An Evidence & Best Practices Based Review for the Development of a Health Assessment Tool

Applying Research Evidence to Land Development Decisions to Increase the Health-Promoting Ability of Built Environments

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for the

Regional Municipality of Peel, Canada

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1. INTRODUCTION

1.1 Context and Background

In December 2005, the Region of Peel Council endorsed the "State of the Region's Health Report 2005 –Focus on Overweight, Obesity and Related Health Consequences in Adults." This report found a number of alarming health trends related to physical activity and body weight in the Peel Region:

Low rates of physical activity. Over half (54 percent) of Peel residents reported being physically inactive in 2003, a higher portion than the province as a whole (50 percent). (Chapter 5, p 30)

Low rates of bicycling and walking for transport when compared to other Canadian municipalities. (Chapter 5, p 30)

High rates of obesity and overweight. 31 percent of Peel residents were overweight, and 14 percent were obese in 2003 (Chapter 3, p 1)

In discussing potential causes of these conditions, the report mentions recent research that connects sprawling, auto-oriented development patterns to obesity and lack of physical activity, and notes the trend in Peel towards "sprawling, low-density development." The report discusses the need for health officials to work with communities and other sectors of the region, such as schools and workplaces, to "reverse the increasing trend in obesity." (Chapter 5, p 31-32).

This prompted the Peel council to adopt Resolution 2005-1395, which directed Peel Public Health to work with the Planning Commissioners and the Commissioner of Community Services for the three area municipalities (Brampton, Caledon and Mississauga) to "*study and make recommendations for planning policies and processes that provide greater opportunities for active living."*

The Resolution also requests that Public Health staff comment on development applications that come to the Region of Peel for comment, in order to ensure that public health considerations are integrated into the Region's development. With a projected population increase of 400,000 additional residents by 2031 (about a third of the current population), there is significant opportunity to make sure new development in the Region of Peel supports active, healthy communities.

1.2. About this report

This report is the first step on the path to developing an evidence based planning tool that can quantify the health impacts of land development and area planning proposals for the Region of Peel. This report will articulate the major needs and issues that such a tool will need to consider; and summarize the research and resources that it can use.

Chapter 2 discusses the conceptual relationship between the built environment, travel behaviour and health outcomes, and briefly summarizes the evidence on the built environment – travel relationship.

Chapters 3 - 6 summarize the peer-reviewed evidence on relationships between built environment characteristics and four health outcomes:

- Physical activity (including amount of walking) & body weight
- Air pollution (including amount of driving)
- Pedestrian Safety
- Mental health

This assessment provides the foundation of evidence that can potentially be tested and incorporated into the planning tool's development. The review will present broad conclusions from the literature and issues that arise from the evidence, in addition to a detailed discussion of the most relevant evidence.

In order to guide the decision about the best approach for the development and application of the planning tool itself, Chapter 7 of this report reviews the best practices for developing and applying tools in these outcomes areas and other health-related outcomes – particularly in the context of Health Impact Assessment, a field growing rapidly in importance in Canada. Chapters 8 and 9 discuss how to apply the evidence to Peel given available data and other resources, and make recommendations about an approach.

2. FROM BUILT ENVIRONMENT TO PUBLIC HEALTH

The built environment is a product of land use decisions and transportation investment; it impacts public health largely because of the transportation choices that result from different built environment patterns.[1]

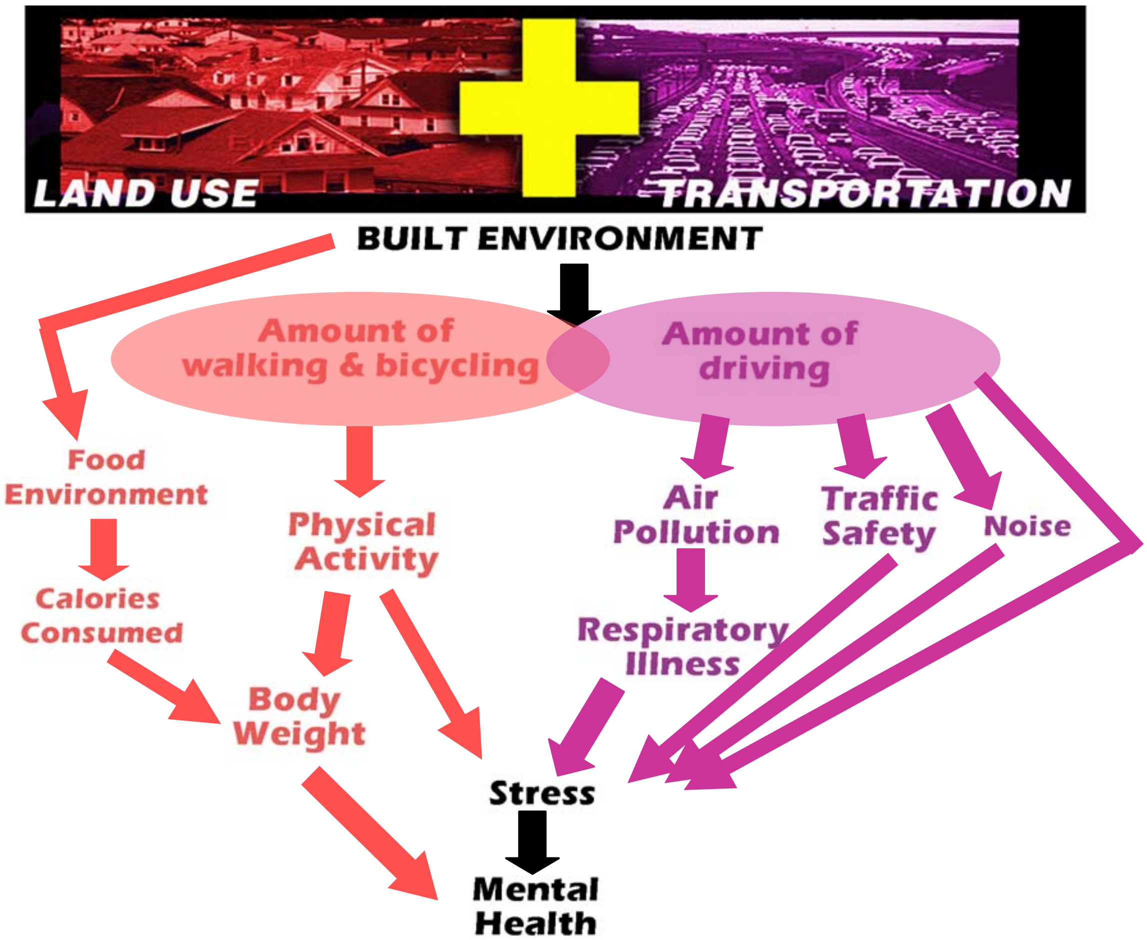


Figure 1. The Built Environment – Public Health Relationship

Some health objectives, such as physical activity levels, are affected primarily by the amount of active travel - walking and bicycling – that people do. Others, such as noise, traffic safety and pollution emissions depend on the amount of automobile travel. All of the outcomes related to how we travel – air pollution and respiratory illnesses, traffic safety, noise, and physical activity - can also impact a person's stress levels, which have been linked to mental health.

Obviously, many other factors also affect health conditions such as body weight, physical activity, stress and mental health. Some of these factors are related to the built environment in other ways – for example, researchers are starting to examine how one's food environment – the

[1] Sallis et al 2004; Saelens et al 2003b; Handy et al 2002; Frank et al 2004.

accessibility to healthy vs. unhealthy food choices – can impact caloric consumption and body weights.

Generally, practices that shift travel from private vehicles to nonmotorized transportation and transit can provide multiple benefits in the form of increased physical activity, less sedentary time in cars, less per capita air pollution and reduced accident risk. There is some substitution between vehicular and active forms of travel, although it is unknown how much.

These changes will take time. Because land use development takes place parcel-by-parcel, it can take time to see new regulations implemented, especially in areas where compact, mixed-use neighbourhoods are a departure from the norm. Additionally, once land use patterns change it will take additional time for the corresponding change in people's behaviours and the desired health outcomes to occur, as Figure 2 illustrates.

Planning and Investment Policies and Practices
(development practices, infrastructure investment, zoning, development fees, etc.)

↓

Urban Form Patterns
(density, mix, connectivity, etc.)

↓

Travel Behaviour
(amount and type of walking, cycling, public transit and automobile travel)

↓

Population Health Impacts
(physical fitness, traffic crashes, pollution exposure, community cohesion, etc.)

Figure 2. From Land Use to Travel Behaviour to Health

However, even though changing land use patterns is typically characterized as a long term strategy, change can happen relatively quickly given leadership and the right combination of incentives, public investment and regulatory changes – especially in smaller, targeted areas. In his 2006 article "Leadership in a New Era" in the Journal of the American Planning Association, Arthur Nelson argued that over half of development on the ground in the US 25 years from now will be built from today forward, giving planners "an unprecedented opportunity to shape the landscape."[2] The fact that land use is a long term strategy does not excuse planners from working for change now. In fact, quite the opposite is true - we need to be changing land use patterns now in order to accommodate future population and growth, support

[2] Nelson 2006.

investments in transit, decrease our environmental impact, and improve the population's health.

2.1 The Built Environment & Transportation Relationship

A large and ever-growing body of research has documented the basic link[3] between the built environment and transportation behaviour. This connection is a fundamental aspect of transportation planning.[4]

The research, however, has evolved considerably in recent years. With the advent of Geographic Information Systems (GIS) and faster, more adept computer and database systems, there has been a veritable explosion of research on this topic, and a number of literature reviews and meta analyses that summarize this body of literature and the findings. Generally, the conclusion is that the built environment and travel behaviour are connected – although there is no causal evidence, significant cross-sectional relationships have been found in many places, at many scales of measurement.[5]

The connection between built environment patterns and transportation behaviour works at two geographic scales: **regional – *where*** development goes in a region, and **local – *how*** that development is designed.

2.1.1 REGIONAL LOCATION

Where major population and employment centres locate is closely connected to travel patterns in general, and commute patterns in particular. The location and size of a region's centres is influenced by factors such as housing availability and affordability, school district and neighbourhood quality, private investment and job growth, transportation investments and access to other centres. The resulting urban form patterns influence travel behaviour by making certain modes of travel more or less convenient or 'costly' than the others[6] - determining the transportation options people have for getting from home to work or school. This concurrently shapes a region's major commute patterns. Since commute trips are typically longer than other types of trips and happen more frequently, reducing commute trips taken by auto can have a relatively large impact on Vehicle Miles Traveled (VMT), and therefore on carbon dioxide and other emissions.

At the individual development level, developments that are located within already established urban or suburban areas of a region, preferably in areas well-served by transit, are more likely to result in positive public health outcomes. Developments on the fringe of urban areas (greenfield or exurban development), even those that have the supportive community design elements discussed in the following section, are going to be linked to more driving and less walking, bicycling and transit use.

[3] Handy 1996, Frank 2000, Ewing and Cervero 2001
[4] Meyer, Kain, and Wohl 1965.
[5] Such reviews have been published by Ewing and Cervero 2001, Frank 2000; Boarnet and Crane 2001, USEPA 2001, Kuzmyak and Pratt 2003, Bento et al. 2003; TRB/IOM 2005.
[6] Boarnet & Crane 2001; Cervero and Kockelman 1997; Handy 1996; Frank et al. 2007c.

The regional location of a given site as measured by distances and travel times to major centres for employment, recreation, shopping or specialized services has been shown to be strongly correlated with travel.[7]

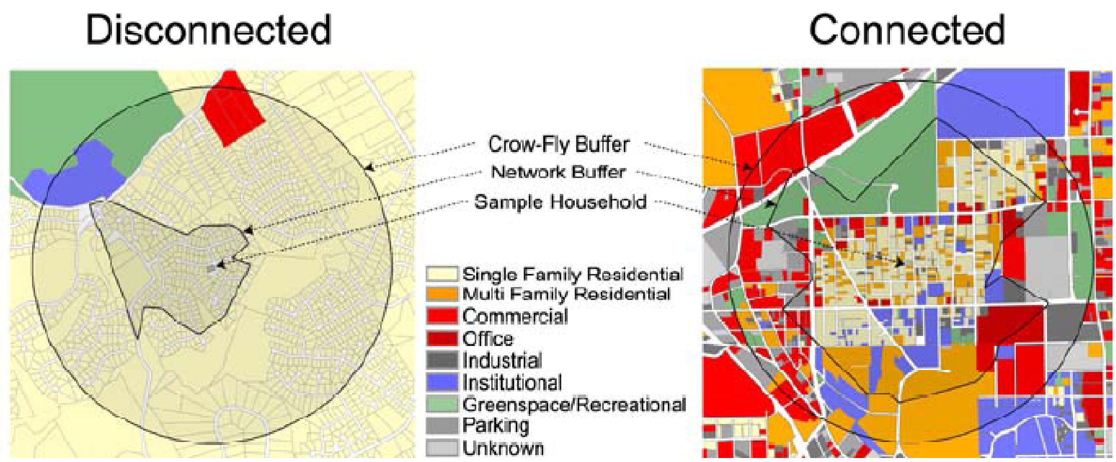
At the regional level, residential density is the easiest variable to measure and is often co-variant with a mixed land use pattern, interconnected street networks, and high-quality pedestrian environments. It thus consistently emerges as a highly significant predictor of travel behaviour in aggregate studies[8]. In a study that compared U.S. metropolitan areas along a 'sprawl index', Ewing et al. (2002) found density to have the strongest relationship to travel outcomes, including VMT. Employment density has also been associated with travel patterns.[9]

2.1.2 NEIGHBOURHOOD DESIGN

How development is implemented at the neighbourhood scale is connected to both local and regional travel behaviour. Compact, walkable, mixed use development allows people to walk or bicycle for short trips in their neighbourhood – these are often errand or social trips, such as trips to the grocery store or to a restaurant. Neighbourhood-scale walkability also factors in the decision to take transit for longer regional trips (such as work trips). Walkability facilitates not just to-and-from transit access, but non-driving access to auxiliary destinations, such as to the bank during the work day or to the daycare centre on the way in to work.

Neighbourhood design relates to travel patterns primarily by impacting **proximity** between destinations and **directness** of travel between these destinations, as shown in Figure 3. Proximity is a function of both the **density (compactness)** of development and the level of **land use mix.** Density and mix work in tandem to determine how many activities are within a convenient distance[10]. **Connectivity** determines how directly one can travel between activities on the street or path network.

[7] Holtzclaw et al. 2002, Ewing and Cervero 2001, Frank et al. 2000, Ewing et al. 2002.
[8] Holtzclaw et al. 2002, Ewing et al. 2002
[9] LFC 2005a; Frank and Pivo 1995; Cervero 1991.
[10] Frank 2000, Sallis et al. 2004, Frank and Engelke 2001.



This diagram contrasts a household located in a typical low-density, disconnected suburban neighbourhood with separated uses on the left with a household located in a more compact, connected, mixed use neighbourhood on the right. The circle represents a 1-kilometer radius (the 'crow-fly' distance) from each household, while the asymmetrical 'network' buffer inside the circle captures the 1-km area actually walkable on the street network. This diagram shows not only how a disconnected street network pattern can impact walking accessibility ***(directness)****, but how a low-density, single use land use pattern restricts the number of accessible destinations within walking distance* ***(proximity)****.* From Frank et al., 2004.

Figure 3. Primary Neighbourhood Design Characteristics Linked to Travel Behavior

As proximity and directness between destinations increases, distance between those destinations decreases. As the distance between destinations decreases, so does vehicle miles traveled[11]. Where distances between destinations are sufficiently short (1 km or less) walking trips will substitute for some driving trips.[12]

2.1.3 OTHER INFLUENTIAL FACTORS

A number of other factors can complement or undermine a neighbourhood's walkability. Presence or lack of sidewalks and other infrastructure for bicycling and walking, building placement and site design, transit accessibility, and visual quality not only impacts the actual safety and appearance of the streetscape, but the *perception* of an area's safety and walkability.

Street Design and Pedestrian / Cycling Facilities – In many newer and suburban areas, street design is focused on moving vehicles, particularly on arterial streets. Multi-lane arterial streets with wide lanes allow for increased traffic volumes and higher traffic speeds can negatively impact other modes of transport through decreased safety, comfort and access. Additionally, the experience of walking or cycling along wide arterials is noisy, less pleasant and generally uninteresting.

[11] Boarnet and Crane 2001b, Ewing and Cervero 2001, Holtzclaw et al. 2002.
[12] Sallis et al. 2004, Handy and Clifton 2001, Bagley and Mokhtarian 2002.

Narrower streets with fewer lanes, prominent crosswalks, longer 'walk' signal lengths and refuge medians are easier for pedestrians of all ages and physical abilities to cross. Street trees and benches add comfort and visual interest. Generally, research has shown that these street designs are connected with higher levels of walking, cycling and public transit use. Walkable streets are also closely linked to pedestrian and cyclist safety – fewer, and less severe, collisions with vehicles. This is largely through reducing traffic speeds. Most of the research on these topics has been focused on how street design impacts safety and walking behaviour. For that reason, more in-depth discussion is in subsequent chapters.

This arterial in the Atlanta region has 7 lanes of traffic to cross and no sidewalk – dangerous to walk along or cross on foot.

This street in Vancouver BC incorporates a variety of traffic calming techniques to create a supportive environment for active transport – landscaped medians at intersections, a wide bike lane and sidewalks on either side of the street

Figure 4. Walkable vs. Auto-Oriented Streets

Building and Site Design – Building design can also support or undermine active transport. Buildings that are located behind large parking lots, far from the sidewalk, are rather inaccessible, less interesting, and perceived as less safe and secure for the pedestrian. On the other hand, buildings built close to the sidewalk, with parking behind or underneath them, windows on the ground floor, and awnings above, will increase comfort and interest. Varied, complex rooflines, balconies, and greenery in the form of planter boxes or landscaping will 'soften' the edges of an urban environment[13] and add to the visual appeal for someone walking by.

Most of this standard strip mall site is taken up by the enormous parking lot out front. In addition to being an unattractive place to walk, it is inconvenient. Pedestrians need to walk another ¼ - ½ mile just to get to a store entrance

In contrast, this street in a Vancouver, BC mixed-use neighbourhood supports all kinds of street life. Because building entrances are placed directly adjacent to the sidewalk, pedestrians can easily circulate. The street trees, iron lampposts, and benches help to create a welcoming outdoor living room for shoppers and residents to sit, stroll, and do business.

Figure 5. Site Design Impacts on Walkability

Design can be difficult to measure quantitatively. Design factors also tend to occur in conjunction with compact, mixed use environments, making it hard to discern their true impact. However, a few studies have been able to measure and isolate the influence of design.

The LUTRAQ (Land Use, Transportation, and Air Quality) study in Portland, Oregon was a landmark study that calculated subjective

[13] Gehl 1987.

measures of the built environment, or Pedestrian Environment Factors (PEFs) - ease of street crossing, sidewalk continuity, street connectivity, and topography. These factors were quantified on a scale, and used in the development of statistical models. From this the researchers found that "a 10% reduction in vehicle miles traveled (VMT) can be achieved with a region-wide increase in the quality of the pedestrian environment" comparable to Portland's most pedestrian-friendly areas.[14] The PEF was subsequently incorporated into studies by Greenwald and Boarnet[15] and the USEPA.[16]

The LUTRAQ study performed a different analysis using age of buildings as a proxy for building placement, and found that VMT drops where more buildings are oriented towards the sidewalk rather than towards a parking lot as was found in pre-World War II development.[17] In a study in the Seattle (Puget Sound) Region, the mean age of development was significantly correlated with household non-auto trip generation – the newer the development, the lower the non-auto share of trips.[18] These findings suggest that the age of residential development may be a proxy that captures the overall quality of the pedestrian environment, including sidewalk provision and building setbacks.

More recent studies in the Puget Sound Region have found a parcel's Floor Area Ratio (FAR) to be a significant predictor of travel outcomes (LFC et al. 2005a). Floor Area Ratio is a frequently used in planning to measure commercial and office development density, and is calculated by dividing the building's total floor area by the total parcel area. For example, a two-story building that covers half the lot will have an FAR of 1. Since the portion of a site not covered by a building is typically parking in urban areas, FAR can function as a rough measure of a parcel's site design in addition to measuring density.

