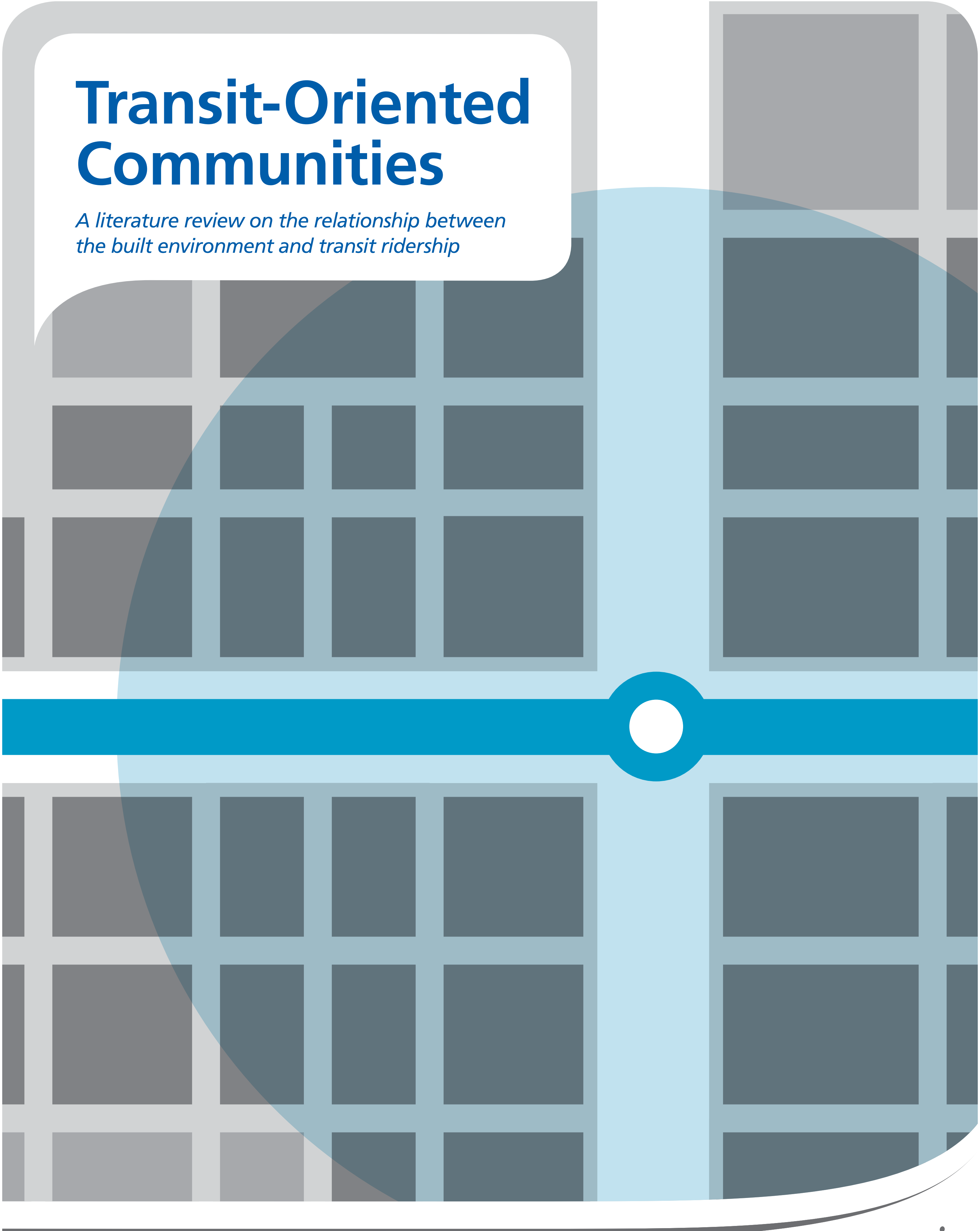
Transit-Oriented Communities

A literature review on the relationship between the built environment and transit ridership



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1.0 Introduction

Two goals in TransLink's Transport 2040 strategy are to have most trips in the region occur by walking, cycling and transit and to have the majority of jobs and housing in the region located along the Frequent Transit Network. Since the built environment is a major determinant of travel demand and mode choice, achieving these goals will require the creation of more transit-oriented communities – places that, by their very design, invite people to drive their cars *less* and walk, cycle and take transit *more*.

