Incorporating the Safe System and sociodemographics into the built environment model of traffic safety: A Transtheoretical Model

Shi[a], Y., Han[a], J.H., & Senserrick[b], T.

[a] Faculty of Built Environment, The University of New South Wales, Australia, [b] Transport and Road Safety (TARS) Research, The University of New South Wales, Australia

Abstract

In recent years, transportation engineering theory of the built environment has paid increased attention to land planning organisation and urban design in preventing traffic crashes. Empirical investigations have been conducted into the relationships between built environment factors and crash occurrence and severity. However, there is a lack of closer examination on the interactions among built environment factors and the safe system approach that is considered 'best practice' in road safety. There is also a lack of attention to how sociodemographic factors might influence built environment factors at the micro and macro level, as well as the safe system. The objective of this research was to make explicit the multiple pathways through which the built environment potentially affects risk of crash incorporating theories of the role of sociodemographics and the safe system. A transtheoretical model is proposed developed from Ewing and Dumbaugh's (2009) conceptual framework linking the built environment to traffic safety to incorporate the road safety framework of the 'safe system' components of safe roads and roadsides, safe speeds, safe road users and safe vehicles, as well as key sociodemographics based on a review of empirical research from urban planning, transport and road safety literature. A transtheoretical model is proposed to point to the importance of future efforts integrating road safety theory into built environment planning work and engineering designs.

Introduction

In the past decades since late 1960s, behavioural road safety measures have played a crucial role in reducing road fatalities in Australia, such that it has been argued that seat belt wearing, random breath testing and speed cameras could explain almost all of the decrease in fatality rates in all states (BITRE., 2010). While substantial attention and priorities have been given to these enforcement and education programs on the basis of human behaviour theory, in the recent national road safety strategy 2011-2020 (page 18), it is pointed out that '*Greater emphasis is now required on non-behavioural means of improving the safety of our road transport system*' (Australian Transport Council., 2011). The ten-year plan is firmly based on the safe system approach, which means that the new decade is also a transition from human factors theory to systems theory in Australia.

The safe system approach considers the interactions between the road, speed, vehicle and user and asserts that a system solution will be achieved based on the interactions among these elements. The ultimate goal is to provide a forgiving environment that prevent serious injury or death when crashes occur (Transport Research Centre, 2008). Currently, the 'forgiving environment' mentioned is more related to 'road environment'. Safety solutions proposed in relation to this aspect of the safe system are mostly concentrated in transport designing and engineering, while in recent years, some planning and public health researchers have started to use the term of 'built environment factors' to incorporate a broader view of environmental factors relevant to safety and have started to explore their impact on road safety through epidemiological methods (Cho, Rodríguez, & Khattak, 2009; Clifton, Burnier, & Akar, 2009; LaScala, Gerber, & Gruenewald, 2000; LaScala, Johnson, & Gruenewald, 2001; Miranda-Moreno, Morency, & El-Geneidy, 2011; Wier, Weintraub, Humphreys, Seto, & Bhatia, 2009). These researchers aimed to introduce safety inventions from transportation and land use at the planning stage as well as the designing stage. Similar voice was

found in several Canadian studies (Hadayeghi, Shalaby, & Persaud, 2003, 2007; Lovegrove & Sayed, 2006), which named this as the "proactive approach" and tried to predict the crash frequency based on macro-level collision models.

Ewing and Dumbaugh (2009) in US developed a conceptual framework (as seen in Figure 1) to review the previous empirical studies of the impact of built environment factors on traffic safety. They classified built environment factors into three categories: urban sprawl, street network design and road design, and demonstrated the impact of these built environment factors on crash frequency and severity on the basis of three mediators: traffic volume, conflicts and traffic speed. Ewing and Dumbaugh's discussion has given extensive explanation on how the built environment affects safety through traffic exposure and speed. This and other epidemiological methodologies and the proactive approaches in past studies have provided empirical evidence on the direct relationships between built environment factors and road safety. However, there is a lack of closer examination on the interactions among built environment factors and other safety components in the safe system and the system approach, which is considered the 'best practice' in road safety.
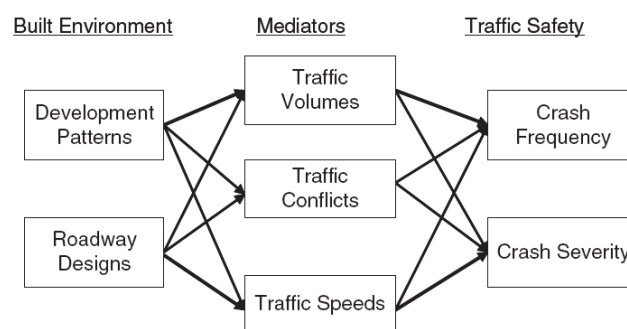
Figure 1. Conceptual Framework Linking the Built Environment to Traffic Safety (Ewing & Dumbaugh, 2009)