2.2 Other Issues in the Research

2.2.1 THE QUESTION OF SELF SELECTION

There has been considerable debate in the scholarly literature over whether the relationship between land use and travel is causal in nature. Some argue that land use patterns may be merely masking the effect of underlying preferences for neighbourhood type and/or travel choice[19]. For example, people who prefer driving to walking will 'self-select' into neighbourhoods where it is easier to drive. The argument is that if a person that prefers driving is located in a walkable neighbourhood, because of those underlying preferences, they will be less likely to walk and more likely to drive.

Recently, researchers have been testing the relationships between neighbourhood design while taking into account people's preferences for neighbourhood designs and/or travel mode. Over the past three years several new studies have been released that confirm the importance of

[14] PBQD el al. 1993a
[15] Greenwald and Boarnet 2001.
[16] Ewing and Greene 2003.
[17] PBQD et al. 1993b
[18] Frank et al. 2000.
[19] TRB/IOM 2005.

land use on travel behaviour – even when controlling for those preferences. Overall, research results suggest that both preferences and the actual features of the neighbourhood in which we reside impact our travel behaviour.[20]

One recent study in the Atlanta region analyzed results of a detailed survey of the travel patterns and neighbourhood preferences for about 1500 households. The study also compared households that were "matched" (survey respondents preferred walkability and were located in a walkable neighbourhood) and "mismatched" (respondents preferred an auto-oriented neighbourhood and were located in a walkable one). In models generated for this analysis that control for demographic factors, a combined index of urban form factors (density, diversity, design, destinations) or "walkability" remained a statistically significant predictor of VMT after adjusting for neighbourhood preferences. Each quartile increase in an index of walkability was associated with a 5.5 mile/day/person reduction in VMT, after adjusting for demographics and neighbourhood preference.[21]

A summary of the results of this study is depicted in Table 1. Overall, it appears that driving is more closely tied to a neighbourhood's actual walkability, while walking seems to be more related to preferences. When comparing Group II to Group IV - the residents of walkable neighbourhoods - average daily vehicle miles were nearly the same regardless of preference. However, when comparing the groups that preferred walkability (Groups I and II) to those that preferred less walkable neighbourhoods (Group III and IV), Groups I and II walked more than Groups III and IV, regardless of location. Those respondents that preferred and were located in walkable neighbourhoods (Group II) walked the most and drove the least overall, and those that preferred and were located in low-walkability neighbourhoods (Group IV) drove the most and walked the least.[22]

[20] Bagley and Mokhtarian 2002; Frank et al. 2007a; Handy et al. 2006; Khattak and Rodriguez 2005; Kitamura et al. 1997; Schwanen and Mokhtarian 2004; Schwanen and Mokhtarian 2005a; Schwanen and Mokhtarian 2005b.
[21] Frank et al. 2007a.
[22] Frank et al. 2007a.

	Walkability & Preference Groups		Percent Taking a Walk Trip (n)	Average Daily Vehicle Miles Traveled (n)
	Preference for Neighborhood Type	Walkability of Current Neighborhood		
I	High	Low	16.0% (188)	36.6 (188)
II	High	High	33.9% (446)	25.8 (446)
III	Low	Low	3.3% (246)	43.0 (246)
IV	Low	High	7.0% (43)	25.7 (43)

Table 1. Walking and Driving by Walkability of Current Neighbourhood and Neighbourhood Preferences

Further, there is recent evidence of latent demand for more walkable neighbourhoods. Some research has documented that a significant proportion of residents in sprawl that would prefer to be in more walkable environments but trade it off for reasons including spousal preferences, work location, schools and cost.[23] Another study, again in the Atlanta region, documented a significant undersupply of walkable environments relative to the demand for such places.[24] Taken together, these studies suggest that simply accommodating the existing demand would allow those who are currently located in auto-oriented environments to choose a more walkable one, thus lowering rates of vehicle travel and emissions.

2.2.2 THE NEED FOR FINE-GRAINED ANALYSIS

Because walking trips are typically 1 km or less, fine-grained analysis is necessary to capture the spatial variation in the built environment that may be having an impact. With Geographic Information Systems (GIS) technology, more planning agencies maintain parcel-based or fine grid-cell level land use data. Data such as this can be systematically and quantitatively measured and linked to travel behaviour information. Travel behaviour data collection, which for years was focused on vehicle and transit travel, thereby undercounting bicycle and walk trips, is also becoming more inclusive. New travel surveys are now often designed to capture nonmotorized trip patterns.

2.2.3 THE NEED FOR OBJECTIVE MEASUREMENT

Many urban form measures are tough to quantify. Many of those are qualitative factors that may relate with the choice to walk, such as level of interest, attractiveness, tidiness, visibility into buildings, or perceived

[23] Belden Russenello & Stewart 2004.
[24] Levine and Frank 2007.

safety and security from crime. Although some well-structured studies are able to measure the impacts of these factors, the need for consistent, careful and objective assessment may preclude the ability to include such factors into an evaluative tool. However, a surprising number of urban design features may be measured objectively using GIS technology, remote sensing, Geographic Positioning Systems (GPS), and digital video technology.

2.2.4 SYNERGY AND CO-VARIATION AMONG MEASURES

The different characteristics that comprise walkability – residential density, land use mix, street connectivity and pedestrian-oriented site design - are interrelated and often occur together in urban areas. Although for research purposes it may make sense to compare "walkable" and "non-walkable" neighbourhoods, it will be more useful for policy and decision making to examine these characteristics separately. This is especially true in the context of development review, since certain characteristics of a development plan may be easier to tweak than others. This means that researchers seeking to identify the impact of individual built environment factors will need to control for confounding variables, in addition to demographic and other factors known to influence travel behaviour, such as transit access.

2.3 Considering Vulnerable Populations

Certain special population groups - children, the elderly, low-income, and different ethnocultural groups - will require slightly different interventions to increase their physical activity levels, reduce exposure to air pollutants and increase traffic safety and community cohesion. In many cases, individuals fall into more than one vulnerable population – for instance, seniors are more frequently classified as low income, with higher proportions of senior immigrants and visible minorities living in poverty.[25]

2.3.1 LOW-INCOME POPULATIONS.

As compared to the province, in 2000, Peel had more residents in higher income categories, and fewer in lower income categories.[26] However, the percentage of Peel residents classified as low income has risen from 9.8 percent in 1990 to 11.6 percent in 2000 and 14.5 percent in 2005 – at the same time poverty has been declining provincially and nationally.[27] According to the Peel Data Centre, there is also evidence that the disparity between high and low income groups is widening.[28]

As might be expected, low-income households are generally less healthy than the population at large. One study of urban Canadian populations documented that children born in low-income households had a greater likelihood of infant mortality, despite an overall decrease in infant mortality.[29] Low-income populations have also been shown to be at a disadvantage for heart attack survival and major chronic diseases such

[25] National Advisory Council on Aging 2005, as cited in Region of Peel Public Health 2006, p. 10
[26] Region of Peel Public Health 2005c, p. 3
[27] Region of Peel 2008.
[28] Peel Data Centre 2008e.
[29] Townson 1999, as cited in Region of Peel Public Health 2001, p. 2.

as high blood pressure and ulcers,[30] and diabetes.[31] Indicators of good health such as active lifestyles, healthy body weights and non-smoking are less prevalent for those with lower incomes or education levels.[32] In Peel, those in the lowest income quartile had higher rates of smoking, higher body weights and lower rates of physical activity.[33] There is also a large overlap between low-income residents, visible minorities and immigrants in Peel – 32 percent of immigrants and 16.8 percent of visible minorities are classified as low-income, as opposed to 11.6 percent of Peel's population at large.[34]

Low-income households also may have less stable access to housing, healthy food and transportation. Even though low-income populations - because they own fewer vehicles per household and are more likely to be transit dependent - walk more than higher income populations, they are also more likely to be overweight and obese. In low-income communities, low-nutrition, low-cost convenience or fast-food restaurants often prevail, and with less mobility it can be difficult for low-income populations to access healthy food. With the trend towards larger supermarkets oriented to auto access, low-income neighbourhoods can be left without access to healthy food – and will probably pay higher prices for lower-quality food from convenience-type stores.

A recent analysis in London, Ontario mapped locations of supermarkets in 1961 and 2005 and found that over time, supermarkets have migrated from the city centre to the fringe. Not only has access to supermarkets worsened over time in most areas, but low-income areas have the poorest access. This access is somewhat mitigated by better transit access in close-in areas of the city, and the authors also point out "other types of small food retailers such as a local butcher, fruit and vegetable market, baker, or ethnic and specialty food stores may…improve residents' access to healthy foods."[35] Results from other Canadian studies have not been consistent with the Ontario analysis – research in Edmonton[36] and Montreal[37] did not find evidence of food deserts in urban areas. Together, these findings point to the need to evaluate specific conditions in order to understand food access in a region.

Low-income populations are also more likely to be living near high-traffic or industrial locations, and can have higher rates of exposure to noise, air, soil and water pollution as a result. Such areas are more affordable, so from a practical standpoint will probably continue to be populated by lower-income residents. Enforcement of environmental standards and environmental (brownfields) remediation can alleviate some of the more acute health hazards. When seeking to locate public (affordable or low-income) housing, industrial land uses, or roadways, these potential

[30] Statistics Canada and Alter et al 1999, as cited in Region of Peel Public Health 2001, p. 3
[31] Centre for Chronic Disease Prevention and Control 2002, as cited in Creatore et al. 2007.
[32] Creatore et al. 2007
[33] Region of Peel Public Health 2001, p. 3.
[34] Region of Peel 2005, p. 13.
[35] Larsen and Gilliland 2008.
[36] Smoyer-Tomic et al. 2006.
[37] Apparicio et al. 2007.

environmental justice impacts to low-income populations should be avoided. In some cases, conservation measures that avoid the need for the new facility (such as a road or water transfer station) may be possible.

2.3.2 ELDERLY POPULATIONS.

At 8 percent of the population, those over 65 make up a rather small proportion of Peel's population. However, it is the fastest growing segment of the population, increasing by nearly 70 percent between 1991 and 2001.[38] By 2021, seniors are projected to make up 13 percent of Peel's population.[39] More of Peel's seniors are classified as low-income than the general population – 46 percent of all unattached seniors, and 50 percent of unattached senior women as compared to 11.6 percent of the total population.[40]

Because it has been shown to reduce many of the ongoing health problems associated with aging (including weight-related problems, flexibility and arthritis) and increase overall well-being, sense of independence and self-esteem, physical activity – particularly walking - is important for the elderly[41]. A walkable built environment can also support 'aging in place' - allowing residents to maintain independence and interaction with the broader community through all stages of life, rather than having to go to a care centre.

In 2003, 50 percent of Peel's seniors were classified as overweight (39 percent) or obese (11 percent), slightly more than the population at large. Over half (57 percent) reported their physical activity level as "inactive." [42] Close to that same proportion of seniors (53 percent) reported that they sometimes or often have activity limitations, with those over 75 and females more frequently reporting activity limitations.[43]

The elderly are generally much more sensitive to walking distances and impedances. Although there have been no formal studies to date on threshold walking distances, many seniors are not able to walk the ¼ - ½ mile that working age adults are. Not only is it more difficult physically to walk the distances that working age adults do, it also takes the elderly longer to walk (around 0.75 m/second as opposed to 1.2 m/second for able-bodied adults). Senior housing facilities and services should be placed within a very short distance of each other, and linkages between those destinations made safe and accessible by canes, walkers and wheelchairs.

Barriers that may be insignificant to a middle-aged adult - an intersection with a short "walk" signal, frequent curb cuts for driveways, slanted or cracked sidewalks - can significantly inhibit seniors' walking levels. In a study that surveyed older adults about the most important

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[38] Peel Data Centre 2008a.
[39] Peel Public Health 2006, p. 5.
[40] Region of Peel 2005, p. 13.
[41] A number of recent studies have documented effects of walking programs on seniors' health, including: Shin 1999, Pollock et. al. 1991, Taylor et. al. 2003, Tanaka et al. 1998, and Kovar et al. 1992.
[42] Peel Public Health 2006, p. 68-70.
[43] Peel Public Health 2006, p. 52.

factors in encouraging pedestrian safety, 80 percent listed safer intersections and crosswalks, and 70 percent listed lengthening the walk phase at intersections.[44] Another survey by AARP of people over 50 found that walking distances to destinations were the single greatest barrier to walking, followed by sidewalk quality, lack of resting places, and dangerous intersections, as detailed in Figure 6.[45]

The elderly are generally frailer, and more likely to have chronic respiratory and other illnesses. For this reason, they are also more vulnerable to the impacts of air pollution and traffic injuries. Injuries to elderly pedestrians, however minor, are more likely to result in serious injuries or fatalities. In terms of air quality, caution should be exercised to make sure that senior facilities and hospitals are not placed in high-traffic locations or in close proximity to truck routes.

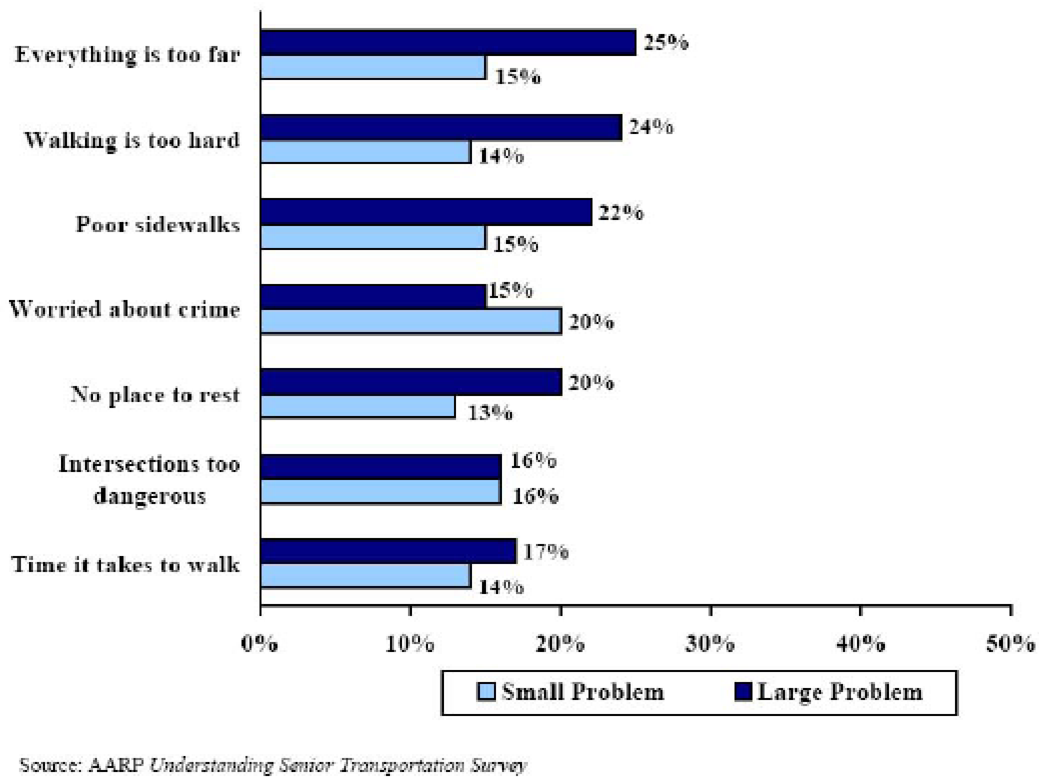

Figure 6. Barriers to walking for people over 50
(Ritter, Straight, and Evans, 2002)

2.3.3 CHILDREN AND YOUTH.

Recent trends in physical activity and obesity are even more dramatic for children and youth. During the period from 1981 - 1996, the number of obese children in Canada tripled (as opposed to a doubling of obesity in adults).[46]

[44] Kerchener and Aizenberg 1999.
[45] Ritter, Straight, and Evans 2002.
[46] Tremblay and Willms 2000, as cited in Peel Public Health 2005b, p. 22

Overweight kids are more likely to grow up into overweight adults and often get the same diseases, such as diabetes, before they reach adulthood. For children and youth, physical activity can prevent health problems from emerging, support learning and emotional development, and is the foundation of an active lifestyle into adulthood. Health Canada guidelines set a target of 90 minutes of physical activity a day (30 of it vigorous) for youth.

Data suggests that there are large portions of the youth population that are inactive. In a recent survey of youth (age 12 - 19) in Peel, 16 percent did not engage in any vigorous physical activity outside of school hours in the week prior to the survey. The percentage of inactive children and youth generally increased with age – about 6 percent of seventh graders were inactive, compared to almost 20 percent of twelfth graders. However, high school students spent more time walking. For grades 9 through 12, at least 30 percent of students reported walking more than 6 hours the previous week, compared to 12 percent of seventh graders and 15 percent of eighth graders. Male students were significantly more likely than females to have spent over 6 hours walking. Two percent of youth surveyed reported no walking at all, and 48 percent spent between one and five hours walking. Forty-eight percent of students reported that they did not ride a bicycle at all during the survey period.[47] Overall, there are indications of a shift from active to sedentary forms of transport in Peel's children similar to that of adults.[48]

As with adults, it will be important to provide opportunities for youth to engage in active transportation such as bicycling, walking and transit. However, the built environment factors that are associated with physical activity and active transport in youth are likely different than those for adults. Where, as discussed in Chapter 2, numerous studies have found links between built environment and walking / physical activity in adults, a recent (2006) literature review found few connections between built environment factors and physical activity in children and youth. However, the researchers found few studies that relied on objectively measured built environment data, and conclude that objective measurement of the built environment is needed in order to better understand potential determinants of physical activity.[49]

One more recent study may provide some insights. In a large sample of youth (n=3161) that measured the built environment objectively, researchers found that the factors that predicted adult walking behaviour in past studies (such as residential density, street connectivity, land use mix) were only significant for youth aged 12-15. Once driving age was reached, and before age 12, built environment variables were insignificant, or less consistently so. For all age groups in the study, household vehicle ownership was the most important demographic predictor of walking among youth, with youth in lower income, non-white, and smaller households significantly more likely to walk and to walk more than a half mile.[50]

[47] Peel Health Region 2005b, p. 32-38
[48] Gilbert and O'Brien 20085, p. 19.
[49] Ferreira et al 2006.
[50] Frank et al. 2007b.

Other research indicates that parks and recreation areas within walking distance will support walking and physical activity in kids[51]. Creating a network of parks will give kids more opportunities to play outside, and enable them to walk or bicycle rather than having to be driven to every soccer game or track practice. Trips to school represent another major opportunity to increase the number of kids using active forms of transport. Over half of Canada's school children are estimated to be driven to school.[52]

Safety of the access routes to parks and schools should therefore be carefully considered – approaches such as traffic calming, signalization, and crossing improvements can help to facilitate safe access. Safety from traffic is crucial – traffic crashes are the leading cause of injury-related deaths for Canadian children over 1 year old.[53] Canada has an active Safe Routes to School program that funds active transportation programs and projects at schools across the country. Programs like this can increase the number of children walking and reduce their exposure to pollution from cars at school pick-up/drop-off areas.

Children are also more vulnerable to harmful air pollutants. There is evidence that children have higher rates of exposure to diesel pollution because of school bus transport.[54] At schools, anti-idling restrictions – particularly for diesel school buses – can limit exposure to pollutants from vehicles, and schools may want to explore the use of alternative fuel or low-emissions school buses. It is also especially important to place schools, ball fields and playgrounds away from high air-pollution sources such as airports, highways, and high-traffic intersections. However, where conflicts already exist, buffers such as HVAC systems, walls, hedges and trees, or awnings may be appropriate and help to preserve air quality for students.

The Public Health Agency of Canada has commissioned the Centre for Sustainable Transportation at the University of Winnipeg to develop provincial-level guidelines for child and youth friendly land use and transport planning.[55] These guidelines were first prepared for Ontario, and include numerous measures that can make walking and cycling safer and more appealing for children and youth. These strategies can have enormous benefits to everyone, not just children.

2.3.4 ETHNOCULTURAL AND ABORIGINAL POPULATIONS.

According to the 2001 Census, 35.8 percent of Peel's population identifies themselves as visible minorities[56], and 43.1 are immigrants. The proportion of visible minorities has doubled, and the immigrant population has increased about 60 percent, since the last Census.

