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Urban sprawl processes characterize the landscape of the areas surrounding cities. These landscapes show different features according to the geographical area that cities belong to, though some common factors can be identified: land consumption, indifference to the peculiarities of the context, homogeneity of activities and building typologies, mobility needs exasperatedly delegated to private cars.

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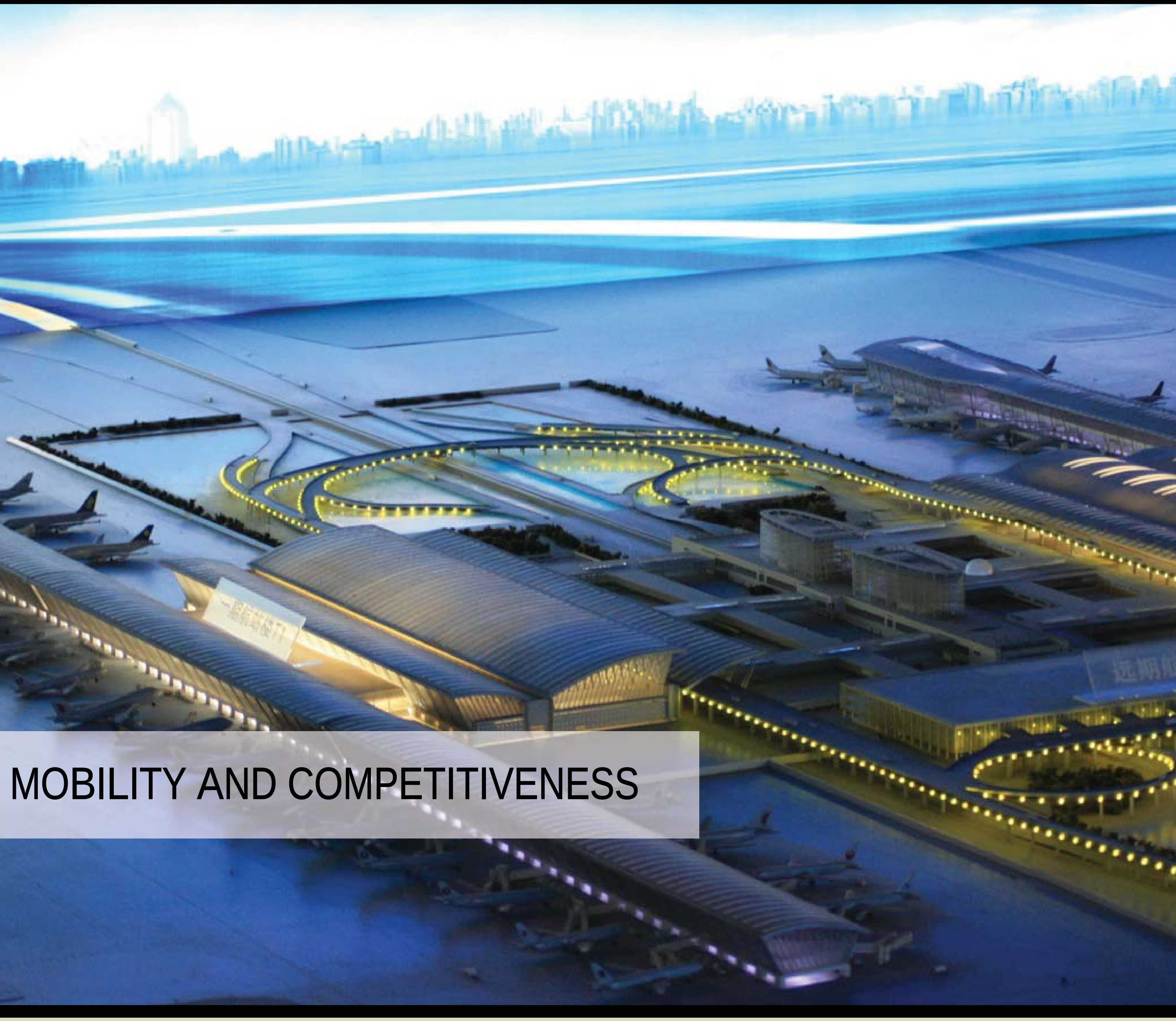