Environmental factors that impact on people's behaviour include physical environment as well as social environment factors. Sociodemographics are identified as nonurban-form factors, reflecting road users' social status and having impact on travel behaviour (Frank & Pivo, 1994). Several sociodemographic factors are also related to crash risk, such as socioeconomic level (Fleury, Peytavin, Alam, & Brenac, 2010), car ownership (Loukaitou-Sideris, Liggett, & Sung, 2007), education level (Cao, Mokhtarian, & Handy, 2009), and age, gender and ethnicity (Clifton & Kreamer-Fults, 2007; Lightstone, Dhillon, Peek-Asa, & Kraus, 2001; Shope, 2006). Thus both physical environmental factors and social factors need to be combined in relation to road safety in the safe system.

The objective of this paper is to propose a transtheoretical model that extends Ewing and Dumbaugh's (2009) built environment framework for traffic safety to incorporate the safe system and sociodemographics. It is not intended to be a comprehensive or critical review of all the relevant literature in either the built environment or road safety fields, but to provide illustrative examples of ways to advance the built environment and traffic safety model to better address current best practice in road safety.

A Transtheoretical Model of Built Environment and Road Safety

Definition of Built Environment

Built Environment has been defined as "the physical features of the urban landscape referring to as modest as a sidewalk or as large as a new town (Cervero & Kockelman, Page 200). Several dimension or "D" variables have commonly been applied in travel behaviour studies to measure the

dimensions of built environment. The three core dimensions (3Ds), which were initially proposed by Cervero and Kockelman (1997), are density, diversity and design. In a later study, the 3Ds were expanded into 5Ds followed by destination accessibility and distance to transit. The 5Ds (Ewing & Cervero, 2010) address almost all of the built environment factors that have appeared in the past empirical studies of travel behaviour as summarised in Table 1.

Table 1. Five dimensions of built environment (Ewing & Cervero, 2010)

BE Dimensions	Definition
Density	Population density or employment density or housing units within a unit of area
Diversity	Number of different land uses in a given area and the degree to which they are represented in land area
Design	Street network characteristics within an area, includes the street network pattern, road geometric design and road safety countermeasures
Destination accessibility	Accessibility to trip attractions (normally the business districts or local stores)
Distance to transit	An average of the shortest routes from the residences or workplaces in an area to the nearest public transit location

For the purpose of discussion in the current paper, built environment factors will be grouped into two levels: the macro and micro level. From the macro level, built environment (density, land use and street network) stands for the characteristics of the urban development pattern, which indicates the compactness or sprawl extent of a particular area. The micro level factors refer to the road/road side design features for different groups of road users, including driver oriented design, pedestrian oriented design and cyclist oriented design.