For different ethnocultural groups, relationships between physical activity and the built environment are more complex and also cut across issues of healthy food choices, cultural traditions and norms, and income. As one example, in a

[51] Babey et al. 2005, Frank et al. 2007b.
[52] Go for Green 1998, as cited in Gilbert and O'Brien 2005, p. 17.
[53] Gilbert and O'Brien 2005, p. 15.
[54] Gilbert and O'Brien 2005, p. 13-14.
[55] Online at: <http://www.kidsonthemove.ca>
[56] Peel Data Centre 2008b.

study in Atlanta, Georgia, when survey populations were broken out into sub-groups by race and gender, after adjusting for income, age, and educational attainment, land use variables were significantly associated with physical activity and body mass index for white but not for black participants. One possible explanation is poorer access to healthy food choices for non-white populations in the Atlanta region.[57]

Diabetes is more common in some ethnocultural populations, particularly African, Hispanic and South / East Asian groups. For example, despite the fact that South Asians and West Asians only make up 4 percent of Ontario's population, they account for 12 percent of the population with diabetes. This is at least partially due to genetic predisposition towards the harmful weight gain patterns that increase diabetes risk.[58] As mentioned in the previous section on low-income, immigrants and visible minorities are also both more likely to be low-income or living in poverty, compounding the health risks for these populations.

Of Peel's immigrant population, 37 percent are new immigrants - entering the country between 1991 and 2001. The vast majority of these new immigrants were from Asia - India, Pakistan, China and the Philippines in particular.[59] In a recent longitudinal study of immigrants, recent immigrants report better health overall than native Canadians. This "healthy immigrant effect" declines over time, particularly for non-European immigrants, possibly as immigrants adopt Western behaviours and diets.[60] Another recent study showed this same effect, with the most recent immigrants having the lowest likelihood of chronic disease compared to native Canadians. The odds of chronic disease increased with the duration of time spent in Canada, with those who have been in the country 30 years or more having about the same odds of chronic disease as the Canadian-born.[61]

Less than 1 percent of Peel residents have Aboriginal origins,[62] but large disparities in health status exist for Aboriginal and First Nations populations. Although their life expectancy has gone up, their overall health levels and life expectancy are still lower than that of the overall Canadian population.[63] Aboriginal populations have the highest rate of diabetes worldwide, in some cases as high as 25–50 percent. In Ontario, First Nations communities had rates of diabetes that were three times that of the rest of the population.[64]

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[57] Frank et al. 2004
[58] Booth et al. 2007
[59] Peel Data Centre 2008c.
[60] Ng et al. 2005.
[61] Perez 2002.
[62] Peel Data Centre, 2008d.
[63] MacMillan et al. 1996, as cited in Tjepkima M, 2002.
[64] Booth et al 2007.

3. PHYSICAL ACTIVITY LEVELS & BODY WEIGHT

In Canada, the prevalence of obesity has more than doubled in the last twenty years, as illustrated in the series of maps in Figure 7. The most extreme forms of obesity, where body mass index (BMI)[65] exceeds 40 or more, increased the most dramatically – 225% between 1990 and 2003.[66] In Peel, as mentioned in the introduction, the trends are similar – 45 percent of the region's population was overweight or obese in 2003.[67]

For each individual, obesity is generally determined by a combination of genetic makeup, calories consumed (what we eat) and calories expended (our activity level). Increasingly sedentary lifestyles combined with a prevalence of high-calorie, high-fat, high-sugar foods upsets this balance, and has resulted in alarming consequences.

When it concluded that short bursts of moderate physical activity could have significant benefits to health, the U.S. Surgeon General's 1996 *Report on Physical Activity* changed the way we looked at exercise. Even modest increases in physical activity tend to reduce mortality rates for both older and younger adults,[68] which means that walking or bicycling for errands, to work or to school can be an important part of an integrated strategy to reduce obesity rates and to meet the Heart and Stroke Foundation's recommendations of 30 minutes

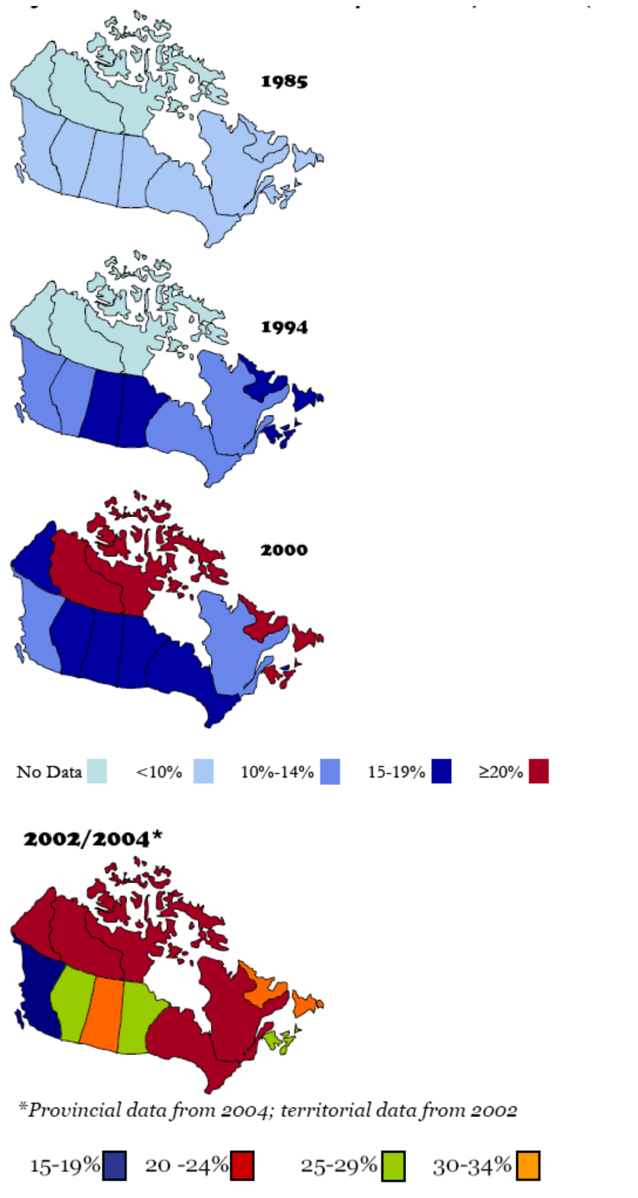

Figure 7. The Prevalence of Obesity in Canada, 1985-2004 *(From Katzmarzyk 2006)*

65 A BMI of over 25 is classified as overwieght, and 30 is generally considered obese.
66 Katzmarzyk and Mason 2006.
67 Region of Peel Public Health 2005.
68 Sallis et al. 2004.

of moderate activity per day. Our surroundings can positively influence these outcomes if they encourage active transportation and access to healthy foods and recreational facilities.

3.1 Health Impacts of Obesity

Diseases associated with obesity and low rates of physical activity – heart disease, obesity, high blood pressure - are currently among the leading causes of disability and death. Katzmarzyk et al.[69] estimated that in the year 2000, nearly 10 percent of all deaths among 20 to 64 year old adults could be attributed to overweight and obesity. In Peel, the rate of adults with diabetes has increased steadily in recent years, from 5.2 percent in 1995 to 6.8 percent in 1999. Province-wide, diabetes experienced a 31 percent increase during that same time period – from 4.72 to 6.19 percent. Compared to the other counties in the province, Peel's diabetes rate is ninth highest, although study authors note that this may be due to improved detection in South Asian immigrant communities.[70]

Health Problems Associated With Inadequate Physical Activity

- Heart disease
- Hypertension
- Stroke
- Diabetes
- Obesity
- Osteoporosis
- Depression
- Some types of cancer

Obesity impacts the overall economy as well, even those who are not obese, through increasing healthcare costs and waiting times. In another study, Katzmarzyk and Jenssen estimated Canada's economic burden of obesity to be $4.3 billion in 2001.[71]

3.2 Research Summary

In general, the consensus in the research is that there is a connection between the built environment, sedentary vs. physically active modes of transportation and the resulting physical activity and overweight/obesity levels.[72] Not only has urban form been found to be associated with the amount of active transport (bicycling and walking) that occurs, it has been correlated with total amount of physical activity.[73] Sprawling land use patterns have also been correlated with higher body weights, obesity, their associated chronic diseases,[74] and in one case, other health conditions.[75] Time spent driving has also been linked to obesity.[76]

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69 Katzmarzyk et al. 2004.
70 Hux et al. (eds) 2003, p. 1.7-1.13.
71 Katzmarzyk and Jenssen 2004.
72 Lopez 2004; Papas et al. 2007.
73 King et al. 2003; Saelens et al. 2003b.
74Ewing et al. 2003a; Frank et al. 2004; Giles-Corti et al. 2003; Saelens et al. 2003a; Frank et al. 2005.
75 Sturm and Cohen 2004.
76 Frank et al. 2004.

In addition to the research that explores the above health outcomes specifically, this section also includes findings from the urban planning/transportation literature on urban form and walking.

Aggregate Level Studies
A US study conducted at the county level found a significant relationship between an index of urban sprawl and physical activity, obesity, and hypertension.[77]

Looking at 100 metro areas across the US, another study correlated values from the same sprawl index with 16 different chronic diseases, including overweight-related conditions (e.g. hypertension), respiratory ailments (e.g. emphysema and asthma), and other conditions such as mental health, abdominal problems and severe headaches. The sprawl index was found to be a significant predictor of the number of chronic medical conditions in a population, although it was not found to be related to mental health.[78]

Overall Neighbourhood Walkability
As part of the Toronto Diabetes Atlas, researchers assessed relationships between neighbourhood design and diabetes using an Activity-Friendly Index (AFI). This index included a number of built and social environment factors: Population density, retail density, access to retail, car ownership rates, and rates of drug-related and violent crime. Residents of activity-friendly neighbourhoods (primarily the close-in, older areas of Toronto) reported more walking or bicycling trips per day and lower diabetes rates, particularly in high-risk areas (lower income neighbourhoods and those with more visible minority residents). Higher-income areas had lower rates of diabetes overall, even in neighbourhoods that were not activity-friendly.[79] A different study by the Heart and Stroke Foundation found that Canadians living in compact, mixed use neighbourhoods were 2.4 times more likely to get the recommended 30 minutes per day of physical activity.[80]

A study comparing two neighbourhoods in San Diego found that people had significantly higher overall levels of moderate (objectively measured) physical activity and significantly lower obesity rates in the high-walkability neighbourhood. Residents in the high-walkability neighbourhood engaged in approximately 70 more minutes of moderate to vigorous physical activity per week than their counterparts in low-walkability neighbourhoods. The researchers note that "virtually all the difference in neighbourhood-based physical activity was in moderate-intensity activity, which suggests that activities such as walking accounted for the total physical activity difference between neighbourhoods."[81]

The SMARTRAQ study based in Atlanta, Georgia used accelerometers to objectively measure total physical activity. The study found a measure

77 Ewing et al. 2003a.
78 Sturm and Cohen 2004.
79 Booth et al. 2007b.
80 Heart and Stroke Foundation of Canada 2005, as cited in Creatore 2007b.
81 Saelens et al. 2003a.

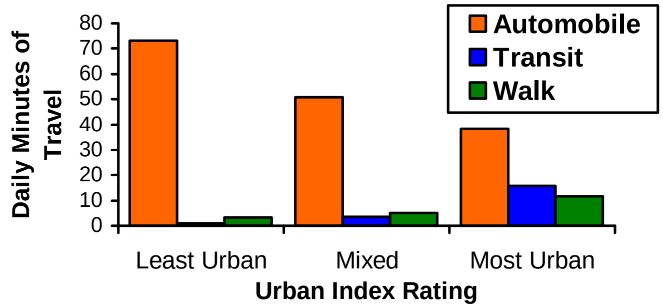
of walkability that comprised **mixed use, residential density, and street connectivity** to be a significant factor in explaining the number of minutes per day of moderate physical activity.[82] Residents of the most walkable areas of the Atlanta region were found to be 2.4 times more likely to get the recommended 30 minutes of moderate physical activity per day. On average, residents of the most walkable environments in Atlanta got approximately 37 minutes of moderate activity per day whereas residents of the least walkable environments got only 18 minutes - less than half as much. The same study also found that, each additional hour spent in a car per day was associated with a 6% increase in the likelihood of obesity.[83]

The Seattle-based Land Use, Transportation, Air Quality and Health (LUTAQH) study found the walkability of an area (as measured by its **density, land use mix, retail Floor Area Ratio, and street connectivity**) to be correlated with lower rates of obesity and auto use, and higher rates of transit ridership, walking and overall physical activity.[84] A 5 percent increase in the overall range of walkability was associated with a 32.1 percent increase in minutes of active transport and about a quarter point reduction in BMI.[85]

Lawton[86] compared average daily minutes of travel by automobile, transit and walking by residents of Portland, Oregon neighbourhoods, as shown in Figure 8. Although the total average time spent traveling is similar for the three neighbourhood types, residents of the most urban neighbourhoods walked an average of 11.8 daily minutes, over three times more than the 3.3 average daily minutes by residents of the least urban neighbourhoods.

Another study based in Atlanta, Georgia also as part of the SMARTRAQ program found that each additional hour per day spent driving was associated with a 6% increase in the odds of obesity, while each additional kilometer walked per day was associated with a 4.8% reduction in the odds of obesity.[87]

82 Frank et al. 2005.
83 Frank et al. 2004.
84 LFC 2005a.
85 Frank et al. 2006.
86 Lawton 2001.
87 Frank et al. 2004.



As an area becomes more urbanized, average daily walking trips increase. Residents of the most urban neighbourhoods walk 11.8 daily minutes, more than one-third the recommended minimum daily requirement, compared with only 3.3 daily minutes by residents of the least urban neighbourhoods (Lawton 2001).

Figure 8. Impact of Urbanization on Walking

3.2.1 INDIVIDUAL URBAN FORM CHARACTERISTICS

Density
The Atlanta SMARTRAQ study found that as residential density increased from under two to over eight dwelling units per acre, mean BMI for white males declined from 27.13 to 25.91. This corresponds to about a 10 pound difference for an average 5' 10" man.[88]

Land Use Mix
Studies that have examined land uses objectively and in detail have collectively that the land use mix that generates the most walk trips is where daily activities (home, work, school) are located near those that are used less regularly (movie theatres, shops, restaurants).[89]

The Seattle-based LUTAQH study found several specific land uses strongly linked to the percentage of household walking trips. These included educational facilities, commercial office buildings, restaurants and taverns, parks, neighbourhood-scale retail establishments, civic uses of land and grocery stores.[90]

The LUTAQH study also found that variety – the ***number*** of retail establishments – was more effective at generating walk trips for non-work purposes than was total square retail footage (for example, a number of small shops would generate more walking trips than a big box store). With each 25 percent increase in the total number of retail locations, walking for non-work trips increased 19 percent. [91]

88 Frank et al. 2004.
89 Lee and Moudon 2004; Moudon and Lee 2003; Hess 2001; Frank et al. 2006; LFC 2005a.
90 LFC 2005a.
91 LFC 2005a.

A mixed land use pattern was directly correlated to lower obesity rates in the SMARTRAQ studying Atlanta. Each 25 percent increase in land use mix around the home was associated with a 12 percent reduction in the likelihood of obesity[92].

Connectivity
Most research on street connectivity has focused on walking, as it is thought that walking (being a slower mode of travel) is more directly impacted by disconnected street networks. Two early studies on this topic found significant relationships between connectivity variables and walking.[93]

Moudon and Hess[94] also found indications that connectivity may be a necessary element (in addition to compact and mixed-use development) to increase walking and decrease driving. They found that almost 20 percent of residents in suburban areas of the Central Puget Sound Region live in "suburban clusters"—medium-density neighbourhoods in close proximity to neighbourhood retail. These suburban neighbourhoods, however, are lacking in connectivity. When the suburban clusters were compared to urban neighbourhoods with similar levels of density and mix of uses but higher levels of connectivity, the suburban clusters generated an average of one-third the pedestrian traffic than their urban counterparts.

Transit Service
The research indicates that good public transit service can also encourage physical activity. Most public transit trips also involve a walking link. One analysis of US travel survey data found that 16 percent of all recorded walking trips were part of transit trips, and that transit-based walk trips tended to be longer than average.[95]

Another US study based on travel survey data found that transit users spend a median of 19 minutes per day walking to transit. Twenty-nine percent of US transit users walked more than 30 minutes daily on their transit trip alone.[96]

Facilitating pedestrian access to public transit may have the greatest health benefits for low-income individuals. Not only are they more likely to be transit users, low-income and non-white people are also more likely to walk to public transit, and more likely to spend more than 30 minutes on their trip to transit.[97]

Street Design and Pedestrian Facilities
Well-designed streets are likely to encourage more physical activity by making bicyclists and pedestrians feel safe and welcome. Enjoyable

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92 Frank et al. 2004. *A note: The changes in obesity across levels of land use mix are also likely to be influenced by neighbourhood selection and access to healthy food choices.*
93 Kitamura et al. 1997; Greenwald and Boarnet 2001.
94 Moudon and Hess 2000.
95 Weinstein, Schimek 2005.
96 Besser and Dannenberg 2005.
97 Besser and Dannenberg 2005.

scenery and attractive neighbourhoods have both been associated with higher physical activity rates.[98]

A Canadian study found sidewalks and crossing lights to be significantly associated with walking to work.[99]

A recent meta-analysis looked at findings from 50 studies that examined the relationship between *perceived* (rather than observed or measured) built environment conditions and physical activity. The analysis identified perceived environmental variables that consistently met criteria for effect size. Out of these variables, the perceived presence of physical activity facilities nearby, perceived presence of sidewalks, perceived presence of shops and services, and perceived lack of heavy traffic were all significantly associated with a higher likelihood of physical activity. The authors conclude that these findings confirm research that has found a "modest, yet significant association" between built environment variables and physical activity. They also note the importance of street design factors as well as nearby destinations, stating that "since…many road systems are designed without the needs of pedestrians in mind, it is time for planners to recognize the health relevance of their work."[100]

Recreational Facilities and Open Space

Research indicates that communities with parks, trails, playfields, and other recreational facilities within walking distance are associated with more physically active residents. One study showed respondents are more likely to meet physical activity recommendations if they live within a ten-minute walk of a park, trail or other place to walk.[101] Another survey found that trail use decreased by almost 50 percent with every quarter-mile (half kilometre) distance increase in access.[102] In the Toronto Diabetes Atlas analysis, researchers found that although parks and other recreational facilities are relatively well-distributed throughout the city, several neighbourhoods with high diabetes rates also had limited accessibility to those facilities.[103]

The LUTAQH study found that the odds of walking increased by 20 percent for each additional park, and 21 percent for each additional educational facility within a kilometer distance from residential locations in Seattle.[104]

Recreational facilities play an especially important role in children's physical activity, and having good street or pathway connections to those facilities is just as important. If parks and recreation areas are within walking distance, kids can be more active on a regular basis. One study showed teens with access to a safe park were more active than those that did not have access to a safe park.[105] Another recent piece of research

98 Wilcox et al. 2000; King et al. 2000; Ball et al. 2001.
99 Craig et al. 2002
100 Duncan et al. 2005.
101 Powell et al. 2003.
102 Troped et al. 2001.
103 Creatore et al. 2007b.
104 LFC 2005a.
105 Babey et al. 2005.

showed that the presence of at least one recreational space within a kilometre of where youths live was consistently associated with walking in youths of all age groups (between ages 5 and 20).[106]

3.3 Other Issues in the Research

3.3.1 THE NEED FOR OBJECTIVELY MEASURED DATA.

Most research into health behaviour is based on self-reported data. Although corrective factors are a standard approach to correct for over / under reporting, self-reported data can be notoriously inaccurate. GPS systems and accelerometer data is one way to generate objectively measured physical activity data, and some studies have done this. However, existing self reported survey datasets are still likely to be used for planning purposes due to additional time and resources needed for additional objective measurement.

3.4 Conclusions and Broad principles

Generally, the research has concluded that there is a connection between built environment patterns, physical activity and obesity – particularly residential density, land use mix and connectivity. Proximity to transit and parks have also been found to be important factors in predicting physical activity. However, at this point little research has studied whether or not there may be a causal connection.[107] The research that exists suggests that both preferences and the built environment impact transportation and physical activity.[108]

Proximity to Individual land uses. In addition to measuring overall characteristics of the land use pattern, for physical activity it is important to assess how a project or a plan provides access to parks, trails, recreational facilities and transit.

Measuring access and issues of scale. Generally, smaller scale measurement is better for research on walking and physical activity, as land use patterns influence walking behaviour at the 1 kilometer threshold or even less. Therefore, a tool that measures land use patterns at the parcel or small grid-cell level is preferred. When measuring walking distances, it is important to measure what is actually walkable on the street network as opposed to using the cruder “crow-fly” buffer measurement; and to account for major barriers to pedestrian movement such as highways.