As no single agency or organization in the Metro Vancouver region has the mandate or capacity to address all of the various inter-dependent components needed to create transit-oriented communities, this effort will necessarily be a collaborative one between TransLink, Metro Vancouver, local municipalities, and the private sector, as well as the wider public. This literature review provides a research foundation from which to facilitate this important regional conversation and to inform TransLink's work in fostering and supporting improved coordination of land use and transportation in the region.

The purpose of this literature review is to identify and summarize the current peer-reviewed research relating to transit-oriented communities. It asks the question: ***how does the built environment impact transit ridership*?**

This literature review focuses on key aspects, or factors, of urban form that affect transit use that are mainly within the sphere of influence of local government and developers. The research suggests that there are six key built environment factors that influence transit ridership: *Destinations, Distance, Density, Diversity, Design, and Demand Management*.[1] Accordingly, the bulk of the literature review is organized under these headings.

The literature review also contains a short discussion of non-built environment factors that affect transit use. The amount and type of transit service affect transit use and are within the sphere of influence of a transportation agency. In addition, there are factors that are outside the influence of either a municipality or transportation agency, such as topography, demographics, and income levels which also impact transit ridership. These factors are discussed towards the end of this document.

1 Cervero and Kockelman in 1997 identified three "Ds" (Density, Diversity, and Design) as essential parts of transit-oriented development. This review of current literature builds on these by adding other influential factors as identified by the academic research, using "Ds" as an organizing structure.

It is acknowledged that metropolitan regions are complex and there are many complicated relationships at play. While the transit-oriented communities concept has been simplified under the "Six Ds" and other factors, it is recognized that these variables are inter-related and can affect one another. At times this complexity makes it difficult to isolate variables. Even when there is a strong correlation between two factors such as density and transit ridership, it is difficult to demonstrate definitively the causal relationship of such factors. The research aims to help the reader understand basic aspects of the relationships, recognizing that each community is different and that these findings will need to be adapted in a context-specific approach to communities within Metro Vancouver.

2.0 Built Environment Factors

2.1 Destinations

Regional accessibility

The demand for mobility is derived from the need to connect origins with destinations. As the transit network increasingly links together concentrations of people with job and commercial centres, educational opportunities and cultural facilities, transit use increases (Arrington & Cervero, 2008). A key indicator of how well origins and destinations are connected is 'regional accessibility'. Regional accessibility is in part a function of the *cost* of a trip, which in turn is a function of the money, time, and distance involved in making that trip; the greater the cost to travel to a destination, the less "accessible" that destination is. Accessibility is different for every mode of transportation (Maat et al., 2004). For example, a destination may be more easily accessible by car than by transit; or may be accessible most conveniently by walking. The challenge with the urban form of the last half-century is that it was largely built to maximize automobile accessibility, with little consideration for other modes of transportation. This has resulted in a high degree of automobile dependence (Kenworthy & Laube, 1999).

"If travel distances, traffic congestion and traffic pollution are to be reduced there must be coordination between transportation, housing and land use programmes."

(Cervero, 2003)

Some polycentric regions, such as Metro Vancouver, concentrate growth to improve regional accessibility by clustering origins and destinations in centres. Localized density is most effective for reducing auto use when these areas are well connected to other parts of the region – and a region can be made 'mixed use' by providing a variety of functions (residential, commercial, industrial, and educational) along transit lines (Badoe & Miller, 2000). On a regional scale, improving the proximity of jobs to housing reduces the amount of travel (Cervero & Duncan, 2006). It is challenging to match jobs and housing within each neighbourhood, as many people no longer live, work, and play in the same neighbourhood. This is why it is so important to connect key regional land use destinations with transit and promote sustainable regional travel (Badoe & Miller, 2000).

In a region with a growing population and economy, growth can be accommodated in a number of different ways. The way that growth is accommodated determines to a large extent if a region is transit-supportive. In a review of the connections between transportation infrastructure and land use, Handy (2005) concludes that new highway capacity will often attract low-density development, whereas growth around rapid transit infrastructure will have a smaller urban footprint. The shape and form of the growth in either case will be adapted to the type of mobility that is most readily available. Thus, the type of transportation infrastructure investments in a region may help shape the choices of location that incoming residents and business make. Land use decisions in turn impact the demand for the type and amount of transportation infrastructure investment.