A Transtheoretical Model

A transtheoretical framework which adapts and extends Ewing and Dumbaugh's (2009) built environment and traffic framework to include safe system and sociodemographic components as explanatory to crash risk is proposed as presented in Figure 2. Sociodemographics as well as built environment factors are proposed to have direct relationships with the mediators, which are extended to include road user and vehicle factors.
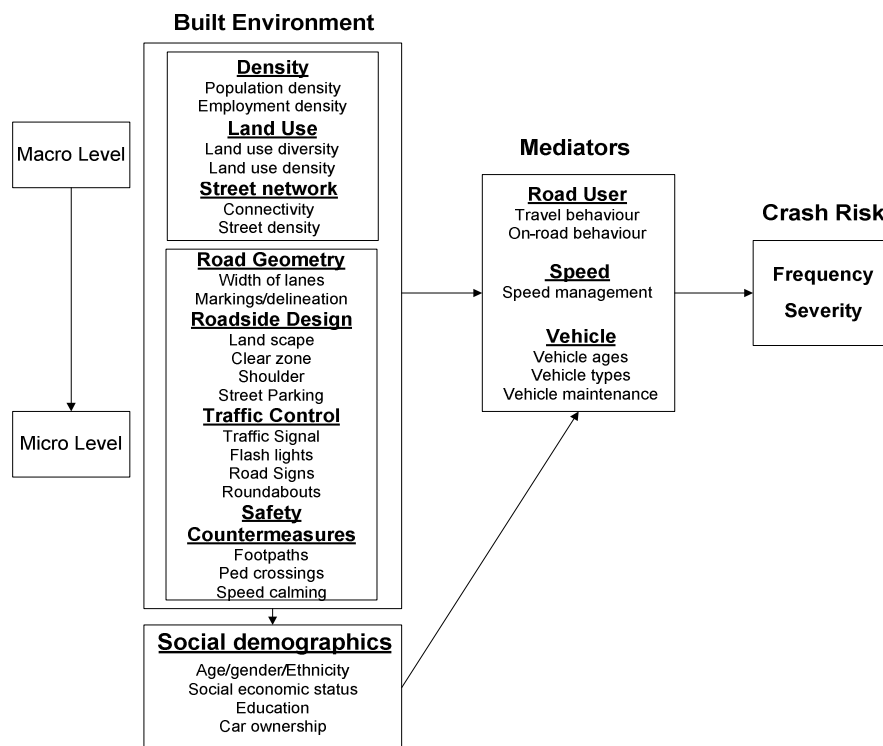
Figure 2. Transtheoretical model of built environment and road safety integrating the safe system approach and sociodemographics

The impacts of the built environment on road users are considered from two aspects: influence on people's travel behaviour and influence on road users' on-road safety behaviour. Travel behaviour is related to people's travel activities and their daily choice on how to use transport, including modal choice, daily trips, and travel time, so people's travel behaviour determines their exposure time, exposure locations and exposure form to crash risk. Road users' on-road behaviour involves motorised driving and riding behaviour, walking behaviour and cycling behaviour. From another aspect, there are different restrictions on speed in different urban forms, so macro level factors also impact on crash risk through the speed limits. The micro level design could determine traffic flows and directions, manage traffic speeds, separate vulnerable road users (pedestrians/cyclists) from moving motorised vehicles, produce or reduce the conflicts, and thus cause or decrease crashes. Built environment might also be a factor impact in people's choice of vehicles and thus affect the crash risk in different areas (explored further in the next section).

The interactions among many of these elements, mediators and crash risk have been clarified in past research studies, the following sections provide more detailed consideration of the overlap and implications for road safety of safe system and built environment theories and role of sociodemographic factors.

Built Environment, Road User and Crash Risk

Macro Level Built Environment Factors

Ewing and Cervero (2010) have conducted a meta-analysis of more than 50 built environment-travel studies to demonstrate the generalised effects of land planning and urban design on travel. They found that vehicle miles travelled is significantly negatively related to job accessibility by vehicles, distance to the central business district, intersection density and the proportion of four-way intersections; that, walking trips are strongly positively associated with intersection density and street connectivity; and that likelihood of transit trips are strongly associated with transit access. It is consistent that compact and diverse land use areas tend to encourage people to make more trips