Demographics. Demographic variables – income, gender, age and auto ownership, among others – are also strongly related to physical activity and body weights. It will be important to factor in demographics to the degree possible when evaluating physical activity impacts of development, particularly in the Peel Region which has a high amount of new immigrants. However, caution is due when performing such work,

106 Frank et al. 2007b.
107 TRB-IOM 2005.
108 Bagley and Mokhtarian 2002; Frank et al. 2007a; Handy et al. 2006; Khattak and Rodriguez 2005;
Kitamura et al. 1997; Schwanen and Mokhtarian 2004; Schwanen and Mokhtarian 2005a; Schwanen and Mokhtarian 2005b.

as it is nearly impossible to predict how demographics could change given different development patterns.

3.5 Key Land Use Factors

These factors represent the built environment factors that are a) strongly associated with physical activity, walking or obesity outcomes in the literature, b) consistently associated with physical activity, walking or obesity outcomes in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

Residential Density. Because it can also serve as a proxy for other urban form factors, residential density is of particular importance at larger geographic scales of measurement or in cases where data is missing. As the data allows, density measures should be measures of net density (the number of residential units per acre of land in residential use), rather than gross density.

Street Network Connectivity. The easiest way to operationalize street network connectivity in a GIS environment is by measuring the number of intersections per acre. This is a more straightforward measure than block size or block length, which can be complicated in suburban areas where the street layout may not match the traditional definition of a block. Intersections, on the other hand, can be defined (for instance, those with three 'legs' or more) and counted. It will be important to exclude intersections that actually represent barriers – that is, roads that dead end at a highway or highway interchanges.

Land Use Mix. Although land use mix is a rather abstract measure, it is a crucial factor to include when looking at physical activity and walkability. Given the appropriate parcel data, the quantitative calculation of land use mix is possible through a GIS or database interface as has been done in a number of prior studies.

Retail FAR. Because it can measure retail density as well as site design, retail FAR is a good measure to use in conjunction with land use mix. FAR is a standard planning measure and is frequently used in development regulations – and therefore is useful to apply to policy or existing regulations.

Number of retail parcels. A simple count of the number of parcels zoned for retail or in retail use in a neighbourhood is a straightforward, easy to use measure.

Proximity to parks, recreational facilities & pathways. Parks, recreational facilities and pathways within walking distance have been consistently correlated with physical activity, particularly in children. Parks, trails and pathways are easily measured in proximity to other land uses in a GIS environment.

Proximity to transit. Transit within walking distance not only impacts transit use, but walking and physical activity as well. Many transit agencies have transit routes and stations as GIS map layers, making analysis straightforward. If GIS data does not exist, measuring distance to/from transit routes/stations can be done by hand in small areas.

Presence of sidewalks. Sidewalks have been directly linked to walking and physical activity. Again, the availability of GIS data layers will make measuring the presence of sidewalks relatively easy. Without GIS data, manual analysis is feasible for small areas.

3.6 Key Outcomes/Indicators:

These outcomes are a) strongly associated with land use patterns in the literature, b) consistently associated with land use patterns in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

Amount of walking / bicycling. Measuring the amount of walking and bicycling can be done by looking at travel survey results, if those travel surveys adequately collect walking and bicycling information. Total minutes of walking and bicycling can be calculated from several questions in the Physical Activity section of the Canadian Community Health Survey (CCHS). This set of questions separates out walking and other activities done for leisure as opposed to walking and bicycling "to work, school or for errands."

Total Minutes of moderate physical activity. Calculating minutes of moderate physical activity could be based on several questions in the Physical Activity section of the CCHS as discussed above.

Body Mass Index/percent obese / overweight. BMI and percent obese or overweight can be calculated based on height/weight information in the CCHS. The CCHS collects both self-reported (p. 14) and measured height/weight information (p. 246).

4. Exposure to Air Pollution

Travel behaviour, and vehicle travel in particular, is directly related to the generation of air pollutants and CO2, the primary greenhouse gas. However, the relationships between air quality, vehicle travel and land use patterns, and their health effects are complex. Air pollution is made up of a variety of substances, each with different sources, patterns of distribution, and health impacts (summarized in Table 2). Each pollutant therefore has a different association with land use patterns and transport, making it difficult to determine how a particular land use policy will affect air pollution levels or exposure risks. It is even possible that a policy could reduce the health risks from some pollutants and increase the risk from others.

High per capita vehicle miles of travel and number of vehicle trips are associated with higher levels of several air pollutants that have adverse respiratory health impacts: fine particulates (PM), toxins, carbon monoxide (CO), oxides of nitrogen (NOx) and volatile organic compounds (VOCs). Generally, actions that reduce per capita vehicle miles and trips, make vehicle traffic smoother, encourage less polluting vehicles and increase the physical separation between vehicle traffic and people are all likely to reduce human health risks from vehicle-related pollution. As population density increases, so do the benefits of these interventions.[109] Short motor vehicle trips in urban conditions tend to have relatively high per-kilometre pollution emission rates due to cold engine starts and traffic congestion, so reductions in the number of such trips tend to achieve relatively large emission reductions. These short trips also have the most potential for replacement by walking and cycling.

Localized air pollutants – Carbon Monoxide (CO), Particulate Matter (PM), Lead, and Airborne Toxics - tend to concentrate near their source, typically fixed locations such as factories, power plants, or roadway/railway corridors. The health risks for these pollutants depend on both the total amount of these pollutants *and* on their location. A number of micro-environmental factors such as traffic conditions (vehicle mix, speed, congestion), climate (amount of wind and rain), the amount of time people spend walking, cycling or driving along the roadway, and land use characteristics such as the proximity of buildings to pollutant concentrations will determine level of exposure and how that exposure varies from one place and time to another. Localized pollutants can, therefore, create a conflict between increased development density (to reduce per capita emissions) and exposure rates (which will be higher in densely developed areas).

Regional air pollutants – PM,[110] Nitrogen Oxides (NOx) and Ozone – form at the regional level. Concentration of these pollutants depends largely

109 Friedman et al. 2001; Frank and Engelke 2005.

110 Whether PM functions as a local or regional pollutant depends on particle size and wind conditions. Large particles, such as those from diesel exhaust, tend to settle in closer proximity to where they are generated and will decrease in concentration sharply from that point. Smaller particles, or those that combine with

on an area's specific geography and weather / climate conditions in combination with the net amount of pollutants being released into the atmosphere. In fact, ozone will often form miles downwind from the source of the pollution, as NOx and VOCs drift in the wind and combine.

Global air pollutants – Carbon Dioxide – create largely indirect impacts to health through impacting climate change. Although the extent and specific location of the human health impacts of climate change are difficult to predict, they are potentially severe and can include increased risk to natural disasters such as hurricanes, drought and flooding, increased risk of vector-borne disease, large-scale displacement and decreased food security.

others to form secondary pollutants, tend to drift further from where they are generated and stay suspended for longer periods.

Pollutant	Source	Health Impacts	Distribution
Carbon Monoxide (CO)	Vehicle exhaust, other combustion of fuels and wood	Aggravates coronary heart disease, impairs central nervous system, increased risk to fetuses	Local
Sulfur Oxides (SOx)	Combustion of fuels containing sulfur (esp. diesel exhaust and coal), other industry; dissolves in water to form acid rain	Wheezing and shortness of breath, particularly in those with asthma. Has been linked to cancer.	Regional
Nitrogen Oxides (NOx) combine with VOCs to form ozone	Fossil fuel burning, other industry	Increases risk of acute respiratory illness, aggravates existing respiratory conditions	Regional
Particulate Matter (particulates are measured in micrograms; PM10 and PM2.5 are considered fine particulates, particles under 2.5 are considered ultrafine) – small particles that remain suspended, such as dust, diesel exhaust, and soot from fires	Burning fires, construction, fields/roads in a dry climate, diesel engines, other automotive sources, 'resuspended dust' from vehicle traffic	Aggravates existing respiratory disease, decreased lung function, increased respiratory infections, and increased heart attack risk (Pope et al. 2000).	Local / regional
Ozone	Formed when NOx and VOCs combine in sunlight	Decreased lung function, inflammation, can trigger shortness of breath/asthma (Bell et al. 2004; Gauderman et al., 2004, Hoek et al. 2002, Areskoug et al., 2000)	Regional
Lead	Lead gasoline, soil contamination, industrial processes	Central nervous system impairment	Local
Volatile Organic Compounds (VOCs)	Evaporation of organic compounds such as solvents, paints, gasoline, pesticides and alcohol. Combines with NOx to form ozone.	With indoor sources, includes dizziness, nausea, increased cancer risk. Outdoors, health effects primarily through contribution to ozone (see above)	Regional
Airborne Toxics (e.g. benzene, formaldehyde, methanol, etc.)	Industrial processes	Have been linked to increased cancer risk	Local
Carbon Dioxide (CO2)	Burning carbon – primarily wood (deforestation) and fossil fuels from vehicles and power plants	Impacts primarily indirect but potentially severe – increased risk of natural disasters, disease, food production and dislocation due to global climate change	Global

Table 2. Characteristics of Major Air Pollutants

4.1 Health Impacts of Air Pollution

As can be seen in Table 2 above – and as could be expected, air pollution primarily impacts the respiratory system. As we inhale these harmful substances, they inhibit lung function in the short term and can trigger acute symptoms such as shortness of breath and asthma. In the long term, they degrade lung function, especially in children, and can lead to other conditions such as cancer, heart disease, and chronic respiratory illnesses. The elderly or young, people with asthma or other respiratory conditions, and people with heart disease are most vulnerable to air pollution. A recent Ontario Medical Association report[111] estimated that air pollution in Toronto contributes to approximately 1,700 premature deaths and 6,000 hospital admissions each year.

It is well documented that those spending large amounts of time in close proximity to busy roadways may experience higher exposure to air pollution (particularly PM) and adverse health impacts as a result. Several studies in Ontario – one in Toronto[112] and one in Hamilton[113] – have researched this phenomenon. The Toronto study found a significant correlation between exposure to ultra-fine particulate matter, as measured along roadways, and hospital admissions for a number of respiratory conditions such as asthma, bronchitis and pneumonia. There was no correlation to hospitalization for other non-respiratory conditions. The Hamilton study found that living near a major roadway decreased lifespan by an estimated 2.5 years (in comparison, diabetes decreased lifespan by 4.4 years, and heart disease by 3.1 years).

People who exercise outdoors, walk or bicycle may face additional air pollution health impacts due to their elevated breathing rates. One recent study documented that using less trafficked streets for bicycle travel or traveling outside of peak travel periods may reduce exposure to air pollution.[114] Still, overall, motorists and transit riders face higher exposure rates than walkers or cyclists, even after breathing rates are taken into account.[115]

These health effects, again, ripple through the economy, primarily through increasing healthcare costs. A recent report for the BC Lung Association estimated that a 10 percent reduction in airborne fine particulate matter (PM 2.5) and ozone emissions in the Vancouver region would produce $195 million (CAN) in health benefits (from decreases in mortality, emergency room visits, and in occurrences of asthma, bronchitis and cardiac incidents) in 2010[116].

With CO2 emissions, the potential health effects are much different, as they will take place through the impact of climate changes due to the increase in CO2 and other greenhouse gases. In 2007, the Intergovernmental Panel on Climate Change (IPCC) released their most recent series of Assessment Reports. These reports reflect a growing

111 Pengelly and Sommerfreund 2004.
112 Buckeridge et al. 2002.
113 Finkelstein et al. 2004.
114 Hertel et al. 2008.
115 Chertok et al. 2004, Rank et al. 2001.
116 RWDI Air 2005

alarm and consensus in the scientific community about human generated global warming,[117] and conclude that climate change is already triggering a cascade of changes in habitat and weather patterns, which will increase in severity as warming continues. They report the direct impacts of climate change include more extreme weather patterns, such as drought, heat waves, and flooding; more catastrophic weather events such as hurricanes and tropical storms; melting of glaciers and polar ice sheets; and a rise in sea level. These changes would trigger displacement of those in coastal areas and low-lying islands due to sea level rise, and shifts in food production and disease vectors due to changes in weather patterns, and habitat and species loss due to changing climate conditions – potentially 25 to 30 percent of the world's plant and animal species are at risk of extinction.[118] These impacts could in turn trigger wide scale famine or food insecurity, disease and warfare; largely among the world's poorest populations. Although it is unclear when these changes would occur, and the extent they will occur, from the data available, all indications are that many of them are taking place much faster than climate models have predicted.[119]

4.2 Research Summary

In the research, a number of outcomes related to vehicle travel can be tied to emissions, including vehicle miles and hours of travel, and number of vehicle trips. However, since there is not a 1:1 relationship between vehicle miles/hours and emissions, estimating emissions from travel patterns allows a more precise understanding of the potential change in different pollutants emissions that might be associated with urban form strategies. A few studies have estimated vehicle emissions, including Frank et al 2000, Frank et al. 2006, Frank & Chapman 2004, and LFC. et al. 2005b.[120] Even fewer have directly estimated carbon dioxide. This summary shall draw on studies that discuss vehicle travel outcomes, as well as those make the connection to emissions.

Aggregate-level studies

A number of studies have found a strong link between regional scale development patterns and VMT.[121] Newman and Kenworthy (1989) published one landmark study, *Gasoline Consumption and Cities*, which compared 32 cities worldwide and found that more compact cities were more sustainable based on less fuel use and more transit ridership.[122]

117 Intergovernmental Panel on Climate Change 2007.
118 Intergovernmental Panel on Climate Change 2007a.
119 Reuters Tue Dec 11, 2007 12:57am EST. "Greenland Ice Sheet Melting at Record Rate."
http://www.reuters.com/article/environmentNews/idUSN1017865420071211
120 In several of the studies cited above (LFC et al. 2005b, Frank et al. 2006, and Frank & Chapman 2004), the approach used to measure emissions outcomes is highly detailed and deserves mention, as it strengthens the defensibility of results presented from these sources. Rather than using a standard methodology, which applies a simple average speed for each trip, the emissions estimates included speed and cold start information for each link of each vehicle trip. Speed was calculated for each link of each auto trip based on the road type (local, collector, arterial, freeway, etc.) and time of day.
121 Ewing and Cervero 2001.
122 Newman and Kenworthy 1989.

A US study concluded that the degree of regional sprawl had a greater influence on vehicle-miles traveled per person than metropolitan population or per capita income.[123]

In a recent literature review and synthesis on climate change, the authors summarize ten different studies that have compared VMT for individual development in infill vs. outlying locations. In all cases, the infill locations generated lower rates of VMT per capita – anywhere from 13 to 72 percent less than their corresponding sprawling locations.[124] When synthesizing this and other research, the authors of this analysis conclude that compact, walkable development "has the potential to reduce VMT per capita by 20 to 40 percent relative to sprawl."[125]

Overall Neighbourhood Walkability
The LUTAQH (Land Use, Transportation, Air Quality & Health) study in Seattle integrated several basic neighbourhood urban form measures—residential density, retail Floor Area Ratio, street connectivity, and land use mix—into a walkability index. The index was found to be a statistically significant predictor of vehicle miles traveled and NOx emissions. A 5 percent increase in walkability was associated with 6.5% fewer vehicle miles traveled and 5.6% fewer grams of NOx emitted.[126]

The Atlanta-based SMARTRAQ study used a similar walkability index that included residential density, street connectivity and land use mix to measure land use, travel behaviour and air quality relationships. People who lived in the most auto-oriented neighbourhoods drove an average of 39 miles per person each weekday—30 percent more than those who lived in the most walkable neighbourhoods. Each step up a quintiled five-part walkability scale was associated with a 6 percent reduction in NOx and a 3.7 percent reduction in VOCs127.

In an analysis based in the Puget Sound region, researchers looked at the relationship between land use, travel patterns and air pollution (NOx, VOCs, and CO). Five variables were tested in a multivariate model: household density, home location employment density (a proxy for land use mix), census block density (a proxy for street connectivity), work tract employment density, and distance to work. These variables were all found to be statistically significant in explaining VMT, VHT, and NOx. The incorporation of the five land use factors into the model along with demographic variables nearly doubled the model's ability to explain household-level NOx emissions. The model for NOx had a higher explanatory power than similar models constructed for CO and VOCs - approximately 38 percent of the variation in household NOx emissions. When considering the large number of variables that potentially influence travel behaviour and emissions, a model that explains 38 percent of emissions is worthy of notice.[128]

123 Ewing Pendall & Chen 2002.
124 Ewing et al. 2007, p 93.
125 Ewing et al. 2007.
126 Frank et al. 2006.
127 Frank and Chapman 2004.
128 Frank et al. 2000.

Neighbourhood-scale walkability also factors into the decision to take transit for longer regional trips (such as work trips) because it facilitates access to transit as well as non-driving access to auxiliary destinations, such as the bank or dry cleaner. Research has documented a link between walkable employment centres and travel mode to work. In numerous studies of employment centres in California, Robert Cervero found that a higher mix of land uses at employment centres was associated with higher shares of employees taking transit and ridesharing to work, and fewer vehicle trips to work.[129]

4.2.1 INDIVIDUAL URBAN FORM CHARACTERISTICS

Regional location

Using distance to work as a proxy for regional location in a Puget Sound Region study, researchers found significant variation in NOx, CO and VOCs by work trip distance, shown in Figure 9 below.[130]

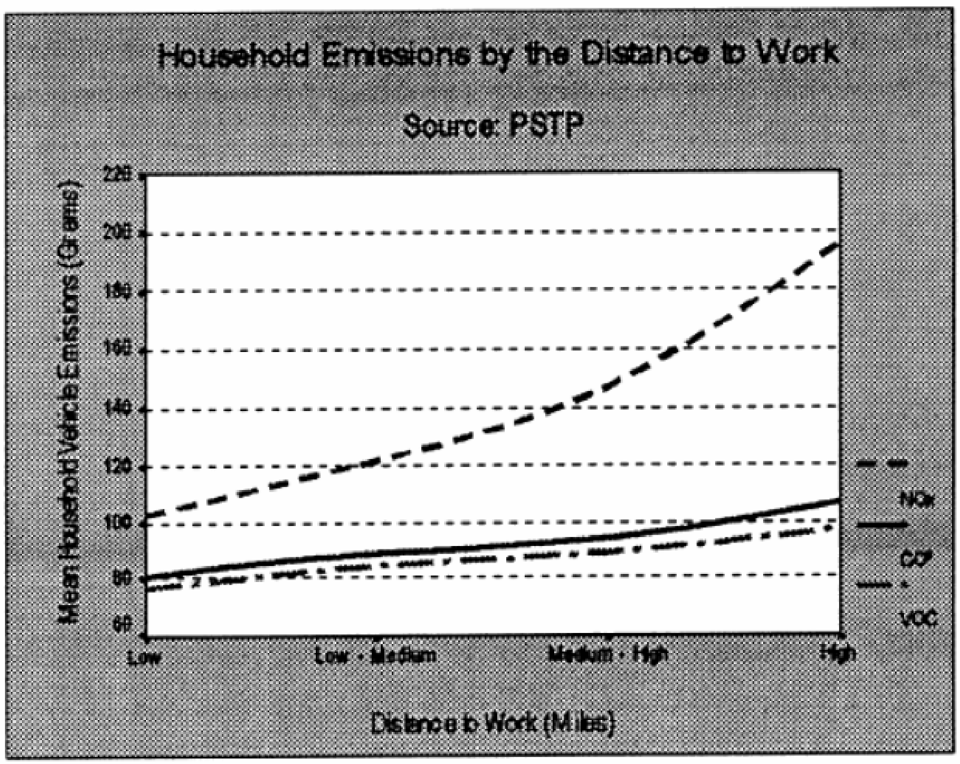

Figure 9. Co-variation in household emissions by work trip distance, a proxy for regional location.

