). Environmental Indicators: What Can They Tell Us. Washington, D.C.

World Bank (1996). Sustainable Transport: Priorities for Policy Reform. Development in Practice Series. Washington, D.C.

World Commission on Environment and Development (1987). Our Common Future. Oxford, Oxford University Press.

Yassi, A. (2001). Basic environmental health. Oxford ; New York, Oxford University Press.