Some researchers continue to advocate that the benefits of auto-oriented development outweigh the costs; many people like the space afforded by low-density development (Gordon & Richardson, 1997; 1998; 2000). However, a consequence of this urban form is that it generally cannot support an efficient transit service, and mobility in these areas will often be limited to private vehicles. A city like Los Angeles, despite high gross densities, is difficult to serve effectively with transit as the density is spread relatively evenly over the entire metropolitan region, without being focused in centres and along corridors (Gordon & Richardson, 1996). Low density, sprawling development patterns also generate costs often overlooked in past studies, such as environmental costs associated with vehicle emissions, the cost of congestion, road infrastructure costs, household transportation costs and others. This highlights the important choices that communities have in making the land use and transportation connection. The type of urban form provides the foundation for the type of transportation mode and vice versa.

In an analysis of urban form and travel in Portland, Jun (2008) found that the farther away from the central city that someone lived or worked, the greater the chances of their driving to get around. Similarly, Bento et al. (2005) found that "population centrality" (i.e. how compact a regional population is assembled) increases the chances that a worker walks to work. Regional urban growth boundaries alone cannot improve regional accessibility (Song, 2005). Instead, density must be strategically deployed in centres and along rapid transit corridors in order to strengthen the use of regional transit (Cervero & Duncan, 2003; Filion, 2009).

Research Summary: ***Good regional transit accessibility generally reduces vehicular travel and facilitates transit use by aligning origins and destinations with the transit network.***

2.2 Distance to transit

Proximity of origins and destinations to transit is associated with increased transit use. In Washington DC, for every 300 metres farther away from a subway station, transit mode share of commuters working in offices declined by 12 per cent and mode share of residents declined by 7 per cent. A 2003 San Francisco study found that employees working at offices within 800 metres of rapid transit stations had a 19 per cent transit mode share, compared to just 5 per cent region-wide. The residential transit mode share was even higher: approximately 27 per cent of those who lived within 800 metres of a station took transit compared to only 7 per cent in a larger area (between 800 metres and 4 kilometres from the station) (TCRP, 2007).

Generally, current planning practice recommends a 400 to 800 metre radius as the pedestrian catchment area for transit service (Canepa, 2007). For local stop transit service, a 400 metre pedestrian catchment area is often used, representing a 5 minute walking distance. For rapid transit, people are willing to walk farther and an 800 metre pedestrian catchment area to transit is generally used, representing a 10-minute walking distance. However, an Australian study examined walking patterns across five transit stations in the vicinity of Perth, a city of approximately 1.3 million. The study found that 55 per cent of people walking to these stations came from points originating more than one kilometre away (Ker & Ginn, 2003). Canepa (2007) demonstrates that people may be willing to walk longer distances to reach transit, in areas of higher density and higher quality urban design. However, other factors such as topography or climate may also affect how far people are willing to walk to reach transit (see Section 3 for further information).

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Research Summary: ***There is a higher propensity to use transit if trip origins and destinations are located within close proximity to transit (within 400 metres of a bus stop with frequent transit service or within 800 metres of a rapid transit station). People are generally willing to walk farther to access higher capacity transit services or in areas that have a high degree of walkability and good quality urban design.***

> **"All else equal, residents of neighbourhoods with higher levels of density, land use mix, transit accessibility, and pedestrian friendliness drive less than residents of neighbourhoods with lower levels of these characteristics."**
>
> (Handy et al., 2005)

2.3 Density

Density is a measure of the *intensity* of the use of land. Density can be measured in a variety of ways, such as people per hectare (residential density), jobs per hectare, people and jobs per hectare, or floor space ratio (FSR) (also known as floor area ratio). Floor space ratio measures the amount of built floor space compared to the area of the lot. Density can be measured in gross or net terms; gross density is typically measured against the total land area of a specified area, whereas a net density typically excludes public roads, right-of-ways and public open space. The area being measured is also typically specified, such as a site, neighbourhood, or entire city, as well as any land uses excluded from the calculations.

In general, the higher the density, the more people, jobs, or built floor space there is per unit area. Higher densities generally support greater levels of transit service, as there are more potential riders in the same amount of space. This section describes what researchers have found about how various types and levels of density impact transit use.