(Source Frank et al., 2000)

Mapping of household CO2 emissions by the Chicago-based Center for Neighbourhood Technology illustrates the regional location principle, shown in the figure below. Yearly CO2 generated by household varies a great deal spatially, with lower per-household emissions within the City of Chicago and close to the rail lines on the map.[131]

129 Cervero 1988, 1989.
130 Frank et al. 2000.
131 Center for Neighborhood Technology 2007.

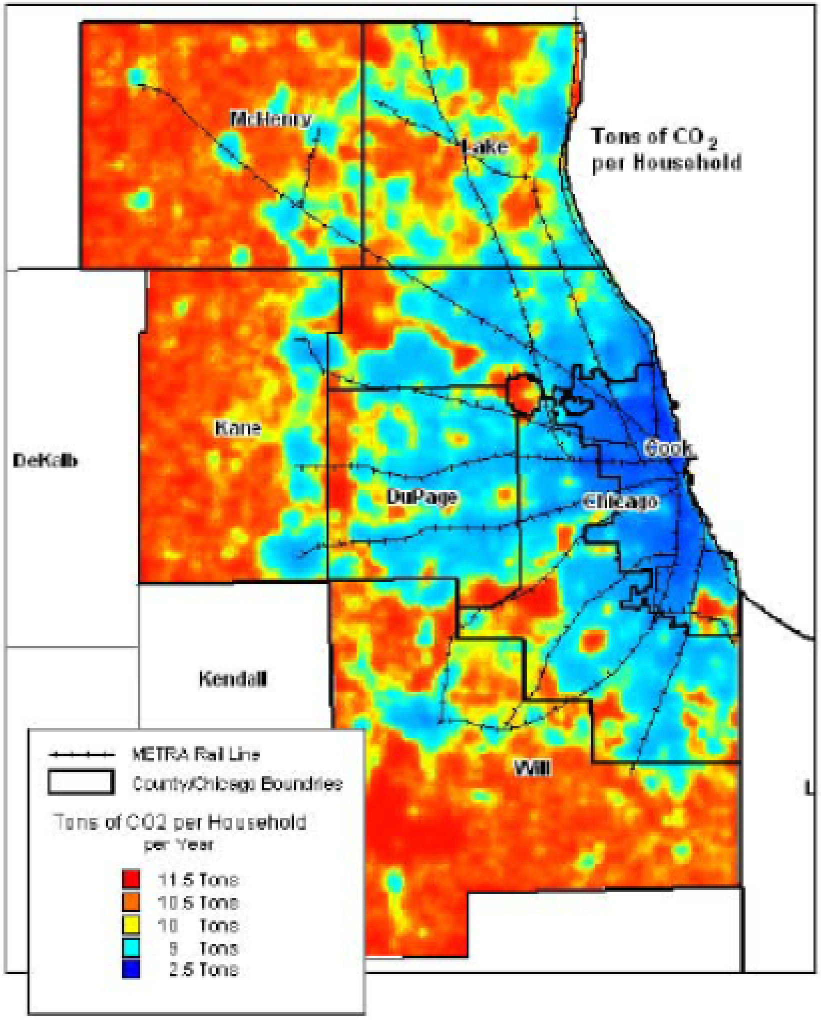

Figure 10. Per Capita Household CO2 Generation in Chicago

(Source: Center for Neighborhood Technology)

Density

As residential density increases, decreases can be seen in per capita hours and miles of automobile travel,[132] as well as in the number of vehicle trips[133] and the share of auto travel.[134]

Increases in residential density have been correlated with lower per capita levels of air pollutants when controlling for income, age, vehicle ownership and household size.135 The results depicted in Figure 11, below, measured density at the census tract level.

132 Ewing and Cervero 2001; Holtzclaw 1994; Dunphy and Fisher 1996; Frank and Pivo 1995; Frank et al. 2000; Frank et al. 2006

133 Frank et al. 2000

134 PBQD 1996; Ross and Dunning 1997; Kitamura et al. 1997; Cervero and Gorham 1995; Cervero and Kockelman 1997.

135 Frank & Engelke 2005; Frank et al. 2000; Frumkin et al. 2004, Frank and Chapman 2004

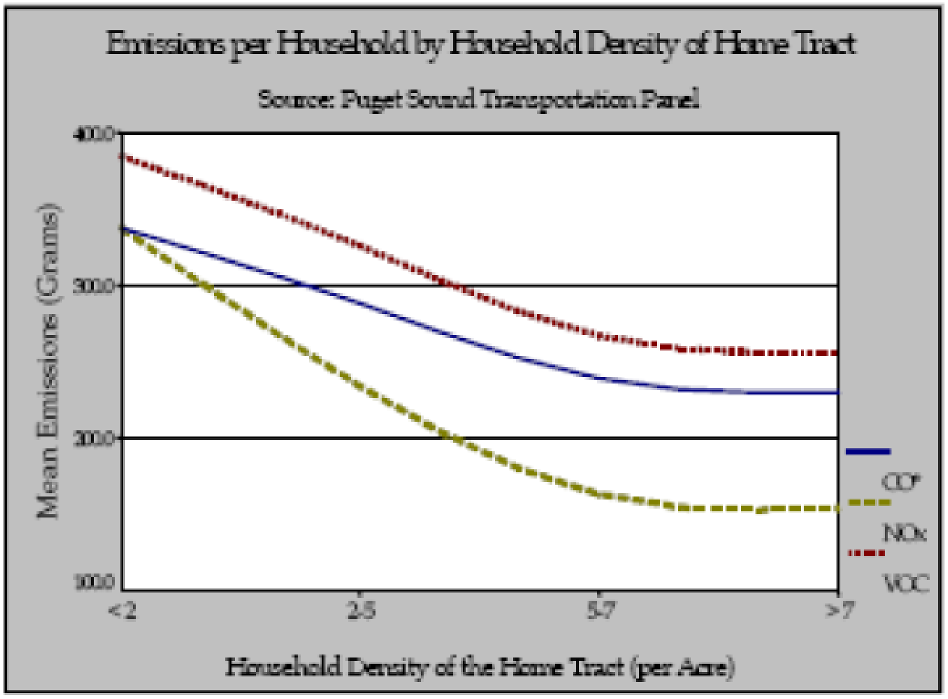

Figure 11. Covariation in emissions and census tract level household density.
(Source: Frank et al, 2000)

Residential density has also been associated with CO2 emissions. In one of the few studies to estimate CO2 directly in association with urban form – the LUTAQH study in the Seattle area - CO2 was found to decline moderately, yet significantly, with increases in residential density, as shown in Figure 12 below. This analysis controlled for gender, age, income, education and drivers' license availability.[136]

Figure 12. CO2 per capita and Net Residential Density

136 LFC et al. 2005a.

In addition to residential density, employment density has also been associated with vehicle travel patterns[137] and emissions.[138] A study in the Puget Sound Region found a threshold of about 75 employees/acre at which driving to work began to drop off in a measurable way.[139] Another study in the Puget Sound Region, which measured emissions directly, found that household-level NOx, CO, and VOC emissions followed a similar pattern, with a sharp drop off when employment densities reached medium-high levels.[140]

Land Use Mix

A number of studies have documented decreased levels of driving in mixed-use places.[141].

The LUTAQH (Land Use, Transportation, Air Quality and Health) study[142] examined the impact of individual land uses on VMT in a multivariate linear regression model. Despite the fact that these destinations account for only a small share of the number of trips generated by a household, the following land uses all accounted for small but significant decreases in VMT:

- The Number of Educational Facilities
- The Number of Grocery Stores
- The Floor Space of Civic Uses
- The Rentable Floor Space of Doctor and Dentist Offices
- The Rentable Floor Space of Neighbourhood Retail Attractions
- The Number of Large Retail Attractions
- The Number of Convenience Stores
- The Number of Fast Food Restaurants

When the same study looked at level of land use mix as a whole, significant differences in VMT and CO2 were observed across levels of mix, as seen in Figure 13 and 14 below.[143] Although the differences are statistically significant, they are also conservative. The use of quartiled data masks larger differences in VMT, CO2 and land use mix. The land use mix variable measured the evenness of distribution of several different land use types: retail, office, single family residential, multifamily residential, education and entertainment.

137LFC 2005a; Frank and Pivo 1995; Cervero 1991.
138 Frank et al. 2000.
139 Frank and Pivo 1995.
140 Frank et al. 2000.
141 Cervero and Kockelman 1997; Frank and Pivo 1995; McCormack et al. 1996, Frank et al. 2006.
142 LFC et al. 2005a.
143 LFC et al. 2005a.

LUTAQH ANOVA ANALYSIS Land Use Mix (controlling for gender, income, age, education, total number of household vehicles, distance to nearest bus stop)	Quartiles of Land Use Mix (1km road-network-based household buffer)							
	1 (LOW)		2 (MED-LOW)		3 (MED-HIGH)		4 (HIGH)	
	Min.	Max	Min.	Max.	Min.	Max.	Min.	Max.
Land Use Mix (scale from 0-1)	-3.25	0.2	0.2	0.28	0.28	0.36	0.36	0.84
VMT	32.26		30.38		27.94		27.15	

Figure 13. Differences in VMT Across Land Use Mix

(Source: LFC et al. 2005a)

Figure 14. Land Use Mix and Mean Daily CO2 per person

(Source: LFC et al. 2005a)

In addition to land use mix, **retail availability** (number of retail parcels) emerged in that study as a significant predictor of VMT, NOx and CO2 emissions in that same study,[144] as shown in Figure 15 below. LUTAQH also found that increases in Retail Floor Area Ratio (FAR) were associated with lower VMT and NOx emissions.

Figure 15. Retail Availability (number of neighbourhood retail parcels) and Mean Daily CO2 Per Person

(Source: LFC et al. 2005a)

144LFC et al. 2005a; Frank et al. 2006.

A different study in the Seattle region also found land use mix to be highly significant in predicting VMT, VHT and emissions. In applying the modeled findings, researchers found that increasing a similar index of land use mix (which included entertainment, residential, retail and office uses) from 0 (the lowest value) to 1 (its highest value) was associated with a 19.7 percent decrease in VMT, a 23.5 percent decrease in VHT, and a 10.3 percent decrease in NOx.[145]

Connectivity

Although most research on street connectivity focuses on its connection to walking trips, more recent studies have been able to draw a connection between connectivity, driving and air pollution as well.

In a study which used parcel level land use data in combination with link-level vehicle speed and start data, increases in intersection density were significantly associated with decreases in VMT, VHT and NOx emissions. When these model results were applied to unit changes in the independent variables, a one-unit increase in intersection density (as measured by the number of intersections per sq km) was associated with a 0.39 percent decrease in VMT and a 0.28 percent decrease in VHT while controlling for vehicle ownership, income and transit access. A 0.1percent decrease in NOx was found under these same conditions even after controlling for VMT. The additional impact of intersection density on NOx is probably due to speed and start patterns.[146] It should be noted that one additional intersection per square kilometer is a very small increase, and much greater variation is common when comparing levels of intersection density across regions.

Some researchers have argued that increasing connectivity also means more vehicle trips, and thus more cold starts, resulting in higher levels of vehicle emissions. These assertions have been challenged by subsequent evidence which take cold start production into account when estimating emissions. These studies demonstrated that overall NOx and VOC emissions rates are lower for residents of more compact, mixed use, connected environments. Researchers believe this was due to the overwhelming impact of travel distance on vehicle emissions rates for those in the most sprawling environments.[147]

In an earlier study by Frank et al. (2000), the generation of NOx was found to be more sensitive to street connectivity than CO or VOCs. This finding, illustrated below in Figure 16, can be attributed to the effect of street network configuration on average travel speed. Lower average travel speeds occur on interconnected street networks, and NOx emissions tend to increase at high travel speeds more than CO or VOCs.[148]

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145 LFC et al. 2005a.
146 LFC et al. 2005a.
147 LFC et al. 2005a.
148 Frank et al. 2000.

Figure 16. Co-variation in emissions by Census tract level street connectivity.

(Source: Frank et al., 2000)

The LUTAQH research found similar results - street connectivity where people live appeared to be the most closely associated with NOx generation. Mean NOx emissions declined from 29 to 23 grams per person per day, a 21 percent reduction, between residents of the least to the most connected environments.[149]

In an ANOVA analysis for the LUTAQH study, the greatest differences in VMT were observed across levels of intersection density (as compared to land use mix, retail floor area ratio, and residential density), as seen in Figure 17 below. The average VMT was 34 daily miles per person in neighbourhoods with the least connected street networks and 25 miles per day in the most connected neighbourhoods—a 26 percent decrease in VMT for residents who live in communities that have the most interconnected street networks in the countywide study area. Again, it is expected that these results are conservative; the use of quartiled data masks larger differences in VMT and street connectivity found in the region. Increases in street connectivity at household and employment locations were also associated with reductions in per capita levels of NOx, VOCs, and CO2 when controlling for household income and size.[150]

LUTAQH ANOVA ANALYSIS	Quartiles of Intersection Density ((1km road-network-based household buffer)							
Intersection Density	1 (LOW)		2 (MED-LOW)		3 (MED-HIGH)		4 (HIGH)	
(controlling for gender, income, age, education, total number of household vehicles, distance to nearest bus stop)	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Intersection Density (# per square kilometer)	0	27.56	27.78	43.35	43.37	58.71	58.75	158.93
VMT		34.03		28.83		30.01		25.46

Figure 17. Differences in VMT across Intersection Density

(Source: LFC et al. 2005a)

4.3 Other Issues in the Research

4.3.1 THE CONFLICT BETWEEN EXPOSURE AND WALKABILITY

When looking at the tradeoffs between more walkable land use patterns and pollutant exposure, walkable environments are likely to be the same places where exposure to pollutants is greatest. Although their residents and workers tend to generate less air pollutants per capita, compact urban areas also tend to generate more traffic overall, and because of higher densities that traffic is also closer to more people. This conflict is of crucial importance for particulate matter and carbon monoxide, which concentrate close to their source. However, studies of the relationships between land use and exposure to air pollutants suggest that exposure to ground-level ozone may be somewhat mitigated through increased

149 LFC et al. 2005a.
150 LFC et al. 2005a.

walkability.[151] The Border Air Quality Study is currently assessing the spatial variation in concentrations of fine particulates (PM 2.5) in more and less walkable areas of the Vancouver and Seattle regions.[152]

The conflict between walkable environments and exposure does not mean that we should forego making our cities more walkable. The cumulative benefits of walkable community design appear to be significant in the near term and even greater in the long term – especially in light of other more global and long-range issues, such as obesity and physical activity, energy supply and consumption and climate change. However, to substantially reduce exposure for residents in compact areas, the little research that has been done in this arena suggests that rather aggressive means to reduce traffic will be necessary. One study modeled speed reduction measures as an exposure reduction strategy and found they had no impact on air quality.[153] Another Norwegian study modeled the cumulative air quality impact of a number of physical, regulatory and economic measures. Avoiding high and medium concentrations of PM and NOx was possible given measures such as implementing toll roads, road cleaning, shifting to alternative fuels, and expropriating homes directly adjacent to roads. In order to avoid the lowest concentrations of PM and NOx, the study found it would be necessary to reduce traffic by more than 30 percent, in addition to major shifts to alternative fuels.[154]

Policymakers that are serious about reducing pollutant exposure will therefore need to aggressively encourage the use of alternative fuels and clean engine technologies, especially in commercial fleets and transit vehicles. Traffic reduction programs in city centres, such as London's congestion pricing scheme, will also be effective if political will is present to implement them. Car-free zones in the city centre, as has been done in many European city centres, removes vehicle pollution in the most congested areas. Toronto already has a few established car-free areas, such as the Distillery District and some of the Toronto Islands, and has been experimenting with 'Pedestrian Sundays' at Kensington Market for several years.

At a minimum, core areas should be buffered from high-traffic corridors associated with the movement of goods. Housing facilities for at-risk populations, such as youth, the elderly and people with respiratory illnesses, should be located away from pollution concentrations. Additionally, buildings near high-traffic areas should be designed to minimize pollutant exposure using HVAC systems, which have been shown to reduce exposure indoors.[155]

4.3.2 THE NEED FOR PRECISE MEASUREMENT

When data is available, emissions should be measured as precisely as possible. The additional precision that comes from detailed emissions estimates actually seems to have clarified some of the questions in the research about how street connectivity and trip generation in compact areas affect emissions (see discussion in the section on street

151 Frank and Engelke 2005.
152 BAQS, Dr. Michael Brauer, PI, UBC
153 Owen 2005.
154 Torp and Larssen 1996.
155 Sultan 2007.

connectivity, above). Estimates that account for vehicle type, travel speed, cold starts and variability in emissions based on speed will be much more valuable and informative than simple per-trip estimates.

4.4 Conclusions and Broad Principles

4.4.1 MINIMIZE EXPOSURE WHILE ENHANCING WALKABILITY.

Several sources give guidance on the buffers necessary around pollutant generating land uses in order to limit pollution exposure. Sources of air pollution that are "point" in nature (i.e. factories, sand and gravel pits, sour gas lines) are permitted and monitored through provincial and federal regulations in order to protect the public from unhealthy levels of exposure and hazards. These guidelines can include setbacks and separation distances from other land uses. For example, the MGA (Municipal Government Act) Subdivision and Development Regulation prohibits the development of a school, hospital, food establishment or residence within 450 metres of working face of the landfill, or within 300 metres of the disposal area of an operating or non-operating landfill. The MGA also prohibits residential development within 100 metres of an oil or gas well.

However, local land use codes also play a role in determining where these facilities can locate. In California, the Air Resources Board (known as CARB) recently published advisory guidance on locating "sensitive uses" near sources of air pollution, summarized in Table 3 below. CARB defines "sensitive uses" as residences (houses, apartments, and senior living complexes), schools, day care centres, playgrounds, and medical facilities (hospitals, convalescent homes, and health clinics). For ports and refineries, CARB encourages working with the local air district to develop specific plans for separation and mitigation, given site conditions, wind and climate patterns.[156]

Pollutant Source	CARB Recommendations
Freeways and High-Traffic Roads	Avoid siting new sensitive land uses within 500 feet (150 m) of a freeway, urban roads with 100,000 vehicles/day, or rural roads with 50,000 vehicles/day.
Distribution Centres	Avoid siting new sensitive land uses within 1,000 feet (300 m) of a distribution centre (that accommodates more than 100 trucks per day, more than 40 trucks with operating transport refrigeration units (TRUs) per day, or where TRU unit operations exceed 300 hours per week). Take into account the configuration of existing distribution centres and avoid locating residences and other new sensitive land uses near entry and exit points.
Rail Yards	Avoid siting new sensitive land uses within 1,000 feet (300 m) of a major service and maintenance rail yard. Within one mile of a rail yard, consider possible siting limitations and mitigation approaches.
Ports	Avoid siting of new sensitive land uses immediately downwind of ports in the most heavily impacted zones.
Refineries	Avoid siting new sensitive land uses immediately downwind of petroleum refineries.

156 California Environmental Protection Agency / California Air Resources Board 2005.

Chrome Platers	Avoid siting new sensitive land uses within 1,000 feet (300 m) of a chrome plater.
Dry Cleaners Using Perchloro-ethylene	Avoid siting new sensitive land uses within 300 feet (90 m) of any dry cleaning operation. For operations with two or more machines, provide 500 feet (150 m) . For operations with 3 or more machines, consult with the local air district. Do not site new sensitive land uses in the same building with perc dry cleaning operations.
Gasoline Dispensing Facilities	Avoid siting new sensitive land uses within 300 feet (90 m) of a large gas station (defined as a facility with a throughput of 3.6 million gallons per year or greater). A 50 foot (15 m) separation is recommended for typical gas dispensing facilities.

Table 3. CARB Guidelines for Separation from Pollutant Sources

(Source: CARB, 2005)

4.4.2 SYNERGY AMONG MEASURES

(See complete discussion in Chapter 3, Physical Activity & Obesity).

4.4.3 MEASURING ACCESS AND ISSUES OF SCALE

(See complete discussion in Chapter 3, Physical Activity & Obesity

4.4.4 KEY LAND USE FACTORS

These factors represent the built environment factors that are a) strongly associated with air quality outcomes in the literature, b) consistently associated with air quality outcomes in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

Several of the land use factors discussed in the previous section - **residential density, land use mix, street connectivity, retail FAR, and number of retail parcels** – will also be important in evaluating emissions, in addition to those listed below:

- Proximity to high-traffic corridors
- Proximity to key pollutant generators – distribution centres, heavy rail transit, dry cleaners, gas stations, and others discussed in Table 3, above.

4.4.5 KEY OUTCOMES/INDICATORS

These outcomes are a) strongly associated with land use patterns in the literature, b) consistently associated with land use patterns in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

- **Vehicle Kilometres of Travel** (VKT): VKT, along with Vehicle Hours of Travel (VHT) and Mode Choice, are practically universal indicators of how much people drive. Out of these three indicators, VKT is the most closely linked to vehicle emissions. However, it does not capture speed or cold starts/number of trips, which is necessary to accurately predict emissions.
- **Vehicle Hours of Travel** (VHT): VHT will reflect distances people are driving as well as the amount of congestion in an area. It is, generally, a better measure of people's experience of driving – more people focus on

the time it will take to get from one place to another, rather than the distance. VHT does not capture speed or cold starts/number of trips either. Because VHT has been linked to obesity in one study (described in the previous section), it therefore could also serve as an indicator of body weight and sedentary activity.