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THE RELATIONSHIP

BETWEEN URBAN STRUCTURE AND TRAVEL BEHAVIOUR: CHALLENGES AND PRACTICES

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ABSTRACT

Since urban structure indicators influence travel behaviour, they have been widely studied. The goal of these studies was identifying effective factors to have sustainable transport patterns. However, investigating these factors has been problematic and the results are not reliable enough to be used universally. There are two main reasons for this: firstly, because socio-economic indicators impact neighbourhoods with comparable design differently; and secondly, factors such as income, and age, as well as self-selection factors are not easy to be evaluated. This paper addresses challenges and practices in this area to propose new objectives for further studies that cover previous shortcomings.

KEYWORDS:
Urban structure indicators; Travel behavior; Different socio-economic contexts; Sustainable urban transport planning; Land use; street network; Public transport

1 INTRODUCTION

Structures and forms of cities must be taken into consideration in order to reduce car externalities in urban areas. Although various cities have different indicators, urban structures have similar factors such as land use, street network, private motorized facilities, and public transport infrastructures. These indicators affect private motorized trips. Literature on this field is filled with the studies that have shown the relationships between urban structure indicators and transport behaviour. Yet, there are some scholars who claim that the influence of urban form on travel behaviour is limited (e.g., Boarnet and Crane 2001; Handy et al., 2005; Stead, 2001). These researchers have not found enough evidence to prove that urban forms significantly influence motorized trips. They claim that built environment traits are weak in defining travel behaviour. For instance, the residents of areas with comparable density, diversities, and designs may show different travel behaviour since they have diverse socio-economic characteristics such as income and age. As a result, these factors need to be controlled. The location of the investigated residential areas relative to the metropolitan center structure is another example that makes different travel behaviour for areas with similar 3D (density, diversities, and designs). This has often been disregarded especially in North American studies.

Generally for the purpose of controlling factors, objective (e.g., demographic indicators) and subjective measures (e.g., attitudes towards choosing travel mode) are utilized. Some scholars such as Cervero and Kockelman (1997) involved a wide range of objective control variables such as age, employment, household members and vehicles, parking cost, transit cost and distance from city canter. Cao et al. (2009) believes that self-selection factors may alter pedestrian behaviour. While some studies consider socio-economic factors, considerable researchers like Naess (2009) think that urban form influence travel behaviour even if self-selection and socio-economic indicators are paid attention. Some built-environment academics such as Srinivasan (2002) are convinced that spatial variables such as corridor factors should be taken into consideration since they prominently affect travel behaviour.

Although previous studies made attempts to produce reliable results by involving both self-selection and socio-economic indicators, their results are still questionable. This is mainly because they have evaluated selected areas of a city or selected cities of a country. Moreover, effective socio-economic indicators are varied depend on the neighbourhood under study which creates limitation for the results and data collection. As a result, the influence of urban structure on travel behaviour can hardly be described by these studies. There are some studies that evaluate representative areas within a city and the results may be reasonably generalized to that city. But quantitative generalization to other cities remains problematic. Along this, this paper proposes considering various cities that have different socio-economical traits to cover self-selection and socio-economic indicators for further research. Thus, the outcomes of future research will be reliable to be used around the world.