Density has the potential to draw origins and destinations closer together when the appropriate land use mix exists, resulting in shorter average trip lengths. Ewing and Cervero (2001) find that trip lengths are primarily a function of the built environment. Trip length factors into calculations of total distances travelled (Vehicle Kilometres Travelled) and total time spent in travel (Vehicle Hours Travelled). Of course, if alternative transportation modes are not available, increasing density may increase congestion, slowing travel times even as distances decrease, leading to greater concentrations of certain air pollutants, and other impacts. This demonstrates compatibility between density and alternative modes, which take up less space per passenger than cars do. Efficient transit service also relies on density (Chen et al., 2008). All else being equal, "higher densities worked in favor of transit ridership and against drive-alone automobile traffic" (Cervero, 2002).

In an international comparison of urban density and transit usage, Kenworthy and Laube (1999) compared urban form and transit data from a representative selection of cities on different continents. The study found that US cities exhibit the most

Selected Cities	Urban density (persons/ha)	Journey to work trips by Transit (% of workers)	Journey to work trips by Walking and Cycling (% of workers)
American Cities	14.2	9%	4.6%
Australian Cities	12.3	14.5%	5.1%
Canadian Cities	28.3	19.7%	6.2%
European Cities	49.9	38.8%	18.4%
Asian Cities	157.4	48.7%	19.4%

Table 1: Comparison of Urban Density and Transit Mode Share in Various International Cities *Source: Kenworthy and Laube, 1999* [2]

2 The study focused on metropolitan regions with mid to large population sizes. The Canadian cities consisted of the metropolitan areas of Vancouver, Calgary, Edmonton, Winnipeg, Toronto, Ottawa-Gatineau, and Montréal.

extreme dependence on the automobile, followed by Australian and Canadian cities, with European and Asian cities being much more transit-oriented with greater levels of walking, cycling, and transit. These patterns are not strongly related to differences in wealth between cities, but do vary in a clear and systematic way with land use patterns, particularly density.

Although the complexity of urban environments makes it difficult to establish causality by isolating variables like density and mode share, a review of the literature indicates a fairly robust consensus that density *is* correlated with larger non-auto mode shares and higher transit ridership. The opposite also holds true – low density environments must rely primarily on the automobile for transportation because they are too spread out to be served effectively with transit. The most effective land use strategy for increasing transit ridership is to increase development densities close to transit (Arrington & Cervero, 2008).

Residential density

Cervero (2007) found that residential development near transit produced an appreciable ridership increase in California. Part of this ridership increase was due to people who *choose* to live near transit – known in the literature as residential self-selection. Current transit users and those predisposed to use transit have been found to seek out transit-oriented developments (Arrington & Cervero, 2008). The presence of self-selection underscores the importance of providing housing choices so that households are able to choose for themselves, via the marketplace, locations that are well served by transit.

In order to provide a range of options for people who would like to take transit, there needs to be an adequate supply of a range of housing types accessible by transit. A study comparing Boston and Atlanta found that Boston, with its balanced stock of housing options both in the denser, older core, as well as in newer communities, provided people with the ability to match their housing location to their lifestyle and mode choice.

"To alter substantially land use-transport dynamics in a fashion that favours public transit patronage, residential density policies must be deployed over long periods and unfold at local and metropolitan levels simultaneously."

(Filion & McSpurren, 2007)

Atlanta, with its predominately low-density building stock, has a greater proportion of people who consider their current housing situation to be mismatched to their preferences (Levine et al., 2005). In further analyzing the Atlanta survey responses, Levine and Frank (2007) write that the findings suggest "an undersupply of compact, walkable, and transit-friendly neighbourhood types relative to current demand."

Filion et al. (2006) found that Toronto does not generate as much walking and public transit patronage benefit from high residential density as it could, due to the fact that many high rise apartment buildings are located far from frequent transit service. This underscores the need to build high density residential development close to existing or planned frequent transit, or to concurrently phase in new development with transit service increases.

Employment density

There is a clear and definitive relationship between employment density and journey-to-work by transit. In an analysis of Portland's MAX rapid transit system, Jun (2008) found that locating employment near a rapid transit station increased ridership and decreased auto trips. Similarly, orienting employment clusters to the rapid transit network increases ridership (Frank & Pivo, 1994; Chen et al., 2008). Research shows that higher density, large employment clusters with low levels of parking and a mix of uses adjacent to rapid transit greatly influences transit use (Badoe & Miller, 2000). This holds true for central business districts as well as suburban employment centres. Density, convenient access to a transit station, and reduced parking requirements at employment centres have the greatest impact on ridership levels (Lund et al., 2006). The strong, clear relationship between employment density and mode choice found in the literature (Badoe & Miller, 2000) supports the effectiveness of a limited number and efficient distribution of employment clusters for improving metropolitan transit mode share. Regions that generate the highest commuter ridership have a high percentage of regional jobs accessible by frequent transit (Arrington & Cervero, 2008). Employment density is therefore one of the most strategic kinds of density to locate near rapid transit, generating definite ridership gains from commuting trips.