- **Mode Choice**: The share of vehicle use in relation to transit, walking and bicycling relates to the amount of driving in an area, and by extension, other pollutants. However, although there is some substitution between driving and other modes, it is not a 1:1 relationship – more walking or transit trips do not necessarily translate into less driving trips and emissions. That is because more walkable environments can also encourage short vehicle trips.

5. PEDESTRIAN SAFETY FROM TRAFFIC

Land use patterns, automobile dependence and traffic safety affect each other in a number of ways. As people spend more time in cars, their risk of being in an accident increases. Roads that are designed to move vehicles as efficiently as possible mean collisions happen at higher speeds, and thus are more severe. For pedestrians and cyclists, the combination of fast-moving traffic and street design that is hostile to non-motorized transport creates an environment that is unpleasant as well as unsafe.

Recent research has found that per capita traffic fatality rates tend to be higher in sprawling communities than in compact, mixed use communities.[157] This is likely a result of increased per capita vehicle travel, higher travel speeds and volumes, and more driving by teenaged and elderly motorists due to poor travel options. Because compact, walkable communities have been linked to lower per capita miles and hours of travel, they can also lower exposure to traffic crashes.

5.1 Health Impacts of Traffic Crashes

Rates of injury and death from traffic crashes are generally higher among males and young people. Because they tend to kill or disable people at a relatively young average age, the potential years of life lost due to traffic crashes is even greater.[158]

In Peel, a 2001 version of the *State of the Region's Health Report* listed motor vehicle crashes as the top cause of death for children from age 1-19, and second-highest cause of death for young people aged 20-44. The 2005 *State of the Region's Health Report* named traffic collisions as the 11th most common cause of death among males in Peel of all ages (2.1 percent of all deaths) – and the second-highest cause of potential years of life lost (6.8 percent of the total years of life lost). Both of these rates are higher than for the province as a whole – in Ontario in 2005, traffic collisions make up 1.3 percent of total deaths, and 5.7 percent of total potential years of life lost for males.

The above statistics for Peel cover all vehicle-related accidents without isolating vehicle-pedestrian or vehicle-cyclist crashes. For pedestrians, generally children are more likely to be involved in crashes, while older pedestrians (particularly above age 65) are more likely to be killed – likely because of frailty.[159]

5.2 Research Summary

Especially in the case of women, children, the disabled and the elderly, safety and security from crime and traffic are absolutely crucial, and have been linked to physical activity rates.[160] Children need a safe environment for their parents to feel safe letting them walk to school, the pool, or to sports practice rather than being driven everywhere. Because

157 Ewing et al. 2003b; Lucy et al. 2003.
158 World Health Organization 2004.
159 U.S. Department of Transportation 2004.
160 Weinstein et al. 1999; Booth et al. 2000.

they move more slowly and may be using a walker, cane, or wheelchair, the disabled and elderly are quite sensitive to the safety of their walking environment.

5.2.1 ENVIRONMENTAL FACTORS

Traffic Speed & Volume

A number of studies have shown traffic speeds and volumes to be strongly linked to the number and severity of collisions. Generally, traffic volumes seem to have a closer connection with collision frequency, while speeds are more closely linked to crash severity. The fatality rate for pedestrians struck by a vehicle travelling under 30 kph is only five percent. At 50 kph, the fatality rate increases to 45 percent and at 60 kph to 85 percent.[161]

A number of different design interventions can be linked to pedestrian safety through their impact on traffic speed. Although enforcement of speed limits can have value, traffic speed is affected more by the "design speed" of a roadway than by the posted speed limit. The design speed is the maximum speed that feels safe to motorists, and can be lowered by narrowing the lane width and by adding other features such as parallel parking,[162] street trees and sidewalks, and traffic calming.

A New Zealand study that examined traffic injuries of child pedestrians found that injury risk was 14 times greater at sites with the highest traffic volumes than at the least busy sites. Risk was over two times greater at sites that had mean traffic speeds over 40 km/h.[163]

A study in Boston found a strong relationship between vehicle volumes and pedestrian risk. This relationship corresponded to an increase of 3-5 injuries per year for each additional 1000 vehicles, for simple intersection configurations.

Other studies elsewhere in the US confirm the overall finding that traffic volume is connected to crash risk for pedestrians.[164]

Wide travel lanes pose particular problems for pedestrian safety by encouraging higher speeds and increasing crossing distances. A 1998 study found that out of a number of variables, street width was by far the strongest predictor of crash risk.[165]

161 U.K. Department of Transport 1997; National Highway Traffic Safety Administration 1999; Zegeer et al. 2002.
162 Jacobson et al. 2000.
163 Roberts et al. 1995.
164 LaScala et al. 2000.
165 Swift 1998.

5.2.2 SPECIFIC INTERVENTIONS

Streetscape Design & Facilities
Sidewalks are crucial in order to protect the safety of pedestrians and make them feel safe, and have been linked to lower pedestrian-vehicle collision rates.[166]

Several other studies have found fewer and less severe accidents on roadways with street trees, landscaping, on-street parking and other features that lower the design speed.[167]

Crosswalks & Intersections
Intersections are common sites of vehicle/pedestrian conflict – a 1996 Ontario study found that the majority of injury pedestrian collisions occurred at intersections.[168] A number of design features can improve pedestrian safety at intersections, including longer walk signal phases, tighter turn radiuses to slow turning vehicles, prominently marked crosswalks and refuge medians for wider roadways.

Traffic circles, found in one study to reduce accidents by 82 percent, have been overwhelmingly successful at slowing traffic and reducing accidents at intersections in residential areas with low traffic levels.[169]

There is also evidence that the simple four-way stop sign can effectively and inexpensively increase safety in areas with moderate traffic levels.

Painted crosswalks alone seem to have little impact on traffic safety. The most extensive study of (unsignalized) mid-block crosswalks in 30 U.S. cities found that on multi-lane roads with moderately high traffic volumes (over about 12,000 vehicles per day), mid-block crosswalks were associated with *higher* crash rates. The authors hypothesize that this is due to "multiple-threat" crashes – where a car in the lane closest to the pedestrian would stop but cars in the adjacent lane would not, creating a hazardous situation as the pedestrian moves into the roadway. The authors conclude that unsignalized midblock crosswalks should not be used in isolation on four-lane roads with traffic volumes over 12,000 vehicles per day, or on roads with speed limits over 64.4 km/h (40 m/h).[170]

The authors of the above study note that additional strategies to increase the visibility of pedestrian crossings may decrease crash risk, particularly in the case of multi-lane, higher speed arterials. In a study in Nova Scotia, researchers studied pedestrian – vehicle conflicts and driver yielding behaviour during the application of a series of design strategies in unsignalized crosswalks. Signage, overhead flashing lights triggered by pedestrian with a push-button, and a painted stop bar for cars (which increases sight distances for pedestrians, reducing the risk

166 Tobey et al. 1983; Knoblauch et al. 1988; McMahon et al. 2002.
167 Dumbaugh 2005; Lee and Mannering 1999; Naderi 2003.
168 Lane et al. 1996.
169 Zein et al. 1996.
170 Zegeer et al. 2001.

of the multiple-threat crash) increased proper vehicle stopping behaviour by 50 percent.[171]

Road Diets & Traffic Calming

The number of through travel lanes has also been linked to traffic safety.[172] This leads to the conclusion that 'road diets' – which reduce four-lane roads to three lanes (one lane in each direction plus a central turn lane) could have safety benefits for pedestrians, as well as reducing vehicle conflicts and providing space for parking, buses or bicycles. However, an analysis of 12 'road diets' in Washington State and California did not show conclusive safety benefits for pedestrians or vehicles. The authors note that road diet conversion should take place on a case by case basis, considering the corridor's specific needs and priorities.[173]

The safety benefits of traffic calming are more pronounced in Europe, where traffic calming strategies are much more extensively and holistically used, and are used in conjunction with other mobility strategies that support active transportation. The author of a 2000 study of European traffic calming strategies states "There can be no question whatsoever that traffic calming greatly reduces the danger of traffic deaths and injuries in residential neighbourhoods." The author cites a review of traffic calming in Denmark, Great Britain, Germany, and the Netherlands which found that traffic injuries fell by an average of 53 percent in traffic-calmed neighbourhoods.[174]

5.3 Other Issues in the Research

5.3.1 MEASURING PEDESTRIAN CRASH RISK

Transportation studies frequently target pedestrian improvements in areas where there are high volume of pedestrian crashes. However, such conclusions should be based on total risk, rather than on crash volume alone. Risk takes into account the likelihood of an accident occurring in proportion to the amount of walking taking place in an area – that is, the number of accidents divided by the total pedestrian volume. Looking at pedestrian safety in this way is using a standard public health measure – risk – to address a planning or engineering problem, and is likely to draw different conclusions about where to put pedestrian safety improvements.

This dynamic – that pedestrian crash volume does not accurately reflect pedestrian risk - may be driven by what is known as the 'safety in numbers' hypothesis. If walking and bicycling are uncommon in an area, drivers may be less aware and attentive towards pedestrians and cyclists in those areas as well. The reverse is also possible – several studies have found that in areas with more people walking and cycling, traffic accidents are actually less likely (even though the total number of

171 Van Houten 1992, as discussed in U.S. Department of Transportation 2004 and Malenfant 1999.
172 Milton and Mannering 1998; Sawalha and Sayed 2001; Vitaliano and Held 1991; and Noland and Oh 2004.
173 Huang et al. 2002.
174 Pucher and Dijkstra 2000.

crashes may be greater).[175] Researchers hypothesize that when drivers observe more walking and cycling they drive more cautiously. Improvements that slow traffic, increase visibility of pedestrians and cyclists, and create safe crossing points can all encourage walking and cycling. This can even create a positive feedback loop, encouraging more physically active modes of transportation, as results from some research indicates that people seeing others in their neighbourhood exercising or being physically active are more likely to increase their level of physical activity.[176]

5.4 Conclusions and Broad Principles

In general, speed and traffic volumes have been documented in the research are being related to the number and severity of crashes. Interventions such as traffic calming, road diets and streetscape enhancements can be effective to slow traffic and improve pedestrian safety, but application of these interventions should be carefully considered in each specific situation in the context of traffic movements, surrounding street and streetscape design, and the needs of vulnerable populations nearby such as disabled, elderly, or youth.

Crashes vs. Exposure. When measuring risk from traffic crashes, the number and location of pedestrian/vehicle crashes need to be assessed in relation to total pedestrian volumes in order to get an idea of which locations are riskiest overall. The locations with the greatest total number of crashes will often be the same locations where pedestrian volumes are greatest, while the locations with the greatest *risk* are likely to be different.

*Need for Widespread, Holistic Application of Interventions***.** Interventions to improve pedestrian safety are going to be most effective when they are part of a holistic area-wide strategy rather than as spot applications. Although addressing a particular trouble spot may be effective in cases of dramatic deficiency, actions that transform a corridor, neighbourhood or even a whole city will send a more consistent message to drivers and avoid the problem of diverting traffic to non-traffic calmed streets. Ideally, such interventions would take place in conjunction with changes to driver education, enforcement and legal systems that support the goal of safety for cyclists and pedestrians. For an excellent discussion on how such strategies have improved pedestrian/cyclist safety in Europe, see Pucher and Dijkstra (2000).[177]

5.5 Key Land Use Factors

These factors represent the built environment elements that are a) strongly associated with pedestrian safety outcomes in the literature, b) consistently associated with pedestrian safety outcomes in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

175 Jacobson 2003; Leden et al. 2000; Leden 2002; Geyer et al. 2005.
176 Booth et al. 2000; King et al. 2000.
177 Pucher and Dijkstra 2000.

- **Traffic Volume**. Traffic volumes are typically counted on main roadways and intersections for planning purposes, and are often integrated into GIS databases.
- **Traffic Speed / Speed Limit**. Generally, speed limit will be more likely to be available, especially in GIS or database form, than actual traffic speed. Regional travel models can estimate traffic speed; however, these estimates are more geared towards measuring speeds during congested conditions (e.g. slower moving traffic) than traffic that is going over the speed limit.
- **Road Width/Number of Lanes**. Although road width or number of lanes is not as closely connected to accidents in the literature, it is more universally available and easier to tabulate by hand in small areas in cases where volume/speed data is not available.
- **Sidewalks.** The presence of sidewalks is important in both actual and perceived safety, although sidewalk data is not always available.

5.6 Key Outcomes/Indicators:

These factors represent the outcomes that are a) strongly associated with the built environment in the literature, b) consistently associated with the built environment in the literature and c) policy-relevant either in ease of measurement, policy relevance or general applicability.

- **Pedestrian Crash Risk**. Pedestrian crash risk is the most precise indicator of where problems are most severe. Calculating crash risk will require data on pedestrian volumes and pedestrian crashes. Most places keep crash records; but pedestrian counts – especially systematic counts over larger areas – often do not exist. Particularly in small areas, conducting pedestrian counts could be worth the additional precision gained by being able to calculate crash/volume ratio.
- **Pedestrian Crash Locations**. Keeping track of high accident locations may be of some utility in identifying where obvious deficiencies occur; however it is important to keep in mind that crashes may not tell the whole story, and focusing on crash locations may cause other dangerous locations to be neglected.
- **Total Pedestrian Crash Rate**. A simple pedestrian crash rate may be the best indicator when volume data is not available.

6. MENTAL HEALTH

The link between urban form and travel behaviour may impact mental health through several pathways – through differences in physical activity and stress levels, contact with nature, community or social networks, and independence for non-drivers. Although compact, walkable environments may be linked to mental health in some respects, standard suburban development can also offer mental health benefits – regular contact with nature, a chance for time alone, a quiet setting. More than the other outcomes discussed in the previous sections, the impacts of one's surroundings on their mental health is likely to depend on individual preferences and whether those preferences are being met in the current living situation. Although it may mean road rage to some, for others driving is a rare opportunity for time alone and quiet reflection.

6.1 Research Findings

There is generally very little research on the relationship between urban form and mental health, and what exists is somewhat inconclusive. In one of the only studies to look at the link between mental health and sprawl, Sturm and Cohen (2004), found no significant relationship - despite finding a correlation between sprawling land use patterns and a number of physical conditions. This review will focus on research which has studied the relationship between mental health and physical activity, driving, access to nature, and community social networks, each of which can be impacted by planning decisions.

6.1.1 PHYSICAL ACTIVITY

Because physical activity can be linked to mental health, benefits from urban form upon physical activity can also be linked to mental health. Regular physical activity has been shown to decrease stress, depression and anxiety in adults, children and adolescents, the disabled and the elderly.[178]

6.1.2 DRIVING

Time spent driving has been linked to a number of conditions that impact mental health, including driving-related stress, anxiety, road rage, and community involvement. In his book *Bowling Alone*, Robert Putnam (2000) found that commute time was the strongest predictor of civic involvement. Every 10 additional minutes commuting was associated with a 10 percent drop in community involvement.[179]

Driving frustrations often revolve around unpredictability and loss of control with respect to traffic conditions, other drivers, and time pressures. The link between driving and physical signs of stress has been documented for the last half of the twentieth century.[180] In studies of commuters, traffic congestion and delays have been linked to high

178 TRB / IOM 2005, p. 59.
179 Putnam 2000.
180 Hoffman and Reygers 1960; Hoffman 1965, Taggart et al. 1969, White and Rotton 1998; Hennessy and Wiesenthal 1997; Platt 1969; Burns et al. 1996; Tomasini 1979.

blood pressure,[181] more sick days out of work,[182] more days in the hospital,[183] and decreased job performance.[184]

However, a few studies have mentioned that some people actually appreciate their driving time.[185] Additionally, train and bus commuting has been linked to similar stress indicators.[186] But all in all, the research suggests that automobile commuting is more stressful for more people than other forms of travel.[187]

6.1.3 PROXIMITY TO NATURE

Regular contact with nature has been linked to mental health[188] – one study found that those that were dissatisfied with their available green spaces had over a two times higher risk for mental health issues.[189] Views of nature have also been linked to physical outcomes - decreased infirmary visits,[190] faster healing after surgery,[191] and with less pain during invasive medical procedures.[192] As a whole, houses with backyards – more frequently found in suburban areas - may offer more regular, accessible contact with nature. However, access to nature is not exclusive to development form or type. It may, therefore, make sense to design more natural elements into walkable environments and ensure access to parks, trails, viewpoints or other natural settings within compact areas. Research on greenspace in urban settings finds that it can function as an escape from life stress, reduce depression, and improve ability to cope with major issues.[193] Clustered compact development may, in some situations, offer the benefits of walkability and better access to greenspace.

6.1.4 COMMUNITY SOCIAL SUPPORT

Living in a strong, well-connected, supportive community can contribute to mental health in several ways. Support from friends, family or a community can help in coping with stress and self-esteem[194], and may shorten hospital recovery time.[195] Those who reported a 'severe' lack of social support networks were over two times more likely to report fair or poor health as those who did not lack these supports.[196] In addition to friendly interaction, a cohesive community can help increase personal security and allow people (particularly vulnerable residents such as seniors and people with disabilities) more opportunities to walk and participate in social activities. It may also help reduce unhealthy activities such as crime, drug use and alcoholism, because neighbors

181 Stokols et al. 1978; Novaco et al. 1979.
182 Novaco et al. 1990.
183 Stokols and Novaco 1981.
184 Schaeffer et al. 1988.
185 Kluger 1998.
186 Lundberg 1976; Singer et al. 1979; Evans et al. 2002.
187 Taylor and Pocock 1972; Koslowsky and Krausz 1993).
188 Louv 2005; Kaplan et al. 1998; Frumkin 2001.
189 Guite et al. 2006.
190 Moore 1981-82.
191 Ulrich 1984.
192 Diette et al. 2003.
193 Kuo 2001; Maller et al. 2005.
194 Cohen et al. 2000.
195 Fontana et al. 1989.
196 Poortinga 2006.

watch out for and help each other. Crime is associated with low levels of social capital.[197]

The lack of transportation options in standard suburban areas means that anybody who is unable or unwilling to use an automobile will be less able to access health services, jobs, and other basic necessities. This can further isolate people, and contribute to feelings of a lack of control and dependence on others, and increase day-to-day stress.

A couple of studies have found that typical suburban land use patterns can isolate people socially, increasing their chances of depression.[198]

However, urban form impacts on social capital are difficult to quantify due to the complexity of these issues, their highly specific nature, and their confounding effects. Not only can social networks vary greatly between neighbourhoods (even ones with similar urban form), but their highly subjective and personal nature can mean one person's perception is likely to be very different from another's.

Again, the research finds benefits to social capital in both walkable and less walkable conditions, and in places with characteristics that do not necessarily correspond to either development typology. In one well-known study, Appleyard found that residents of less auto-traveled streets were more likely to know their neighbors than residents of streets with more traffic.[199] A study in Atlanta found that tenure in residence and places where kids have the ability to play safely in the street are associated with increased familiarity with neighbors.[200] Many suburban areas are areas where people may be more likely to own their home, have lived in one location for a long time, and know their neighbors. And even though they may reduce an area's walkability, cul-de-sac street designs do offer places for kids to play.

6.2 Conclusions and Broad principles

Evidence shows built form which enhances the sense of community, and provides areas of solace and opportunities for safe physical activity can reduce the burden of mental disease. Some of these characteristics – supportive community networks and open space - can be found in either walkable or non-walkable neighbourhoods. Planners should strive to incorporate positive characteristics of the suburbs – higher levels of home ownership, safe play areas or streets for children, and access to green space - into new infill development.

There is also a clear mental health benefit that can be found through increased physical activity and decreased driving associated with walkable neighbourhoods.

6.3 Key Land Use Factors, Outcomes and Indicators

The little quantitative evidence on the mental health / built environment relationship does not point to specific urban form factors such as

197 Kawachi et al. 1999.
198 Murphy 1982; Champion 1990.
199 Appleyard 1981.
200 SMARTRAQ 2003.

density, connectivity and land use mix that might improve mental health outcomes (although these factors, by increasing physical activity, could thereby indirectly impact mental health). However, proximity and accessibility to parks and open space could be assessed within a planning context. Additionally, the amount of physical activity/walking and amount of driving (VHT), both of which are treated as outcomes or indicators in previous sections, could be used as indicators or mental health as well.