In addition, some factors such as park and ride facilities, shape factors and car trips facilities have not been investigated thoroughly. This paper however tries to encourage further studies to investigate the effectiveness of park and ride facilities on personal vehicle usage to see whether the criticism around this issue is constructive. In previous literature, intersection and block density were used to evaluate connectivity. These factors which are also significant in describing the figures of the cities and the patterns of the street networks also can be evaluated by future research to describe shape factors besides connectivity. As a result, instead of block density and intersection density, polygons per area and nodes per polygons besides considering location of neighbourhoods are proposed to be taken into consideration by

future studies. Moreover, since the studies on efficiency of the automobile trips facilities in reducing private motorized trips were scarce, it is also recommended to investigate this issue more deeply in further studies.
The relationship between urban structure indicators (e.g. land use, street network, public transport and private motorized trips infrastructures) and travel behaviour is evaluated by various studies. This paper presents the structure of urban form to indicate the factors that are prominent in case of travel behaviour in urban areas. Urban form, travel behaviour and how they affect each other in various studies are discussed in this review.

2 CHALLENGES AND PRACTICES

2.2 LAND USE

The relationship between land use and travel behaviour has been the subject of interest of many researchers (e.g., Handy and Mokhtarian, 2005; Kuzmyak and Pratt, 2003; Modarres, 1993; Morris, 2004). For example Cervero and Kockelman (1997) studied the effects of density, diversity and design on trip generation and choice of travel mode. Some scholars have improvised Cervero and Kockelman's study later on to 4Ds by involving accessibility of destinations in it (e.g., Cervero, 2002; DKS, 2007; Ewing and Cervero, 2001 and 2010). Accordingly, car usage ratio is under the influence of several main factors, which are: density (population and employment density), diversity (mix land use and jobs proportion), design (non-motorized design variables like walking facilities) and destinations accessibility (DKS, 2007).
Although density is not the only factor that influences vehicle miles travelled (VMT) (Crane, 1996; Dunphy and Fisher, 1996; Handy, 1996; Myers and Kitsuse, 1999), population and employment densities are two land use indicators that affect travel behaviour (e.g., Boarnet et al., 2004; Chatman, 2008; Ewing et al., 1996 and 2009; Frank and Engelke, 2005; Greenwald, 2009; Pickrell and Schimek, 1999; Schimek 1996; Sun et al., 1998; Zhou and Kockelman, 2008). Naess, 2005 found that the density of jobs and population in the local neighbourhood affect the dwelling on travel behaviour. But this effect was small compared to the distance of the dwelling to the city center. Several studies conclude that the population and job density within the metropolitan area clearly affects travel behaviour. But the density within a local neighbourhood is not likely to affect travel behaviour.
Holtzclaw (1994) found that the number of cars and VMT per household will reduce, if density increases. Along with this finding, Burchell et al. (1998) and Ewing (1997) also found that higher density decreases VMT. Kitamura et al. (1997) also claimed that the percentage of non motorized trip has positive relationship with residential density. Higher dwelling unit density reduces daily car use per household (Zagars, 2007) and higher commercial density also decreases vehicle kilometres travelled (VKT) per person (Heldel and Vance, 2007). Higher household density is another effective factor that reduces VMT (Bhatia, 2004; Chatman, 2003; Holtzclaw et al., 2002; Kuzmyak 2009).
Since mix land use provides walkable destinations, it decreases the percentage of private motorized trips. This characteristic of mix land use makes it the interesting topic of research for a lot of scholars (e.g., Chapman and Frank, 2004; Frank and Engelke, 2005; Frank et al., 2009; Heldel and Vance, 2007; Kockelman, 1997; Kuzmyak et al., 2006; Kuzmyak, 2009; Pushkar et al., 2000; Sun et al., 1998). The other

significant effect of mix land use is that it makes more job-housing balance. Having a job per housing balance around 1.0 can decreased motorized travel (Kuzmyak and Pratt, 2003; Weitz, 2003). Similarly, the results of Crane and Chatman's (2003) study show that the average commute distance can be reduced by 1.5% when the percentage of employment experiences 5% increase in metropolitan areas. Job-housing balance considered effective on VKT and VMT by various studies (e.g., Bento et al., 2003; Cervero and Kockelman, 1997; Ewing et al., 1996 and 2009; Greenwald, 2009; Kuzmyak et al., 2006). It is prominent to consider the geographical scale in this case. Jobs-housing balance is effective to reduce out-commuting at a city level. In a local suburban neighbourhood scale this issue may reduce in longer commuting distances for the non-local employees, although jobs-housing balance can reduce average commuting distances among the local residents.