Density thresholds necessary for frequent transit

A general consensus has emerged in the literature, that, all else being equal, higher densities support increased levels of transit service and usage. But what are the minimum densities needed to support frequent transit service? Are there thresholds above which frequent transit can be efficiently provided?

In an early landmark study that is often cited, Pushkarev and Zupan (1977) examine residential density, the size of employment clusters, and the cost of providing various transit services in six U.S. cities. The study concludes that an average net residential density of 37 units/hectare supports frequent levels of transit service. This density over the pedestrian catchment area supports a service frequency of 10 minutes or less over a 20 hour operating span within the study area. Several characteristics have changed since this study; notably, car ownership rates have risen in the study area, cities have decentralized considerably, and the average number of people per household has decreased. All these factors may change the level of density needed to support transit.

In a more recent study addressing the same question, Messenger and Ewing (1996) employed methods that allowed them to take into account the interrelationships between socio-demographic, land use, and transit service variables. The densities which are required to support different levels of transit service and transit productivity are modeled and calculated. An increase in service frequency boosts the transit mode share but also increases the number of transit trips that must be generated to achieve any productivity standard (because more scheduled trips are made). The study found that a minimum residential density of 27 to 48 units per hectare is required to support service frequencies of 15 minutes.

A third study, based on extensive data collected from an international study of transportation in cities, finds a significant increase in car usage at densities below 35 people and jobs per hectare (Newman & Kenworthy, 2006). Using longitudinal data sets collected twenty years apart, they find that this basic relationship holds true over time, with an estimate band between 30 to 40 people and jobs per hectare. However, the study notes that rail transit has the capacity to absorb much higher densities at nodes: "For automobile dependence to be overcome, Ped Sheds [the areas in which people can conveniently walk to transit] with an urban rail node will have the potential for much higher densities" (p 47).

Research Summary: ***Increasing residential and employment density near transit is one of the most important factors for reducing levels of automobile dependence and increasing transit ridership. There is typically a minimum density threshold, likely a range, that is necessary to support frequent transit levels of service.***

2.4 Diversity

Mixed land use

Mixed land use means having a complementary and context-appropriate combination of shops, services, housing types, offices, and employment opportunities within the same area that allow people to meet most of their daily needs nearby. Mixed use can include: a) vertical mixing within a building, such as with commercial on the ground floor and residential above; b) horizontal mixing, with commercial buildings located adjacent to residential buildings; or, c) a mix of uses within a wider area. Local mixed use at transit nodes and along transit corridors encourages trip chaining – by combining more than one destination in each trip (for example, by going to the hardware store and the grocery store on the way home from work, rather than making a separate trip for each of these destinations) (Frank et al., 2008). Land use mix and accessibility are relevant to travel behaviour, even more than household characteristics (Badoe & Miller, 2000). Local diversified land use at origins and destinations is associated with reduced driving (Jun, 2008; Cervero, 2002). Chen et al. (2008) found that increasing land use diversity creates a potential reduction in travel distance by increasing one's access to activities and services.

In a study of Portland, Jun (2008) found that mixed land use zoning at place of residence decreased the likelihood of driving alone, while the more exclusively residential a neighbourhood was, the more likely a trip choice would be by car. Similarly, the results of a study by Cao et al. (2009) show that "mixing land uses tends to discourage the generation of auto trips and facilitate the use of transit and non-motorized modes" (p 555). Cervero and Duncan (2003) found that retail located within a one-mile (1.6 kilometre) radius of a person's residence made it more likely that they would walk to the store rather than drive (p 1481).

Housing diversity

By separating types of use as well as types of housing through zoning regulations, suburban areas "are actively preventing a spontaneous mixing of population" (Giuliano, 1995, p 12). This results in a uniformity of demographic profiles in an area. By having a mixed, diverse housing stock with a variety of housing types, tenures and price points, a community can attract a broader cross-section of people and be better able to support transit.