7. APPLYING THE EVIDENCE TO PLANNING DECISIONS

7.1 Existing Quantitative Planning Tools

7.1.1 LAND USE / TRAVEL MODELS

In the planning field, a number of tools and models exist to quantitatively estimate evaluate the impact of decision alternatives. Typically, the outcomes evaluated by these models are limited to traditional travel outcomes, such as VMT, VHT, and mode share. However, as previously discussed, traditional travel indicators may provide a reasonable estimate of the impacts a plan or policy might have on health conditions such as physical activity and air pollution.

Generally, traditional four-step travel models are inadequate to capture the impacts of small-scale land development decisions, particularly if those decisions are designed to increase active transportation. Four-step travel models may often be focused on vehicle and transit, paying little or no attention to non-motorized transportation. In some cases, such as the LUTRAQ study discussed below, the analysis entailed modifications to the traditional travel model to make them more sensitive to land use and pedestrian travel.

Some quantitative tools are designed for more detailed urban design analysis. These tools, I-PLACE3S and INDEX, incorporate more detailed measures of the built environment and pedestrian conditions and outcomes such as energy use, transit boardings, and walking trips, in additional to more traditional travel outcomes (VMT, VHT). The approach uses a set of empirically tested elasticities that relate built environment patterns to travel outcomes. Both I-PLACE3S and INDEX can be used in conjunction with regional travel models and in regional or small-scale planning efforts.

Applicable Case Studies:
Sacramento Region Blueprint - Used I-PLACE3S model to evaluate a set of growth scenarios in comparison to a base case. The six-county Sacramento region is likely to grow dramatically, attracting an estimated 1.7 million more people to the region in 2050 than there were in 2000 – over 3.6 million residents and 1.5 million homes. A 'base case' growth scenario, which projected current growth trends, was compared to a 'Preferred Blueprint' Scenario which concentrated growth. The I-PLACE3s model was used in conjunction with the regional travel model to compare impacts to the environment, land use and transportation between the two scenarios.

SMARTRAQ LCI analysis – Evaluation of Livable Centers Initiative Plans for the SMARTRAQ Project. Based on the results of the SMARTRAQ study in the Atlanta Region, the SMARTRAQ research team evaluated three community plans produced for the Livable Centers Initiative (LCI). Using Atlanta Regional Commission and SMARTRAQ data, the team modified the INDEX model to reflect research evidence from SMARTRAQ. The modified version of INDEX was then used to predict the degree to which miles of driving, air pollution, transit ridership and other factors would change in coming years under the LCI plans in comparison to existing conditions and trend scenarios.

In all three sites that were evaluated - the City of Marietta in Cobb County, the Perimeter Center area in DeKalb and Fulton counties and the West End in the City of Atlanta - the analysis found that the LCI plan would reduce the miles of driving per person, increase use of transit, improve walking conditions and reduce vehicle emissions over the projection of status-quo trends.

The Perimeter Center LCI makes an excellent case for the potential of land use planning to affect transportation. Of the three study areas, the plan for Perimeter Center resulted in the largest declines in emissions, travel distance and time (results shown in Table 4). According to the analysis, adding housing and pedestrian amenities to Perimeter Center, an employment hub with an existing rail line, would help to cut emissions, vehicle miles driven and trips by about one-fourth over continuing with current trends in this close-in suburban area.

Perimeter Center Results	**Current Conditions**	**LCI**	**Trend**
Total Population	6,639	18,319	7,473
Total Jobs	99,630	110,120	107,520
Single-Family Dwelling Share	51%	23%	50%
Multi-Family Dwelling Share	49%	74%	50%
Rail Transit Boardings (daily total)	4,473	17,709	4,473
Vehicle Trips (trips/day/person)	4.01	3.03	3.95
Vehicle Miles Traveled (miles/day/person)	18.41	13.88	18.21
Air Pollutant Emissions (lbs/yr/person)	252	190	248
Greenhouse Gases (lbs/yr/person)	6,720	5,066	6,650

Table 4. Results of the Perimeter Center LCI Analysis

The LCI plan would reduce the average distance between home and a rail station from 1.5 miles to about a mile, though many residents would have a station within an easy walking distance (about a third of a mile). Partly as a result, the predicted number of people boarding the rail station each day would increase four-fold under LCI, from 4,473 to 17,709. The plan also would eliminate the need for one vehicle trip in four, resulting in a 25 percent reduction in the number of miles driven per person each day. These reductions in driving are consequently projected to cut air pollutants and greenhouse gases by one quarter. *Source: (SMARTRAQ executive summary, 2007).*

U.S. Environmental Protection Agency 'Smart Growth' Case studies. In order to evaluate the benefits of infill development, the U.S. EPA modeled the impacts of infill vs. greenfield sites in three urban regions: San Diego, California; Montgomery County, Maryland; and West Palm Beach, Florida. Infill sites were chosen based on their central city or central business district location, the availability of redevelopable land, and the availability of project-serving infrastructure. Greenfield sites had the potential to develop in the near future. The amount and nature of a study area project's land uses were held constant; however, the density and layout of development were consistent with the "dominant development pattern" in the area – that is, aspects of neighbourhood design (density and street connectivity) were altered in addition to its regional location.

A standard regional travel demand model was run twice in each study region – once with the infill site, and once with the greenfield site – in order to estimate the regional travel and environmental impacts of development at each site. The travel model provided basic transportation system performance indicators at the regional level, some of which then became inputs for INDEX. INDEX then analyzed the performance of the infill and greenfield sites at the neighbourhood level using indicators such as density, transit accessibility, number of stores and other destinations within walking distance of homes, and other design characteristics. Using travel model outputs, INDEX also estimated the energy use and emissions impacts of the developments.

In each case measured, infill development generated dramatically lower VMT and emissions, and cost less for the local jurisdiction and households. Results for travel times and congestion were less consistent. Table 5 below summarizes the results.

	Per capita VMT	Travel time	Vicinity congestion	NOx emissions	CO2 emissions	Infrastructure costs	Household travel cost
San Diego	52% of greenfield	Auto: 50-52% of greenfield Transit: 39-102% of greenfield	24% of greenfield	49% of greenfield	52% of greenfield	10% of greenfield	58% of greenfield
Montgomery County	42% of greenfield	Auto: 95-285% of greenfield Transit: 27-84% of greenfield	1114% of greenfield	54% of greenfield	51% of greenfield	8% of greenfield	46% of greenfield
West Palm Beach	39% of greenfield	Auto: 68% Transit: n.a.	99.8% of greenfield	50% of greenfield	48% of greenfield	n.a.	42% of greenfield

Table 5. Infill Development Compared to Greenfield Development in Three Regions

(Source: Allen, E. G. Anderson, and W. Schroeer. "The impacts of Infill vs. Greenfield Development: A comparative Case Study Analysis," U.S. Environmental Protection Agency, Office of Policy, EPA publication #231-R-99-005, September 2, 1999)

LUTRAQ – enhancement of traditional travel models to reflect land use and pedestrian conditions. The LUTRAQ (Land Use, Transportation and Air Quality) project in Portland compared the benefits of more compact, walkable land use planning, demand management and transit investment to the benefits of the a highway bypass. LUTRAQ found that altering land uses and investing in light rail in Portland suburbs could lead to increases in transit usage, cycling/walking and a decrease in VMT and air pollution, thus negating the need for the highway.

In order to model these concepts, the LUTRAQ alternative altered the existing land use, transit and demand management assumptions in the Portland regional model and making modifications to the model so that it was more sensitive to changes in the pedestrian environment and land use patterns. These modifications were based partially on research cited in this document (PBQD 1993a, 1993b) that looked at the walking environment in the region.

By successfully modeling these relationships, the LUTRAQ alternative was included in the Western Bypass MIS by the Oregon Department of Transportation (ODOT), and chosen as the preferred alternative. This was the first time in the US that such an alternative was accepted by a state DOT as an option to a highway.

The LUTRAQ alternative included more compact, mixed use, walkable land use patterns concentrated along light rail lines in conjunction with demand management actions. When the LUTRAQ alternative was compared to the bypass, it was found to surpass the bypass "in virtually every respect." (Morris 1996). The LUTRAQ alternative was found to have:

- 22.5 percent fewer work trips made in single-occupant vehicles
- 27 percent more trips made on transit and by walking and biking

- 10.7 percent fewer hours of vehicle travel during the afternoon rush hour
- 6 percent fewer hydrocarbons; 8.7 percent less NOx; and 6 percent less CO.
- 7.9 percent less CO2 and 7.9 percent less fuel used.

Sources: Parsons Brinckerhoff Quade & Douglas (1997a) and Morris (1996).

7.1.2 AIR POLLUTION EXPOSURE MODELS

There are a number of modeling tools available that are used by planners to estimate changes in emissions or air pollutant exposure based on changes in travel or land use conditions.

MOBILE is the U.S. EPA's model that estimates the amount of hydrocarbons (HC), oxides of nitrogen (NOx), and carbon monoxide (CO) generated from vehicles (passenger cars, motorcycles, light- and heavy-duty trucks). MOBILE estimates are commonly used in regional planning, and shape decisions on U.S. air pollution policy at the local, state and national level.

URBEMIS is an emissions modeling program that also can estimate changes in travel trips resulting from smart growth land use and transportation strategies. URBEMIS takes into account both on site land uses and design features, as well as a project's location and surroundings. Consistent with current evidence, increased street connectivity on site and to adjacent destinations, increased density, the presence of complementary uses on site or nearby, and the presence of a supportive pedestrian / cycling environment results in lower estimated levels of vehicle use and emissions. The elasticities used in URBEMIS to adjust projected trip generation are documented in the 2002 URBEMIS users' manual and derived from a variety of peer-reviewed research papers and government reports (URBEMIS 2002 users' manual, Appendix D).

Pollutant dispersion models estimates exposure that results from air pollution, based on sources such as traffic or smokestacks, pollutant characteristics, and climate/weather conditions. **CAL3QHC** and **CALLINE4** are two examples of dispersion models.

The **HIAir** model can estimate the impacts of changes in exposure on life expectancy and other health events. Developed by the European Environment and Health Information System (ENHIS), HIAir is based on data collected across Europe. HIAir can estimate the number of health events that could potentially be prevented (or the gain in life expectancy) from a change in air pollution exposure.

Applicable case studies:

Oak to Ninth Avenue Health Impact Assessment. As part of the Oak to Ninth Avenue HIA, a UC Berkeley research team used existing analytical tools to evaluate air pollution impacts of a proposed large mixed-use development in Oakland (UC Berkeley Health Impact Group, 2007). Researchers used the CAL3QHC dispersion model to assess exposure to particulate matter from the vehicles on the adjacent freeway. Published concentration-response functions for air pollutants and health effects were used to quantitatively forecast the impacts to mortality and respiratory illness based on modeled exposure. Ventilation systems were incorporated into the design of the buildings as a result.

7.2 Risk Assessment or other Quantitative Estimates

Using multivariate models or elasticities from research on relationships between urban form and travel conditions, research results can be applied to estimate health impacts of different planning decisions. These applications express how much change can result in a public health (dependent) variable based on a change in a built environment (independent) variable, and can be applied to alternatives analysis in order to estimate how different built environment scenarios might change public health conditions.

It may then be possible to determine the combined impact of multiple policy actions on multiple outcomes, using top-level measurements such as number of prevented or additional deaths, years of life gained/lost, quality-adjusted years of life gained/lost (QALYs / DALYs), or net monetary benefit/loss. By bringing together large amounts of information in a common metric, these measures facilitate the comparison of potential impacts of various policy alternatives.

Quantitative estimates are particularly appropriate for larger projects or decisions, and when there are a number of potential policy actions and/or health outcomes that need to be understood. However, analyses such as these can be time consuming and resource-intensive. Because numerous assumptions and simplifications must be made, quantitative estimates and create a false perception of precision. Care must be taken to manage expectations, articulate assumptions clearly and transparently, and recognize the limitations of the data and methodology available.

Quantitative estimates will be most accurate when local data is used to perform the analysis. However, if data is not available, it is possible to apply research results from other places, as was done in the Chino case study discussed below. Given the caveats necessary to consider when applying research results to other places, such analyses can shed light on the potential relative impacts of different policy options with limited time and technical resources. By incorporating numerous research relationships into an existing modeling structure (as is being done for the King County HealthScape study discussed below), it is possible to create a tool that can be used repeatedly, as opposed to a "one-off" analysis.

Modeling Physical Activity or Obesity. Applicable Case Studies:
Chino, CA Physical Activity & Obesity Alternatives Analysis. As part of the Chino General Plan development process, the Public Health analysis developed a methodology for the application of research results that link built environment patterns and public health (in particular, walking, physical activity and obesity). This methodology was applied to the alternatives for three Chino neighbourhoods being examined in-depth: Chino Town Square, a centrally located commercial area proposed for redevelopment; Eastern Riverside, a corridor containing a variety of institutional, commercial and residential uses; and Civic

Center South, an industrial area just south of the Chino Civic Center complex.

Researchers applied elasticities based on data and results from the SMARTRAQ research in Atlanta, Georgia.

- Net Residential Density – number of households / land area in residential use
- Land Use Mix – Evenness of square footage of development across residential, commercial, office, and institutional land uses
- Street Network Connectivity – number of intersections per square kilometer Jobs-Housing Balance – ratio of reported jobs to households
- Three health-related measures derived from the SMARTRAQ analysis were used as outcomes to be predicted by the built environment measures:
- Percent Obese
- Daily Minutes of Moderate Physical Activity
- Percent Taking a Walk Trip

In each of the study areas, the analysis found that, based on results of the research, changes to the built environment would have clear impacts on public health. Changes to the amount of walking was most apparent in all alternatives, as walking is the outcome most closely connected to a built environment that is supportive of active transportation. Changes to total amount of moderate physical activity and obesity were also apparent but less dramatic as a whole. In all cases, the trend alternatives were found to have little impact on public health outcomes. The other alternatives, which entailed more dramatic changes to the city's generally suburban development pattern, were found to have greater benefits.

King County HealthScape Project - Modifying I-PLACE3S to include physical activity and CO2 indicators as outputs. For the King County HealthScape project, the I-PLACE3S model is being enhanced so it can assess impacts to CO2 emissions and physical activity. I-PLACE3S will be modified using results from research performed in King County on the relationships between the built environment, travel, physical activity, obesity and emissions. The enhanced model will be calibrated and tested in an Impact Assessment for the 98th Street Corridor in White Center, an unincorporated urban area about 12 km from downtown Seattle. King County plans to use the enhanced I-PLACE3S model to estimate the impacts of land development decisions such as changes to development regulations, proposed transit-oriented development, and for development proposal review.

The methodology for the model development was piloted in a project as part of the Chino, CA general (comprehensive) plan discussed above, which looked at physical activity and obesity outcomes for three land use alternatives in each of three neighbourhoods. The Chino analysis was performed outside of a modeling structure.

The research results from the first phase of the King County project provide a considerable basis for this work, allowing the evaluation of residential density, retail Floor Area Ratio, street connectivity, and transit accessibility on physical activity, obesity, travel behaviour, air pollution and CO2 emissions outcomes. These objective built environment measures will be statistically related with these outcomes and those relationships will be programmed into I-PLACE3S. The model will also allow for adjustment of demographic factors such as age, income and ethnicity.

Once developed for King County, the new version of I-PLACE3S can serve as a pilot and, with additional work, can be used in other urban areas. The land use, transportation and physical activity data that has been collected in King County has also been collected in the Atlanta, San Diego, and Baltimore regions. This allows the development of multi-region relationships that may be more broadly applied in a wide variety of regions in North America.

Several aspects of the I-PLACE3S model make it an ideal structure for the inclusion of public health and climate change outcomes. I-PLACE3S is a web-based application and is usable at a number of settings and geographic scales. Its modular structure is expandable and flexible. Finally, I-PLACE3S was developed by public agencies; because it is the public domain, this increases its flexibility and broadens its potential utility.

Modeling Pedestrian Safety / Risk Applicable case studies:

San Francisco Pedestrian Injury Model. In order to predict how proposed neighbourhood rezoning plans might affect pedestrian injury collisions, the San Francisco Department of Public Health modeled the impact of a number of environmental factors on pedestrian injuries at the census tract scale. Traffic volume, proportion of arterial streets, land area, car ownership, commuting via walking or public transit and residential population were all found to be significant factors. These model results were used to predict the impact of the rezoning on pedestrian safety, using planning estimates of increases in population and traffic volume, as shown in Table 6 below. These increases were largely a result of the high current rates of pedestrian injury collisions in the planning areas, and the increases in population proposed as a result of the rezoning.

Planning Area (N, Census Tracts)	Traffic Volume (% increase, CT)	Population (% increase, CT)	Predicted % Change in Pedestrian Injury Collisions
Eastern SOMA (N=5)	15%	25%	20%
Mission (N=13)	15%	8%	14%
Show Place Square/Potrero Hill (N=9)	15%	39%	21%
Central Waterfront (N=3)	15%	58%	24%
All Eastern Neighbourhoods (N=23)	15%	16%	17%

Table 6. Changes in modeled Pedestrian Injury Collision Counts associated with Proposed Eastern Neighbourhoods Plans

(Adapted from Wier, 2007)[201]

7.3 Qualitative Tools:

It is important to recognize the benefits of qualitative assessment methods, whether they are used in place of or to supplement quantitative data. Qualitative methods, such as surveys, community meetings and focus groups are frequently used as a way to define community concerns and set the scope for an HIA effort. In this way, they also function as a way to engage stakeholders in decision-making. A number of HIA efforts have recognized this, particularly those recently developed under the San Francisco Department of Public Health.[202] Qualitative information can add an important personal perspective to a quantitative estimate - as noted by Dannenberg et al. (2007), "…residents at a public hearing who highlight the qualitative benefits of a new playground for their children may carry more weight in a political decision than a precise estimate of how many children will use the new playground. Many of the recommendations from HIAs now based on non-quantitative information would be unchanged if there were quantitative data available."[203]

Applicable Case Studies

Atlanta Beltline HIA The Atlanta Beltline is a massive redevelopment project that will transform a freight rail loop around Atlanta's core into a network of parks, trails, transit, and commercial and residential development. A team of urban planning and health researchers conducted an HIA for the Beltline, focusing on five primary areas of potential health impacts:

- Access to health promoting amenities and goods
- Opportunities for physical activity
- Safety
- Social capital
- Environmental issues (air quality, water resources, noise and brownfields)

The analysis emphasized the most vulnerable members of the population, including the young, elderly, people with disabilities, renters and the carless.

There were several qualitative aspects of the Beltline HIA analysis. To define the scope of the analysis, content analysis of newspaper articles, a survey of the study area population, and targeted outreach were used to identify the primary areas of concern (listed above). The survey in particular identified several areas of concern that were not in the original scope of analysis, such as air quality.[204]

201 Wier, 2007; more detail available at www.sfdph.org/phes. For a discussion of this process applied to a study area in Oakland, CA, see Lee, 2005.
202 See www.sfdph.org/phes
203 Dannenberg et al. 2008.
204 Center for Quality Growth and Regional Development 2007.

Eastern Neighborhoods Community HIA (ENCHIA).This HIA developed in response to a large planning study focused on rezoning in several of San Francisco's neighbourhoods. The process emphasized involvement of stakeholders that have been traditionally left out of the Environmental Impact Assessment process, such as immigrant and low-income residents, and used a Community Council to determine the HIA's scope and content. Deliberative decision-making, where laypeople review the scientific evidence in light of their own situation, was used throughout the process. The Council identified 7 broad elements of a healthy community:

- Environmental Stewardship
- Sustainable and Safe Transportation
- Public Safety
- Public Infrastructure/Access to Goods and Services
- Adequate and Healthy Housing
- Healthy Economy
- Community Participation

For each of these elements, a set of objectives was developed. The Council also developed a list of over 100 measurable Community Health Indicators that could be used to assess the effectiveness of plans and policies. To fill gaps in knowledge where data was not available (particularly for vulnerable populations), informant interviews and focus groups were conducted by ENCHIA staff. These focus groups identified a number of social (crime, noise, mobility) and economic (loss of job and housing security) concerns that they felt had an impact on their health and wellness – concerns that were then evaluated as part of the ENCHIA itself.[205]

7.4 Sketch Level Assessment

In cases where time, data or resources are an issue, other 'sketch' level tools and approaches may be appropriate to assess and communicate potential health impacts of decisions.