The indicators related to the land use design are also significant to motivate or demotivate individuals to use their private cars. Although land use design is much more than just street networks, Kulash et al. (1990) utilized simulation to study traditional and conventional networks. They found that VMT in traditional patterns of circulation is 57% lower. It should be taken into consideration that studies which focus on street network variables are criticized due to their ignorance of the location. On the other hand, correlations between street design and VMT is found to be substantially reduced or vanish in studies that control the distance to the city canter. Bhat and Eluru (2009) studied types of urban neighbourhoods and their effects on VMT per household. Cao et al. (2009) found that urban neighbourhood affects vehicle miles that an individual drives. The neighbourhoods in new urbanism areas also influence daily miles travelled and VMT per household (Khattak and Rodriguez, 2005; Shay and Khattak, 2005).

Urban travel behaviour can be affected by non-motorized travel facilities and patterns of the streets. Driving gets reduced by more walkable communities (Handy and Mokhtarian, 2005). The effects of sidewalk width on VMT per household were examined by Cervero and Kockelman (1997). Length of sidewalk also considered by Fan (2007) as an effective factor for reducing miles travelled per person in Raleigh-Durham, NC. VMT can be also altered by bicycle lane density (Bhat and Eluru, 2009; Bhat et al., 2009).

Moreover, travel behaviour is under the influence of parking facilities as the segments of design factor. Availability of parking spaces increases private motorized daily trips (Moeinaddini and Zaly, 2011). When parking areas are convenience and cheap, motorized vehicles' ownership and usage increase as well (Litman, 2006; Mildner et al., 1997; Morrall and Bolger, 1996; Shoup, 1997; Weinberger et al., 2008). Vaka and Kuzmyak (2005) found that when parking costs increase 10%, vehicle trips reduce between 1 to 3 per cent. Park and ride facilities are also provided to motivate people to alter their private travel modes to public transport (Bolger, 1995; Noel, 1988). Yet these facilities have been also criticized since they consume lands and motivate people to use automobile at least to reach car parking in transit stations (Parkhurst, 2001).They also negatively affect car reduction strategies, although these strategies were part of the target of their policies (Meek et al., 2009).

Travel behaviour can be altered by destination accessibility. For instance accessibility to shops reduces VMT per household (Bhat and Eluru, 2009). In this regard, the relationship between VMT and the accessibility of household job per household by public transport (proportion of households that can reach public transport for their work trips) was studied by Bahatia (2004). There is also a negative relationship between vehicle mile and hour travelled with job accessibility by cars (Cervero and Duncan, 2006; Cervero and Kockelman, 1997; Ewing et al., 1996 and 2009; Greenwald, 2009; Kockelman, 1997; Sun et al., 1998). The negative effect of job accessibility by public travel modes on VMT per household is evaluated by Frank et al. (2009) and Kuzmyak (2009). It is also found that travel behaviour can be influenced by distance to the Central Business District (CBD) (Boarnet et al., 2004; Naess, 2005; Pushkar et al., 2000; Zegras, 2007). Travel behaviour is also under the influence of distance to transit station and bus stop (Bento et al., 2003; Frank and Engelke, 2005; Frank et al., 2009; Hedel and Vance, 2007; Pushkar et al., 2000; Zegras, 2007).

2.2 STREET NETWORK

Street and square arrangements influence form of cities more than other factors (Crawford, 2005). Since the indicators of street network are the significant part of urban structure and form, they influence travel behaviour greatly. Studies on this issue have utilized a wide variety of scales from neighbourhoods to cities to find the relationship between factors of urban street network and travel behaviour. Street network influences trips to local destinations such as grocery stores and primary schools more than longer trips, although the accessibility to the transit stop can encourage the use of transit for longer trips like daily commutes.