Research Summary: ***Locating a mix of land uses and diversity of housing with a variety of types, tenures, and price points near transit fosters increased transit ridership and also supports walking and cycling.***

2.5 Design

Urban design: Public realm and amenities

Urban design means different things to different people. In general, it involves the "Ds" already discussed - the arrangement of land uses, buildings, and facilities with sufficient levels of density and diversity, together with attractive and visually interesting buildings, yards, streetscapes, and public amenities. In addition, trees and green space contribute to a sense of place and a pedestrian-friendly environment. Canepa (2007) found that people will walk longer distances in areas of greater density with better urban design. Whether walking to transit or walking the entire length of a trip, having more to look at can make the journey a more interesting experience. Similarly, Chen et al. (2008) describe a well-designed pedestrian environment as one that will entice people to get out of their car to experience the character of a neighbourhood. People are more likely to walk to transit in areas that have shops, sidewalks, and trees (Pikora et al., 2003).

Cervero and Bosselmann (1988) asked residents of the San Francisco Bay area to identify their preferred neighbourhood type, based on photos of different types of development. Although the overall preference was for low-density neighbourhoods, the study showed that higher densities were chosen when amenities, like shops and community centres, were present. Communities can be made more supportive of transit and physical activity through the strategic location of amenities like schools and neighbourhood parks along transit corridors and in centres (Brownson & Boehmer, 2004).

Transit passenger facilities

The provision and design of transit passenger facilities and amenities can also influence the use of transit. For example, providing real-time information at transit stops and stations also has the potential to increase ridership (Litman, 2008). In addition, the quality of transit facilities at stations, such as signage, travel information, and amenities, can also attract new riders (Brons et al., 2009).

Street network connectivity

Street connectivity is a measure of how well streets connect places. Grid street patterns support cost-efficient transit service through offering more routes between origins and destinations. Since the 1970's, many communities have been built with larger block sizes and less internal connectivity (such as cul-de-sacs, T-intersections and dead ends) than traditional grid city forms. Larger block sizes have higher traffic volumes along arterial roads, whereas a finer grid pattern allows traffic to disperse throughout the network. A finer grid network with more intersections allows for more route choices, more opportunity for ground floor retail and a more even distribution of vehicle traffic (Handy, 1996). In measuring an area's walkability, Frank et al. (2009) found that a street connectivity of greater than 30 intersections per square kilometre was pedestrian-friendly. As most transit trips start and end as a pedestrian trip, walkability at trip origins and destinations has an important influence on transit use. Connectivity can also be provided with pedestrian and bicycle paths; for example, a suburb with cul-de-sacs can still provide connectivity to transit by creating a path to connect the cul-de-sac to a nearby road with transit service. In a meta-analysis of travel and the built environment, Ewing and Cervero (2010, p 265) conclude that "bus and train use are equally related to proximity to transit and street network design variables".

Complete streets: Sharing the road

Laplante and McCann (2008) reference the concept of 'complete streets' to describe a road that facilitates transit, cycling and walking, in addition to travel by automobile. In some cases, making streets more complete involves widening sidewalks, adding bike lanes and crosswalks, installing or improving transit stop furniture and weather protection, and installing bicycle parking and street benches.

Rodriguez and Joo (2004) found that the presence of sidewalks en route to transit will increase the odds of using transit. Adding a crosswalk to a road segment was correlated with a 57 per cent increase in pedestrians on that segment (Rodriguez et al., 2009). "An integrated and continuous pedestrian and bicycle network that connects points of origin with popular destinations should be in place before we can observe major modal changes" (Loukaitou-Sideris, 2004, p 24). Areas that are dark and not well-lit at night, or environments where traffic is a safety threat, reduce the likelihood of people walking (Loukaitou-Sideris, 2004). The feeling of safety is improved with the presence of buildings and their occupants (Pikora et al., 2003).

Research Summary: ***Urban design brings together and builds on the other "Ds" to create interesting and walkable***

"A complete street is a road that is designed to be safe for drivers, bicyclists, transit vehicles and users, and pedestrians of all ages and abilities.

(Laplante & McCann, 2008)

environments that are conducive to transit use. Transit accessibility is also affected by the street network design; a higher intersection density and smaller block size allows for greater connectivity. A connected network of streets and sidewalks, with trees, green space, and buildings lined up with the street rather than set back, encourage multi-modal movement and improve access to transit.