7.4.1 CHECKLIST TOOLS

The Healthy Development Measurement Tool (HDMT). Developed by the San Francisco Department of Public Health, The Healthy Development Measurement Tool (HDMT) uses indicators to support a systematic Health Impact Assessment of proposed planning decisions. The HDMT developed in the evaluation of the Eastern Neighborhoods plans in San Francisco, and is currently being used to look at the health impacts of other land use development policies, plans, and projects.

The tool includes over 100 health indicators in two categories – Primary Indicators, which are quantitative, and Secondary Indicators, which are

205 San Francisco Department of Public Health 2007.

qualitative and complement the Primary Indicators. Many of these indicators include baseline data, and targets that can be incorporated into developments or plans. The HDMT is currently being used to evaluate several transportation and neighbourhood plans in the City of San Francisco.

Source: More information about the HDMT and case studies of HDMT applications are available online at: *www.TheHDMT.org*.

7.4.2 RAPID ASSESSMENT

Bungendore Health Impact Assessment

In 2003, population growth in Bungendore, Australia highlighted the need to provide services for current and future residents. An HIA was tested as a structured approach for assessing links between health and urban development. The Bungendore Health Impact Assessment evaluated two different future growth scenarios: infill development (development occurring within existing boundaries of the village) and greenfield development (rezoning of agricultural land for residential and other purposes as well as infill development). The village of Bungendore had a population of approximately 2000 people and future growth scenarios accommodated an additional 2350 people for the infill development (total 4350) or an additional 7150 people for greenfield development (total 9150).

In a screening process, three elements were chosen as most relevant to assess within a rapid HIA methodology: physical activity, water and neighbourliness. The rationale for the inclusion of the three elements varied; for physical activity, it was based on consistent evidence of the links between the physical environment and physical activity, and the growth of obesity rates in Australia as a problem.

The following elements were identified as important in promoting physical activity in Bungendore:

- Mixed land use
- Housing Density
- Footpaths, cycle ways and facilities for physical activity
- High street connectivity
- Street design that is attractive and safe
- Transport infrastructure and systems linking residential commercial and business area as well as other destinations.

A rapid assessment HIA methodology used the existing literature to identify possible health impacts and mitigation actions from the two urban development growth scenarios. The report did not form an opinion as to whether future growth was positive or negative but simply identified possible health impacts likely to be generated and recommended mitigation measures to minimize these impacts.

8. APPLYING THE EVIDENCE IN THE PEEL REGION

8.1 Context and Background

This project sets the groundwork for an evidence based toolkit which can be used by Peel Public Health and others in identifying direction and relative magnitudes of potential public health impacts. This toolkit will support the goal of providing greater opportunities for active living in the Peel Region.

An approach to tool development should be guided by the data available, as well as the needs of the users. These two factors are discussed in more detail in the following chapter.

8.1.1 LEVEL OF EFFORT VS. NEEDS.

The tool's robustness should be balanced with the staff and technical resources available – get the most analytical power, without creating overwhelming demands on the users, or causing a large delay in review time. The tool should be appropriate for its likely uses in terms of data demands, preparation time, and level of detail.

In order to ensure that active living and other public health considerations are integrated into the region's development, the Region of Peel has requested that Peel Public Health staff comment on planning decisions, including secondary and block plan level development plans and other broader scale planning / development alternatives. Therefore, the tools must be applicable in two primary contexts:

Block plan level review

For single / smaller projects or for screening purposes

However, the tools should also support the evaluation of broader scale planning alternatives.

Bram East Subarea 2 Block Plan

Block Plans are used to coordinate infrastructure and design of large-scale greenfield development. They are often developed by groups of developers that own adjacent parcels of land. This process entails multiple meetings between a City and the developers to ensure block plan guidelines are met before a City and the Region formally review and comment on the block plan proposal.

8.1.2 DATA AVAILABILITY.

The types, extent and variation of data that are available greatly dictate the nature of the tools that can be developed. Results will be most accurate when detailed local land use, transportation and public health data are used to perform the analysis: parcel level land use data, trip level transportation data, and location specific public health data (to the degree possible given confidentiality requirements).

There are two primary datasets for this tool development. The first is the health and behavior data which provide the outcomes impacted by development patterns (the independent variables in the analysis). The second set of data is used to measure the built environment across the entire region (the independent variable). Peel Region and Toronto have both types of data.

Health and Travel Behavior Data. The health and behavior outcome data comes from two waves (2003 and 2005) of the Canadian Community Health Survey (CCHS), conducted by Statistics Canada and from the 2006 Transportation Tomorrow Survey (TTS). TTS is a travel behavior survey conducted by Ministry of Transportation with other partners. The location of participants from both surveys is known to the postal code level. Due to confidentiality issues in the TTS survey, those data are only available as postal code level aggregations (averages, minimum, maximums, and frequencies). This level of aggregation limits the analysis because trip and demographic attributes are not connected at the trip or person level, but rather are presented for the group of individuals living in a given postal code. While trip level data are preferred because of the flexibility it allows for analysis, the provided TTS data are usable, with the limitations, in model development. In contrast, the CCHS data are person level. While the exact street address of the participants is not provided the postal code they live in is.

Geographically, the CCHS observations in Peel are concentrated largely in Brampton and Mississauga and more dispersed in Toronto, while the TTS participants are present in more parts of both Peel and Toronto. Figures 18 and 19 below indicate which postal codes CCHS and TTS participants live in. In both areas the locations of observations is a reflection of population concentrations.

Because the analysis will measure the built environment around the postal code for survey participants, the geographic concentration of the CCHS observations limits the variation of the built environment that can be included in the analysis. Without a large range of variation in the built environment measures, the understanding of the association between the built environment and changes in health and behavior outcomes will be limited. The inclusion of built environment data from the Toronto region in the analysis will help to address this concern through the ability to evaluate a fuller spectrum of built environment types.

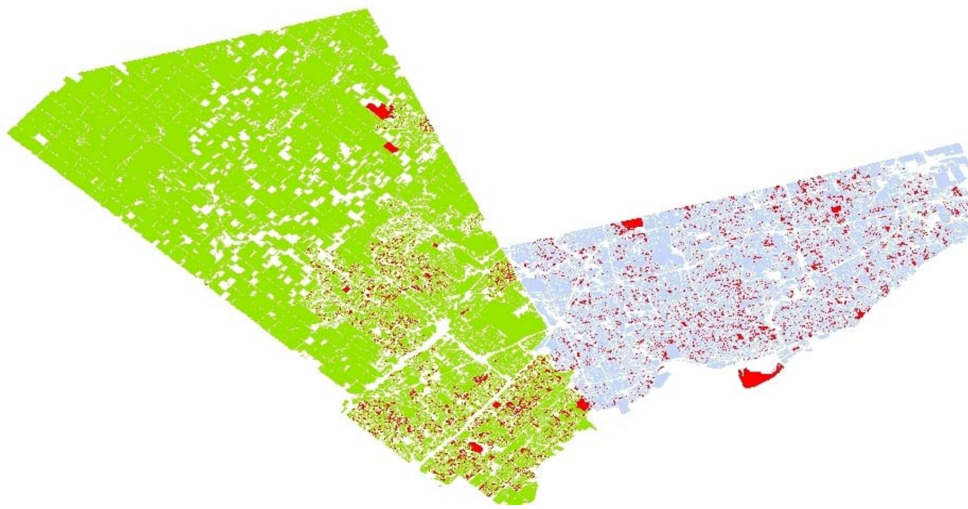

Figure 18: Postal Codes with CCHS Data (red) in Peel (green) and Toronto (blue)

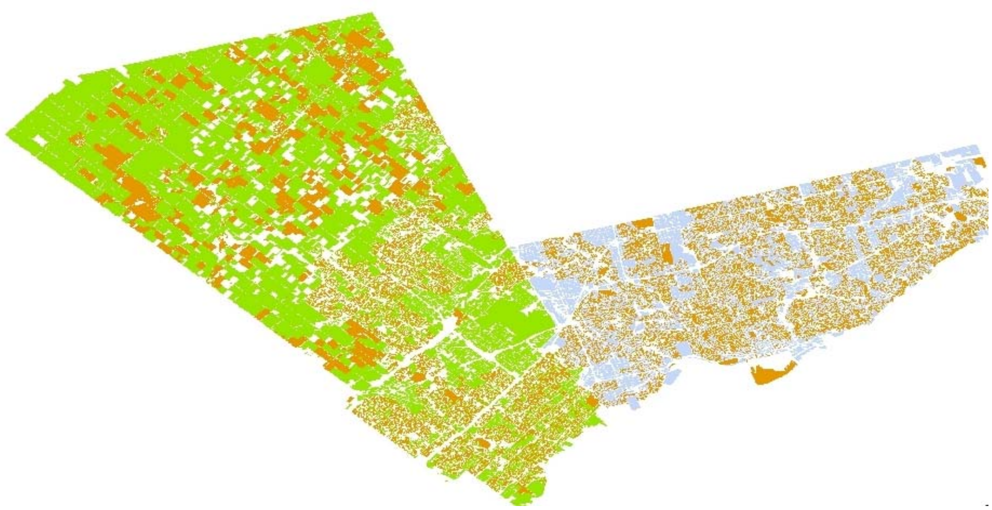

Figure 19: Postal Codes with TTS Data (orange) in Peel (green) and Toronto (blue)

Table 7 below shows which outcomes are recommended for testing and possible inclusion in a health assessment tool. This set of outcomes is recommended based on the data available and their consistent association with the built environment measures in the research, as discussed in the literature review.

Table 7. Recommendations for Outcomes

	Definition	Data Source	Scale
VKT	Per capita Vehicle Kilometers traveled	TTS data	Postal code average for Household / person
Mode Share	Percentage Total Trips which are Walk/Bicycle trips	TTS data	Postal code average for Household / person

Walk / Bicycle Trips	Number of walk & bicycle trips	TTS data	Postal code average for Household / person
Physical Activity	Physically Active >15 minutes (yes/no). Phys. Act. Index Classification (Active/Moderate/Inactive)	CCHS data	Person
BMI	Ratio of height and weight.	CCHS data. Variable name: HWTEDBMI.	Person
Percent Overweight / Obese / Likelihood of Obesity	Categorized BMI	CCHS data	Person.
Energy Expenditure	Variable derived by using the frequency and time per session of reported physical activity as well as its MET value.	CCHS data. Variable name: PACEDEE.	Person.
Prevalence of High Blood Pressure	Present or not.	CCHS data. Variable name: CCCE_071.	Person
Prevalence of Diabetes	Present or not.	CCHS data. Variable name: CCCE_101.	Person
Vehicle Emissions	Grams of emissions (NOx, VOC, CO2) emitted per motorized trip	Other regions and studies – e.g. Seattle.	Person/trip level

At this point it is not possible to model safety due to lack of data availability. To model safety, it would be necessary to have data on crash location, crash severity and crash type (i.e. vehicle – pedestrian vs. vehicle – bicycle). These data have not been obtained.

While local trip level vehicle emissions data are also currently not available it is possible, if budgeted for, to incorporate this outcome in the modeling effort. Including emissions can be done by using research results from other regions (e.g. Seattle) and local data for calibration. It is also possible to create local trip level emission estimates by using the trip level data from the TTS; however currently the TTS data have only been provided at the aggregated postal code level, due to confidentiality concerns. To create these estimates other attributes about the vehicles used for each trip (e.g. model year and type), and vehicle fleet characteristics (e.g. distribution of model years, fleet mix of automobiles vs. trucks) would also need to be present in the data.

Built environment data. The second set of data used to create built environment measures comes from government planning and transportation agencies. These data are used to calculate built environment measures for each postal code in the region (to match the scale of the outcome data).

As discussed previously in this document, fine-grained, objective built environment measurements allow the most robust and precise analysis of the built environment. The Peel Region has very detailed versions of the two most important types of data sets. Spatially registered parcel data for the Peel region is available, which indicates the functional use of each parcel, its size and the number of residential acres. A region-wide, spatially registered road network is also available which indicates road functional classification (e.g. local neighborhood road or highway). Other important data, such as bus stop and park locations (for select parts of the region) and Census data (for the region) are also available. Table 8 summarizes the extensive set of data available for the Region of Peel and Toronto. The green checks indicate we have data for that area of the region. The greatest limits placed on possible analyses are created by the lack of commercial and office building floor area data (building floor area data only exists for residential land uses in Peel, and it has not been provided for any land uses in Toronto) and the lack of park, transit and sidewalk files for Toronto.

Table 8: Data summary -- basis for urban form measures

	Peel and Toronto	Peel	Mississauga	Brampton	Caledon	Toronto
Roads	✓	✓	✓	✓	✓	✓
Land use parcels	✓	✓	✓	✓	✓	✓
Postcodes	✓	✓	✓	✓	✓	✓
TAZ	✓	✓	✓	✓	✓	✓
Census Tracts, blocks & dissemin Areas		✓	✓	✓	✓	
Parks		✓		✓		
Transit Data (Bus Stops)			✓	✓		
Sidewalks			✓	✓		
Trails			✓			
Building Footprints				✓	✓	
Building Square footage		✓ (residential uses only)				(requested from Toronto)
Aerial Photos		Individual files for each region of Peel	✓	✓	✓	

Table 9, below, identifies which of the built environment measures identified in the literature review can be developed using Peel and Toronto data, and subsequently correlated to health outcomes. Which outcomes will ultimately be incorporated into a tool will depend on strength of statistical relationships with the outcomes.

Table 9. Potential Built Environment Measures – independent variables to be used in modeling

Measure	Definition	Data sources
Net Residential Density	Number of residential units divided by area in residential use	Parcel and Census data provided housing unit count. Parcel provided residential land area.
Street Connectivity	a) Number of intersections (3-way or greater) per square kilometer. OR/AND b) Number of cul-de-sacs (dead ends) per square kilometer.	Street centerline file
Land use Mix – intensity	Evenness in the relative amount of land area for different uses. Example land use types include: --Multi-family residential -Single family residential - Retail - Office	Parcel files
Presence of specific land use	Presence within postal code buffers of different land use, e.g. retail and parks.	Parcel files
Transit availability (for Brampton & Mississauga)	Number of bus stops within buffered postal codes. Divide by postal code area to create bus stop density measure.	Transit Centers, Routes and Bus Stops for Brampton Bus Stops and Routes for Mississauga. Related data for Toronto has not been provided.
Presence of sidewalks (for Brampton & Mississauga)	Percent of roads with sidewalks.	Sidewalk data is only available for Brampton and Mississauga. Trails are also available for Mississauga. Related data for Toronto has not been provided.

The next section offers recommendations regarding the types of tools which can be created given the available data and sufficient resources.

9. RECOMMENDATIONS FOR TOOL DEVELOPMENT

Based on the previous review we recommend funding be provided to develop two evidence-based planning tools that can assist in systematically identifying direction and relative magnitude of potential public health impacts of different development proposals. Given the goals of the project, the Peel region's needs, and the technical and staff resources available, we recommend these tools to be:

- A detailed health assessment model for block plan level review and above
- A simpler, "checklist" level tool for development review

Additional details about these two tools are provided in the next sections.

9.1 Health Assessment Model

For block plan review, statistical relationships (elasticities) between the built environment and public health outcomes can be integrated into a modeling tool. This modeling tool can be used to assess relative health outcomes (e.g. more or less physical activity) in association with variations in urban form (e.g. more or less density, land use mix, connectivity, etc) across alternative development proposals.

The Health Assessment Model should be developed in three basic steps: creation of built environment measures, research/ statistical modeling and the application of the research results into a modeling tool.

9.1.1 BUILT ENVIRONMENT MEASURES

Creation of a fully functional spatial database at the postal code level and containing the built environment measures summarized in Table 9 is needed. The measures should be developed at the postal code buffer level using the following five major steps:

1. Assess of data quality and data improvement.
2. Prepare the road network for network analysis and buffer creation.
3. Prepare the parcel data base for aggregation.
4. Aggregate parcel data to the buffer level.
5. Calculate built environment measures.

9.1.2 STATISTICAL MODELING

Using Region of Peel and Toronto data associations will be explored between measures of the built environment (density, mixing of uses, street connectivity) and physical activity and health outcomes such as diabetes and other chronic health conditions. Modeling these relationships, where possible, will include moderating effects of physical activity (in the case of chronic health conditions), and adjust for socio-demographic factors. Built environment relationships with health related outcomes are expected to be unique for different populations. Assessing relationships across age, income, gender, and other factors may be possible by making use of results in the existing scientific literature or through additional analyses of our own. However, because the development proposals to be assessed will largely be for new projects, it will be challenging to know the demographic make-up of the future populations.

From the model results we will develop *elasticities* (coefficients or multipliers). Elasticities estimate within a certain level of confidence how a given change in a particular element of a development proposal (the X, the independent variable) can result in a given change in a public health outcome (the Y, or dependent variable) when adjusting for socio-demographic factors and other moderators where possible (e.g. auto ownership). Built environment measures (such as mix use and density) often co-vary, and it can be difficult to tease out the effect of any one factor on a given outcome. This issue may impact the structure of the modeling framework.

As mentioned in the previous section, for outcomes where public health related data are not available (e.g. vehicle emissions or safety), it is possible, given funding, to make use of existing data from other regions or to extrapolate research from published papers and monographs. These results can be tapped for model development where possible, and then generalized to the Region of Peel. The model can be further calibrated using local data. This is similar to the analysis done in Chino, CA (see Chapter 7 for details). Given the caveats necessary to consider when applying research results to other places, such analyses can shed light on the potential relative impacts of different policy options in areas where local data is limited.

9.1.3 APPLICATION OF RESEARCH RESULTS.

In addition to modeling the actual statistical relationships, it will be necessary to determine the form in which those relationships can be applied in order to facilitate repeated testing.

The simplest approach would be to build the elasticity calculations into a spreadsheet format. The user would calculate the applicable built environment measures in GIS or via other means, and enter the values into the spreadsheet. This is generally a less user-friendly, less visual and more technical approach but simpler to build initially. This basic approach was used to model physical activity and obesity impacts of neighborhood development in Chino, CA. The Chino analysis was a "one-off" analysis, however, and no tool was developed to allow repeated testing.

Instead, we recommend incorporating the elasticities from the research into an existing urban planning forecasting model. This approach is more complex to develop, but has the benefits of an existing user interface and is set up to test and compare numerous alternatives. Another benefit is that existing software packages can also evaluate a number of other planning-related outcomes in addition to public health outcomes, and may have the ability to interface with GIS or regional travel model data. This potentially broadens their utility. A number of tools and models currently exist to quantitatively estimate evaluate the impact of decision alternatives, several of which are discussed in Chapter 7. We are currently adding public health and climate modules to the PLACE3S model as part of the HealthScape project in King County, Washington.

9.2 Checklist Assessment

For single or smaller developments, we recommend development of a simpler "checklist" assessment that can systematically identify which features of the proposed development support or undermine public health goals. A checklist allows the rapid evaluation of probable development impacts in a systematic fashion, allowing a developer, planner and public health staff to identify features of a development to change in order to mitigate potential negative impacts. With a checklist, the emphasis is on assessing "indicators" - features of the built environment which are associated with outcomes in the research.

There are several checklists being developed or already available. Mississauga has developed a checklist to assess health impacts of development. Other examples of evidence-based checklist tools are the Healthy Development Measurement Tool (HDMT) developed by the City of San Francisco Department of Public Health and the LEED-ND (neighborhood development) checklist developed by the US Green Building Council. Both of these tools are quite detailed and are discussed further in Chapter 7.

Checklists can vary in complexity and format – some are visually oriented, some rely on qualitative assessment, and some require detailed GIS-based assessments. Typically, a checklist results in a "bottom line" score which indicates whether mitigation or changes in the project are necessary, and gives guidance to which particular features of a development could or should be improved. A checklist may also set minimum thresholds (score) for those built environment features that are deemed crucial.

In designing a checklist, the emphasis should be on the existing review process and what can be done given timelines for review, desired precision/detail of review, staff time and skill sets, and types of data available. For Peel, development proposals are often guided by the block level plan. However, a minimum scoring threshold may be established through the application of a checklist which could serve as a screening tool for block level plans and other smaller project level reviews. Checklists will also be useful to assess areas where the evidence is not clear or yet available, or where a qualitative judgment is deemed appropriate. Factors such as streetscape and intersection design characteristics, landscape elements, and other factors may be best covered through such an approach.

The above two tools will provide Peel Public Health with an evidence based foundation with which to respond to the Peel Council's Resolution 2005-1395 for the Peel Public Health staff to comment on development applications that come to the Region of Peel, in order to ensure that public health considerations are integrated into the Region's development.

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