Street density influences travel behaviour (Cervero and Kockelman, 1997; Bento et al., 2005; DKS, 2007). It affects vehicle kilometre travelled (VKT) per person negatively (Hedel and Vance, 2007). Some studies that took pedestrians and walking trips into consideration, have proposed that street length affects travel behaviour. Sidewalk length affects daily transit travel time, daily walking time by person, and miles travel by person (Fan, 2007). Sidewalk ratio also can alter transit mode choice (Cervero, 2002).

Intersections are the important parts of urban street network structures. The density and the proportion of four-way intersections can decrease non-work vehicle miles travelled (VMT) per person (Boarnet et al., 2004). It is also found by Cervero and Kockelman (1997) that four-way intersections influence VMT per person. Higher proportion of intersections per road kilometre reduces VKT per household (Pushkar et al., 2000). The proportion of connected intersections is significant for miles travelled per person (Fan, 2007). The influence of the proportion of three-way intersections on individuals who use private cars per household also studies by Zegras (2007). The relationship between intersection density and VMT is estimated by ample studies (e.g., Chapman and Frank, 2004; Ewing et al., 2009; Frank and Engelke, 2005; Frank et al., 2009; Greenwald, 2009; and Chatman, 2008).

Various studies show that intersection density influence street connectivity. In order to determine street connectivity Zhang (2006) calculated the proportion of four-way intersections in origins and destinations. Connectivity index can be defined by the proportion of intersections per total number of intersections and dead-ends. This index is a value between 0 and 1, and values over 0.75 are desirable (USEPA, 2002). Dill (2004) asserted that more connectivity can increase walking and biking. VMT can be decreased by connected road networks (Kulash et al., 1990). So more local street connectivity decreases traffic jams (Alba and Beimborn, 2005).

Intersection density also affects transit mode and trips (Frank et al., 2008 and 2009; Greenwald, 2009). The possibility of transit mode choice is increased by higher proportion of four-way intersections (Cervero, 2007; Lund et al., 2004). The rate of connected intersection alters daily transit travel time for individuals (Fan, 2007). The relationship between four-way intersection density and non-personal motorized vehicle choice for work has been studied by Crevero and Kockelman (1997). Walk mode choice and trips are also under the influence of intersection density (Boarnet et al., 2008; Ewing et al., 2009; Frank et al., 2008 and 2009). The higher rate of four-way intersections can increase walking desire (Boarnet et al., 2011; Boer et al., 2007) and bike trips (Chatman, 2009). In this regard, the impact of intersection density on cycling also was studied by Greenwald (2009).

VMT and car usage can be reduced by grid street patterns. Connected roads, that these patterns provide, increase walking rate and decrease car usage (Crane, 1996; Ryan and McNally, 1995; Plaut and Boarnet, 2003). It is found that the residence of the areas with grid-street-patterns take more non-work motorized trips (Boarnet and Sarmiento, 1998). Among grid, cul-de-sac, and mixed street patterns the second one causes more and further trips (Crane and Crepeau, 1998). Some scholars such as Rajamani and his colleagues (2003) examined the influence of cul-de-sac rate on transit and walking mode choice.

Fused-grid street pattern are those cul-de-sac streets which are linked to each other by green areas to offer connectivity for non-motorized trips. These patterns not only enhance the liveability of community, but also raise non-motorized trips (Frank and Hawkins, 2007). Some researchers believe that providing accessibility for non-motorized modes and reduce connected roads for driving that are possible by applying special street network patterns can decrease traffic volumes and increase green travel modes (e.g., Glotz-Richter, 2003). An example of these patterns would be ring roads for motorized vehicles. Zhang (2004) also asserted that connected street patterns increase non-motorized mode and transit choice for both work and non-work trips. Path directions can influence transit and walking modes for commute trips (Rodrigues and Joo, 2004).