2.6 Demand management

Transportation Demand Management, or TDM, is a general term for various strategies that encourage changes in travel behaviour (how, when and where people travel) in order to make more efficient use of transportation resources (Victoria Transport Policy Institute On-line TDM Encyclopedia). Two key aspects of TDM that influence individual behaviour and travel patterns are trip costs and parking.

Trip costs

The relative cost of a trip varies by mode and can impact the attractiveness of one mode compared to another. The direct cost of a trip includes the financial cost and the value of time spent taking the trip. Indirect or external costs include congestion and air pollution amongst other costs. Because of improved fuel efficiencies, the average financial cost (adjusted for inflation) of one kilometre of car travel in the United States fell by almost 50 per cent between 1980 and 1993. During the same time period, the average cost of transit fares rose by 47 per cent (Cervero, 1998). In the UK, higher transport costs increase the propensity of people to consume goods locally and use alternative modes of transportation (Giuliano & Dargay, 2006). Kenworthy and Laube (1999) found that the cost per kilometre of auto travel is related to the degree of automobile dependence in cities. Asian and European cities were found to have the highest auto costs per kilometre and were the least auto-dependent, and American cities were found to have the lowest auto costs per kilometre and were the most auto-dependent.

In research on major transportation corridors between a suburban shopping district and a city centre, Casello (2007) finds that increasing the cost of driving at the same time as making alternative modes more competitive results in mode shift from automobiles to transit. A positive feedback loop is then created where higher ridership supports even better levels of transit service, which in turn attract even more riders.

Parking

Research has found that mode choice decisions also depend on variables such as parking cost and supply (Jun, 2008). Chatman (2008) found that significant mode shift cannot be achieved where there is high road volume capacity and plentiful free parking. Increasing the cost of parking, reducing the amount of free parking, and limiting the amount of parking supply increases the cost of using a car and reduces its convenience relative to using transit. Parking lots also take up considerable space, and result in a less pedestrian-oriented environment (Filion et al., 2000). Researchers used satellite photographs of a 'typical Midwestern county' in the United States to discover that there were 6.3 parking spaces per family, not including street parking, driveways or garages (Davis et al., 2010). Together, these findings demonstrate the transit ridership and land consumption impacts associated with the amount of space devoted to parking in auto-oriented communities.

"Denser development will not influence travel very much unless road level-of-service standards and parking requirements are reduced or eliminated."

(Chatman, 2008)

Cars generally occupy more space than other modes of transportation, requiring not only road space but also parking at both the trip origin and destination. Roadway and parking requirements contribute to a "design template for auto-oriented development" (Levine et al., 2005, p 317). Freund and Martin describe how places that are primarily designed for the car lead to a constant state of tension between pedestrians, cyclists, and drivers. These auto-oriented spaces do not facilitate play or relaxation. In surveying office workers at suburban employment centres, Filion et al. (2000) found that the amount of space occupied by surface parking and the lack of pedestrian infrastructure made them inhospitable environments for walking and helped explained the low number of pedestrians in these centres.

Research Summary: ***The cost and convenience of travel by private automobile and other modes influence levels of automobile dependence. To be effective in fostering a mode shift from auto to transit, demand management measures need to be accompanied with improvements to the supply of transit and pedestrian and cycling infrastructure.***

3.0 Transit Supply and Other Factors Affecting Transit Use

The following factors have been shown to have important impacts on transit ridership, but are not directly related to land use or the built environment.

Transit supply factors

The availability of frequent transit service is necessary for making transit-oriented communities work. Matching transit supply with demand is one of the primary objectives of transit agencies; transit-oriented communities are places that have enough demand to support frequent transit service. The frequency and span of service, in turn, shape demand and ridership in a positive feedback loop. A generally accepted threshold level of service for transit-oriented developments is frequencies of 15 minutes or better during most of the day (Dittmar & Ohland, 2004). Reliability of transit service is also an important factor that affects people's willingness to take transit. Transit riders have been found to be more sensitive to unpredictable delay than predictable waiting times, indicating the importance of service reliability (TCRP, 2007).

Frequent service can be effectively provided by different vehicle and transit service types. In some cases, the type of transit service influences ridership levels. For example, people have been found to walk farther to access rail compared to bus transit (Besser & Dannenburg, 2005). In addition, some people find rail systems simpler to understand and easier to use than conventional bus systems. However, bus rapid transit has the potential to address this gap by running along dedicated rights-of-way and providing many of the features of rail-based systems (Currie, 2005), and are more easily deployed in some urban settings.