by walking, public transit or cycling (Cao et al., 2009; Cervero & Murakami, 2010; Cervero & Radisch, 1996; Ewing, Schmid, killingsworth, Zlot, & Raudenbush, 2003; Saelens, Sallis, & Frank, 2003) while car use tends to be more frequent as areas with long blocks and sparse residents (Cervero & Radisch, 1996). Most past studies that have focused on the influence of built environment and urban forms on people's travel behaviour/physical activities have done so from a human health aspect (Berke, Koepsell, Moudon, Hoskins, & Larson, 2007; Forsyth, Hearst, Oakes, & Schmitz, 2008; Handy, Boarnet, Ewing, & Killingsworth, 2002). While referring to road safety, the effects of built environment factors are much more complicated. Hadayeghi et al. (2003) examined 463 traffic zones and found that the number of crashes increases as vehicle kilometres travel increases. However, when looking into pedestrian and cycling exposure, the concept of 'safety in numbers' was proposed and an inverse relationship was found between collisions rates and numbers of people walking or bicycling (Jacobsen, 2003). Ewing et al. (2003) also created a sprawl index (most compact counties with highest index values) for 448 counties and found that the sprawl index was significantly negatively correlated with the all-mode traffic fatality rate as well as pedestrian fatality rate after adjusting for pedestrian exposure. These studies indicated that compact urban form is also safer than low density areas for people, which could also be explained by the impact on driving behaviour, such as slower speeds and increased driver vigilance in higher density areas (Dumbaugh & Rae, 2009).

The layout of street network impacts the directness and quality of travel as well aspeople's modal choice and travel activities in the community (Frank & Engelke, 2001). The safety performance of traditional gridiron street patterns has been compared with the contemporary street network such as warped parallel and loops and lollipops (limited access design with cul-de-sac and loop streets for traffic calming) in the US studies (Rifaat, Tay, & De Barros, 2010; Rifaat, Tay, Perez, & Barros, 2009). It was found that loops-and-lollipops were associated with fewer crashes involving two vehicles and should be encouraged. Further, street density and connectivity have been shown to be critical factors that contribute to crash risk. It was found that fatal or severe crashes often occurred with very low intersection density and both street networks that combine high network density with low connectivity or low density with high connectivity are not safe designs (Marshall & Garrick, 2010, 2011). However, more safe system factors need to be considered while considering urban form design, such as speed limits, road features and so on.

Referring to the land use arrangement in urban community designing, different types of land use generate different numbers of trips and attract different groups of road users. Certain land uses will generate significant volumes of both motorised traffic and pedestrians such as schools, shopping centres, railway stations and large commercial strips, and therefore increase exposure opportunity for more traffic conflicts between the two. It was consistently found in previous studies that areas with a larger proportion of commercial and retail land use had higher crash risk (Kim, Brunner, & Yamashita, 2006; Priyantha Wedagama, Bird, & Metcalfe, 2006; Rifaat et al., 2009). Thus location planning for these land uses is critically important for safety, and retail and commercial uses should be oriented towards lower-speed thoroughfares and pedestrian-scaled configurations in higher-density communities are better choices than those located adjacent to arterials (Dumbaugh & Rae, 2009).

Another macro level aspect of land use is highly related to driving and pedestrian behaviour relates to alcohol. It has been found that alcohol availability also impacts on crash risk, such that a higher number of alcohol outlets is associated with an increase in the number of crashes and pedestrian collisions (Kuhlmann, Brett, Thomas, & Sain, 2009; LaScala et al., 2001; Rifaat et al., 2009; Schuurman, Cinnamon, Crooks, & Hameed, 2009). The relationship could be explained by increased impaired driving and drunken pedestrian behaviour (Lang, Tay, Watson, Edmonstion, & O'Connor, 2003; Vaez & Laflamme, 2005).

Micro Level Built Environment Factors

A safe road environment should be able to warn, inform, guide, control and forgive road users (Road and Traffic Authority, 2006). The impacts of micro built environment factors like road design and road side design on people's travel behaviour and safety behaviour could be explained by these five functions.

Stop/give way lines give the priority to main roads and indicate the orders of moving for vehicles from different directions. The pedestrian friendly design, such as footpaths, overpasses and underpasses, pedestrian fences and refuge islands provide a physical barrier between pedestrians and vehicles and thus reduce the pedestrian-vehicle collision risk (Retting, Ferguson, & McCartt, 2003). It has been found that the probability of such a collision is two times more likely at a site without a footpath than at a site with one (Ossenbruggen, Pendharkar, & Ivan, 2001). Raised medians and clear zones also physically separate vehicles on multi lanes and road side objects, reducing the relevant collison risk. Traffic calmings measures such as raised pedestrian crossings, roundabouts and speed humps force drivers to decrease their travel speeds and reduce relevent crash risks. Traffic lights eliminate conflicts among vehicles and control the traffic flow from different directions through the time intervals between colour changes of lights. Similarly, pedestrian lights separate the time of pedestrians moving from vehicles moving. Different types of signpostings remind the drivers of hazards on road in advance and provide other relevant advice.