Size, length, and density of blocks may be created by street patterns which affect travel behaviour. Walking trips are affected by block size (Boarnet et al., 2011; Hess et al., 1999; Joh et al., 2009; Targa and Clifton, 2005). Moreover, block length influences miles walked per person (Boer et al., 2007). The effects of block density on VMT per household have been studied by Bhat et al. (2009). The efficiency of quadrilateral blocks for non-personal vehicle choice to take trips to work and VMT per household is also studied by Cervero and Kockelman (1997).

Travel behaviour alters by the patterns of the streets. Marshall (2005) took an attempt to classify and analyze the different types of street patterns. Kissling (1969) evaluated the significance of linkage and nodal accessibility level that are affected by network structure. A study done by Xie and Levinson (2011) shows that street network arrangement and connectivity are the important parts of network topology. Some attempts have been taken to find a method for identifying and classifying grid patterns (e.g., Yang et al., 2010). Jiang et al. (2009) proposed human mobility patterns for the structure of street network. Borchert (1961) by using the number of road and street intersections per square mile defined the patterns of metropolitan settlement.

Crawford (2005) reviewed the different types of street patterns during Medieval time, Renaissance, Baroque, Industrial era, Modernism, and New urbanism. In his study the formation of street types (grid, radial, and irregular) is described. According to Kostof (1991) capitalist expediency, military necessity, religious symbolism, simple haste and aesthetic preference caused streets to form like grids. The mentioned studies indicate the history of street forms only and travel behaviour has not been focused by them.

2.3 PUBLIC TRANSPORT

Mobility and accessibility are important indicators of urban growth. Cities are built to lessen travel and enhance exchange opportunities (Engwicht, 1999). Public transport in cities came into existence to fulfil transportation needs as well as mobility and accessibility demands. Public transportation has developed fast and during this period automobile usage caused a lot of externalities (Litman, 2009a); therefore, the need for vast public transportation system felt more than ever. Economic development, mobility enhancement, and health improvement are some of the various benefits of public transport development.

Public transport has a significant role in reducing vehicle travel kilometres (Litman, 2009b). A study done by Nelson and his colleagues (2006) in Washington DC revealed that rail transit system reduces traffic jam and therefore, aids car users. Lower private driving and greater public transport usage as the result of better quality for public transport systems in Toronto also reported by Schimek (1996). With regard to the benefits of public transport mobility, a wide range of studies propose the preference of using public transportation, and decreases the tendency to use personal vehicles to have sustainable development.

Public transport can be evaluated by different kinds of indicators. Accessibility, availability, affordability, reliability, safety, and security are branches of these factors. The rate of public transport usage increases sharply, when an area alters toward more urban development (Litman, 2009c) since accessibility needs also increase. The requests for public transport systems grow since they provide more accessibility compared to personal travels. As a result, more and convenient accessibility raises public transport usage and reduces private car usage. If transit access increases, the number of cars and VMT per household will decrease significantly (Holtzclaw, 1994).

Accessibility of public transport can be affected by land use planning. Transit oriented development (TOD) patterns in this regard can increase the rate of pedestrians and trips by public transport (Cervero and Gorham, 1995). Traditional neighbourhoods however have higher rates of transit and green trips (Friedman et al., 1994) and people travel more by public system rather than using personal cars where commercials and residential land uses are located close together (Cervero, 1996). A study done by Florez (1998) shows that in three neighbourhoods in Caracas traditional patterns had fewer private motorized trips, less travel times, and more public transport usage. This issue can be the result of traditional characteristics of the design of the local area and their location relative to relevant trip destinations. Estupiñán and Rodríguez (2008) found that neighbourhood traits and contextual variables relate to a developing country affect public transport trips. This study was done in Bogota in Colombia.

The distance to the nearest rail station has relationship with transit trips (Kitamura et al., 1997); in a sense that the closer to station, the less people drive and the more the use public transit modes (MTC, 2006). The walkability of areas near stations also can increase transit trips (Ryan and Frank, 2009). Therefore, the quantity of car ownership among the residents of TOD is lower in comparison with other areas (Evans and Pratt, 2007).