Car ownership levels

A car is a significant household investment and once it is purchased, is likely to be used. Browson and Boehmer (2004) report that the likelihood of walking and biking is inversely related to the number of automobiles owned per household. Transit-oriented communities provide transportation choices (walking, cycling, and transit) which enable households to own fewer, if any, automobiles. In an auto-oriented community, owning a car is necessary for mobility; in a transit-oriented community, it becomes only one of several options for mode choice.

Topography and climate

A study by Rodriguez and Joo (2004) found that local topography influences choices to walk or cycle, with an increase in slope associated with lower odds of walking or cycling. Cycling mode share is impacted to a greater degree by slope increases than walking mode share. Local topography has little or no effect on walking accessibility to transit; slopes would have to be significantly steep to stop people from walking short distances to a transit stop. Hawthorne's 1989 survey of walkers found that heavy rain, cold, heavy snow, strong wind, and heat discourages walking. Walkers prefer temperatures in the 10 to 20°C range. Bus shelters, covered station areas, and continuous weather protection in commercial areas can provide increased comfort levels and facilitate transit use in inclement weather.

Income, age composition, preferences, and travel needs

The cultural, economic, and age composition of the population can be strong predictors of mode choice (Cervero & Duncan, 2003). Generally, low income households are associated with higher levels of transit use (Ewing & Cervero, 2003); to a lesser extent, cultural differences can impact transit use; for example, people of different ethnic backgrounds may be more familiar with using non-auto modes of transportation or may be more comfortable with higher densities (Giuliano, 2003).

Personal preferences impact mode choice and residential locations. People who lived in a transit-oriented development were surveyed to find out their reasons for choosing to live there. The top three reasons given were the quality of the neighbourhood, lower housing cost, and access to transit (Lund, 2006).

Attitudes about driving influence driving behaviour. Research shows that even though many people wish other people would drive less, they themselves enjoy driving and choose to drive even when they do not need to (Handy et al., 2005; Mokhtarian et al., 2001). Those who drive more tend to live in lower-density, suburban areas and have a "pro-driving" attitude, showing that travel behaviour, attitude, and the built environment are mutually reinforced (Bagley & Mokhtarian, 2002). However, there is evidence that preferences and habits can change. Handy et al. (2005) found that even though attitude explains travel behaviour in the present, changes in the built environment can influence mode choice over time. These long-term elasticities show that if transit-supportive land use and transit supply are introduced, driving culture has the potential to transform, over time, into more of a transit culture.

The mobility needs of children, teenagers, elderly people, the poor, those with medical limitations and others are not well met in an auto-oriented mobility system. People who cannot or choose not to drive must rely upon others or they must use non-motorized or public means of transportation. Transit-oriented communities can better meet the needs of these groups.

4.0 The Complexity of Real-World Urbanism

An urban environment is not a controlled experiment. As noted earlier, it is difficult to isolate the effects of one variable from those of other variables (Boarnet & Crane, 2001). Attempts to measure the impacts of one variable on another, like density on ridership, are confounded by a multitude of factors like self-selection and income levels. Bagley and Mokhtarian (2002) suggest that socio-economic characteristics are more significant predictors of mode choice than the built environment. People with lower incomes are more likely to use alternative modes of transportation (Ewing & Cervero, 2001). People who use transit also have a tendency to live in more affordable and higher density housing units. These relationships show the complex connections between variables such as density, affordability, income, transit ridership, and transit service levels.

5.0 Summary of Findings

This literature review provides a research foundation to inform and support improved coordination of land use and transportation planning in the region. It has demonstrated, through reference to the peer-reviewed research, that the built environment and other factors strongly influence transit ridership. The existing literature suggests that the "Six Ds" of Destination, Distance, Density, Diversity, Design, and Demand Management have a significant influence on key transportation indicators, such as reducing VKT (Vehicle Kilometres Travelled) and increasing transit, cycling and walking mode share. These built environment characteristics and resultant transportation performance help define transit-oriented communities as being places that, by design, invite people to drive their cars *less* and walk, cycle and take transit *more*.

Research on the built environment as it relates to transit usage shows that each of the six variables in isolation is insufficient to create a transit-oriented community, together with the provision of high quality transit services. For example, density is a necessary condition, but insufficient on its own, to support a high level of transit service. To be truly effective, the "Six Ds" must be incorporated and integrated together to the greatest extent possible to create a transit-oriented community, together with the provision of high quality transit services.

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