Built environment could also impact and reduce risky road user behaviour on the road. Monotonous road environments can decrease drivers' vigilance and induce greater fatigue and therefore disruptions of monotony can have a positive effect and help alleviate driver fatigue (Thiffault & Bergeron, 2003). Landscape aesthetic design can improve drivers' perception, reduce fatigue and have a positive impact on roadside safety (Mok, Landphair, & Naderi, 2006). However, roadside advertising billboards can also be an outside-of-vehicle distraction to drivers and have been shown to have adverse on lateral control and driver attention (Young et al., 2009). Risky pedestrian behaviours include walking against traffic lights, not using crossings and walking on the street. Long block sizes with an absence of crossings can result in pedestrians directly crossing busy streets to save time and when safe pedestrian routes are arduous (e.g., pedestrian bridge or underpass), pedestrians will more often choose an easier if also more hazardous route (Khan, Jawaid, Chotani, & Luby, 1999). Provision of footpaths guides pedestrians to walk along roads in a safe area, while absence of footpaths can force pedestrians to share traffic lanes with vehicles and put them in danger.

Built Environment, Speed and Crash Risk

The faster a vehicle is moving prior to contact with another vehicle or a stationary object, the longer stopping distances are needed to avoid a collision and also the greater the exchange of energy resulting in more damage to a property or to a struck pedestrian. Thus increase in speed lead to increases in both crash and crash severity/injury risk (Anderson, McLean, Farmer, Lee, & Brooks, 1997). From a review of three related studies on collision speeds, Pasanen (1992) found that pedestrian fatality risk increases significantly when vehicle travel speeds increase, and the probability of pedestrian death reaches nearly 100% when speeds exceed 80km/h. Elvik and Christensen et al. (2004) conducted a meta-analysis on 98 "speed and accident" studies and found that there is a strong statistical association between speed and road safety. It was estimated that a 10% reduction in the mean speed of traffic would result in a 37.8% reduction in the number of fatalities. The report also pointed out that a reduction in speed will almost always improve road safety. Baruya (1998) conducted a comprehensive analysis of the speed distribution and crash frequency on a sample of UK and European roads and found that crash frequency changed when speeds changes, much more significantly in urban areas than in rural areas, which indicated that the impact of speed on road safety was influenced by the road environment and other factors. Kloeden

et al. has conducted a set of case control studies on the relationship between travel speed and the relative risk of involvement in a casualty crash in South Australia and found an exponential increase in risk of involvement in a casualty crash with increasing travelling speed. The risk was found double with each 5 km/h increase in travel speed in 60km/h speed limit zones in Adelaide metropolitan area. In rural area (80 km/h and above speed limit zones), the risk of involvement in a casualty crash was more than twice as great when travelling 10km/h above the average speed of non-crash involved and nearly six times as great when travelling 20km/h above that average speed (Kloeden, McLean, Moore, & Ponte, 1997; Kloeden, Ponte, & McLean, 2001).

Controlling speed is one of the most efficient methods to improve road safety (Archer, Fotheringham, Symmons, & Corben, 2009; Mohan, 2002; Rock, 1995). Variation in speed can be caused by variation in street widths, driveway and intersection densities, traffic and pedestrian volumes as well as the character of the surrounding environments (Gårder, 2004). From a macro level, travel speeds in dense urban areas are typically lower than in rural areas. There are more traffic and pedestrian flows, higher intersection densities, shorter road links and lower posted speed limits in urban areas, which lower the actual driving speeds. And in urban residential neighbourhoods, due to their functional design, higher speed traffic volumes are directed to the non-residential arterial streets, which relevantly decreases the speeds in residential area (Gattis & Watts, 1999). From a micro level, driving speed can be reduced through some road engineering approaches, and these engineering solutions could make the traffic environment and the actions of motor vehicles much safer (Leaf & Preusser, 1999). These engineering designs include road features (road width, deflection angle), traffic calming designs (speed humps, roundabouts and medians) and speed warning facilities (stop/give way signs, camera, flashing lights).