Indicators related to availability may affect urban public transport. Travel modes are under the influence of infrastructures and facilities which are fragments of availability factors. Therefore, considering the facilities for public transit users during planning process is important (Asadi-Shekari and Zaly Shah, 2011). Almost half of the transit users prefer to take taxi or travel by automobile in the absence of transit services as reported by Transit Performance Monitoring System (FTA) in 2002. Many researchers such as Hale (2011), Hensher (2001), Kittelson et al. (2001), Polzin et al. (2002), and Xin et al. (2005) took availability effective and utilized it in their evaluations of transit services.

Affordability also has attracted scholars' attentions in public transport evaluations. The results of the studies done by Hensher and King (1998), TRL (2004), and Litman (2004) show that an increase of 1% fare drops the rate of passengers up to 0.4%. Transit costs affect people from low and middle class priority to choose travel mode, therefore, expenses relate to public transport have mobility advantage. Quite predictably, affordable costs make public transits popular among greater groups of people (Litman, 2011). Litman

(2011) and Plozin et al. (2008) believe that when people alter their travel behaviour to public transport they can save operating and parking costs, vehicle ownership and its insurance expenses. McCann (2000) in this regard says that people who make use of good public transport facilities spend less on transportation and are able to save 3000$ per annum.

Ridership can be affected by the quality and quantity of transit service. The results of the studies that have been done in this area show that reliable public transport has the quality to encourage people to change their travel behaviour from private car usage to public systems of transportation. However, technical improvements are needed for such reliability. Studies such as Levinson (1991) and Turnquist (1981) show that maximum reliability can be attained by controlling run time and headway delay. Information and public involvement are other social factors that affect the reliability of public transportation systems.

Urban public transport usage is also under the influence of convenience, safety, and security. Indicators such as safe and secure facilities are significant in evaluating public transportation system. Litman (2005) considers transit trips safer than private car usage. In fact, private motorized users are under safety and security threat such as aggressive driving (STPP, 1999). Garcia (2005) suggests that in order to decrease safety risks, transit trips should be handled by responsible people.

2.4 PRIVATE MOTORIZED

When population rose and industrialization got popular, the usage of private motorized vehicles started to grow sharply in urban areas. To tackle this issue, in 1980s and 1990s congestion pricing was established. Some of these strategies proposed by some organizations were successfully implemented, to name a few: the toll rings in Norway (Larsen, 1995), the Area Licensing Scheme in Singapore (Behbehani et al., 1984), Congestion Pricing in Stockholm (2006) and London Congestion Charging (2003). These strategies raise costs of transportation by personal vehicles; as a result people get motivation to alter their travel behaviour. Although the toll rings in Norway established for funding of urban highway construction, lately the fees have been raised, so in the future they will reduce the traffic. Generally, people welcome ways that reduce their costs of living (Loukopoulos et al., 2004; Salomon and Mokhtarian, 1997).

Private motorized trips facilities influence travel behaviour. When convenience arises by excess of cars and cheap ownership, private car usage increases undoubtedly. There are not enough studies which casted light on efficacy of private motorized trip indicators such as distance of a private motorized trip, cost and proportion of private cars passengers and etc.

3 DRAWBACKS OF PREVIOUS STUDIES

Several studies have examined relationship between urban indicators and car usage at various scales from site to local and regional. However, previous efforts have some major drawbacks that make their results insufficient to cover different urban structure indicators and various socio-economic contexts. Firstly, they just cover some cities of a selected country or some neighbourhoods from a single city. Although previous studies can describe the impacts of urban structure on car usage in different socio-economic contexts by means of analytical, qualitative generalizations describing how the causal mechanisms tend to operate, analytical results from one study in a particular city cannot be generalized to different cities. Secondly, there are limited studies that evaluate effectiveness of various urban indicators in reducing car usage in one relationship model. Since urban structure indicators affect each other, relationship behaviour can be changed by impacts of these indicators. Finally, there are limited literature about the effectiveness of park and ride facilities, shape factors and private motorized trips facilities. Accordingly, this paper suggests that further studies evaluate the effects of various urban structure factors (including park and ride facilities, shape factors and private motorized trips facilities) on travel behaviour in different cities around the world in one relationship model. This issue leads to find effective urban structure indicators in various socio-economic contexts. The effects of these indicators can be used to have more reliable car reduction strategies.