As drivers are likely to behave less aggressively and be more cautious on narrow streets, narrow roads can also lower traffic speeds. Gattis and Watts (1999) found that road width speeds on wider local street segments were statistically higher than speeds on narrow local streets. Fitzpatrick et al. (2001) also discovered a positive relationship between 85th percentile speed and wider average lane widths.

Traffic calming designs are physical structures that are self-enforcing of traffic speeds, and are cost efficient and often applied in high pedestrian exposure areas (Department of Transport, 2012). Tester and Rutherford (2004) conducted a matched case-control study among children being struck by automobiles. They found that speed humps were associated with lower odds of children being injured within their neighbourhood and made children's living environment safer. The presence of medians and roundabouts were also found to significantly reduce traffic speed (Antov, Abe, Surje, & Rõuk, 2009; Fitzpatrick et al., 2001). Speed warning facilities also play assistant roles of enforcement, such that signage could remind drivers of the speed limit, while cameras could detect speeding and reduce the high speed violation problem (Feng, 2001).

Built Environment, Vehicle and Crash risk

Vehicle ages, vehicle types and vehicle designs determine vehicles' safety performance. There is a strong association between vehicle age and risk of car crash injury. In a recent published by from MUARC (Newstead, Watson, & Cameron, 2012), crashworthiness ratings and aggressivity ratings by year of manufacture and vehicle models of Australian and New Zealand fleets were measured by the combination of injury risk (of injured drivers) and injury severity (of drivers involved in crashes). Crashworthiness ratings measure the relative safety of vehicles in preventing severe injury to their own drivers in crashes whilst aggressivity ratings measure the serious injury risk vehicles pose to drivers of other vehicles with which they collide. A number of commercial vans and utilities along with some small vehicle models and medium and compact 4WDs were identified as having relative poor crashworthiness and high aggressivity. Light cars tend to have low aggresivity but also poor crashworthiness while large and medium 4WDs tend to have converse performance. The study

also showed the relationships between vehicle crashworthiness and year of manufacture, a general and significant improvement in crashworthiness seen with increasing year of manufacture. Similarly, in a study in Auckland (Blows et al., 2003), it was found that the risk of being involved in an injury crash in vehicles manufactured before 1984 was approximately three times that in those manufactured after 1994. The decreased performance with age could be explained by safety defects such as tyre and brake failure. And another factor is the crashworthiness design, as older cars are also less likey than newer cars to have safety features such as airbags. Other vehicle designs to improve crashworthiness were also proposed by researchers, such as seats and head restraints design for reducing whiplash injury and relevant crash avoidance system (Anderson & Baldock, 2008). A aggresivity could also be reduced by vehicle designs, e.g. vehicle body stiffness and the geometric design of cars are risk factors determing the injury outcomes for a struck pedestrian (Corben, Senserrick, Cameron, & Rechnitzer, 2004). However, sociodemographic factors linked to vehicle age and risky bahavior can also be at play in the above studies. For example, young drivers and low socioceonomic drivers tend to drive older vehicles, and also have a higher crash risk (Senserrick et al., 2007; Williams, Leaf, Simons-Morton, & Hartos, 2006).

Several studies have investigated the impact of neighbourhood design on vehicle-type choice (Cao, Mokhtarian, & Handy, 2006; Potoglou, 2008). They divided vehicles into two types: light utilities and passenger cars and found that traditional neighbourhood designs (high accessbility and integration of land use) were correlated with the choice of passenger cars while surburban designs (large yards and off-street parking) were associated with the choice of light duty trucks. Though these studies focused on the aspect of vehicle emissions, the results provide some implications of the impact of built environment on road safety through vehicle choices. Reseachers consistently found that light utilities are less crashworthy and safe than passenger cars in single vehice crashes, such that drivers of these vehicles are more likely to be killed or seriously injured (Wang & Kockelman, 2005). Moreover, because of different vehicle mass, speeds and front vehicle design, some vehicle types maybe more dangerous for pedestrians. It was found that utilities and vans were associated with more pedestrian deaths and higher pedestrian injury severity and that larger cars were associated with more traumatic brain, thoratic and abdominal injuries at the lowest speeds compared to conventional passenger cars. (Ballesteros, Dischinger, & Langenberg, 2004).