4 CONCLUSIONS AND DISCUSSIONS

Different urban structure indicators (e.g. land use, street network, private motorized facilities and public transport infrastructures) that have more impacts on car usage are discussed in this paper. Table 1 summarizes effective indicators that are significant in urban structure and travel behaviour relationship studies. Although, there are ample studies that evaluate urban structure and private motorized trips relationship, there are not sufficient studies that examine this relationship in various socio-economic contexts. The scale of majority of studies are various from site to local cities and they usually consider different neighbourhoods in a city or different cities in one country and there are very few studies that consider various cities in different parts of the world.

Urban form indicators were selected from one or two sets of land use, street network, private motorized facilities and public transport indicators and there are limited studies that consider combination of these indicators in one relationship model. For instance, just two types of networks in different neighbourhoods compare with each other regardless of the effectiveness of other indicators. In addition, there are limited studies for some effective indicators such as park and ride facilities, street network shape indicators and private motorized trips facilities.

Consequently, future studies can examine relationship of urban structure indicators with travel behaviour in various cities with different socio-economic contexts. This relationship can be estimated for land use, street network, private motorized facilities and public transport indicators separately and also in one relationship model. Further studies also can try to evaluate the effectiveness of indicators that have not been investigated thoroughly.

Nowadays there is an interest among researchers who are working on sustainability to think about future sustainable cities and some of these researchers consider these future cities without cars and propose some ideas to reach these car free developments. Urban structure model that is suggested for future studies can help to predict structure of car free developments. This structure can be a combination of all effective indicators that are use to build the model. Future research may also examine fast changes of urban structure indicators by updating their data sources and evaluating the urban structure and travel behaviour relationships in different parts of the world to cover the changing results.

Overall, currently, more green and sustainable urban areas are needed. To have these kinds of areas having fewer private motorized trips in cities is a prominent goal. So future research will attempt to evaluate the relationship between private motorized vehicle usage and urban structure indicators to indicate how this relationship can be used to reduce private motorized vehicle usage in urban areas in different parts of the world.

Urban structure indicators	Travel behaviour indicators	The direction of the impact
Household density	VMT per household	Negative
Population density	VMT per household	Negative
Job density	VMT for commercial trips per person	Negative
Retail job density	Non-work VMT per person	Negative
Dwelling unit density	Daily car usage per household	Negative
Job-housing balance	VMT per household	Negative
Land use mix	VMT per household	Negative
Plaza density	Daily car usage per household	Negative
Population centrality	VMT per household	Negative
Accessibility to shopping	VMT per household	Negative
Distance to CBD	VKT per household	Positive
New urbanism neighbourhood	VMT per household	Negative
Bicycle lane density	VMT per household	Negative
Street block density	VMT per household	Positive
Intersection density	VMT per household	Negative
Proportion of 4way intersections	Non-work VMT per person	Negative
Proportion of 3way intersections	Daily car usage per household	Negative
Street density	VKT per person	Negative
Sidewalk length	Miles travelled per person	Negative
Street connectivity	Walk, bike and transit mode choice	Positive
Job accessibility by transit	VMT per household	Negative
Distance to transit stop	VMT per household	Positive
Walk minutes to transit	VKT per individuals	Positive
Distance to Metro	Daily car usage per household	Positive
TOD	Commute VMT per person	Negative

Tab.1 Some effective urban structure indicators based on previous studies

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