Besides, there might be some other built environment factors that impact on the choice of vehicles; for example, people in higher density areas might give up vehicles altogether due to road congestion, poor road conditions and if well-serviced by public transport facilities.

Sociodemographics and Crash Risk

Sociodemographics have usually been used as control variables in past studies, and have been shown to be significantly associated with travel behaviour, illustrating road users' preference and distributional effects (Cao et al., 2009), thus influencing road users' exposure to crash risk. As individuals' travel behaviour is influenced by the choice set of travel modes available to them, the number of vehicles has a positive correlation with vehicle trip frequency and a negative association with transit trip frequency (Cao et al., 2009). A higher level of walking was found to be associated with a lower level of socioeconomic status (Carlin et al., 1997), which wasexplained by decreased car ownership level and higher residential density in more deprived areas. Education was found to be positively associated with walking/biking trip frequency, as recreational physical activity is positively correlated with higher education (Cao et al., 2009). In the road safety studies, an inverse association has been found between socioeconomic condition and injury rates (Abdalla, Raeside, Barker, & McGuigan, 1997; Graham, Glaister, & Anderson, 2005). Some potential reasons proposed for this include that as people in socioeconomically deprived areas have poorer access to vehicles and are more likely to be pedestrians, they cross more roads than people in higher socioeconomic areas and are thus exposed to greater risk (Roberts, Norton, & Taua, 1996; Towner, Jarvis, Walsh, & Aynsley-Green, 1994). Sociodemographics also relate to crashes through their

impact on driving behaviour. For example, young drivers and male drivers are more likely to engage in risky driving and have higher crash and violation rates than their older driver and female counterparts (Ivers et al., 2009; Turner & McClure, 2003)

Access to a car is influenced by income (Abdalla et al., 1997) and people's choice of vehicles is also closely correlated to their economic status. It was found that individuals with higher household incomes have a greater tendency to drive 4WDs than passenger cars and utilities and well-educated people have less utilities (Cao et al., 2006; Potoglou, 2008). It was assumed that lower socio economic rural and romote areas have worse roads and the residents usually have older cars, possbily leading to poorer road crash outcomes. Wealthier persons drive newer and safer cars, often upon better roads (Tziotis, Roper, Edmonstion, & Sheehan, 2006).

Conclusions and implications

We have proposed combining built environment and safe system models with explicit inclusion of sociodemographic factors into a transtheoretical model of the built environment and road safety in order to more holistically consider factors impacting on crash frequency and severity. To ascertain whether changing or accounting for built environment factors is an effective way to improve road safety performance, it is important to understand potential mechanisms of impact of the built environment on crash risk from the macro level to micro level taking into account safe vehicles, speed and road user components of the safe system. It is also important to consider interconnectedness of built environment and sociodemographic factors and their associations with other safe system elements and crash risk, particularly as these might change over time, such as when poorer industrial areas become gentrified. Understanding the direct and indirect interactions among the system components could provide the theoretical basis and guiding for future strategic interventions. It is important and significant to study the issues and conduct more empirical research to link crash risk with built environment factors. More work is needed in the future to gather evidence of the multiple relationships based on a systematic approach and provide appropriate recommendations for interventions on planning and designing.

References

Abdalla, I. M., Raeside, R., Barker, D., & McGuigan, D. R. D. (1997). An investigation into the relationships between area social characteristics and road accident casualties. *Accident Analysis & Prevention, 29*(5), 583-593.

Anderson, R. W. G., & Baldock, M. R. J. (2008). Vehicle improvements to reduce the number and severity of rear end crashes (CASR052): Centre for Automotive Safety Research, The University of Adelaide.

Anderson, R. W. G., McLean, A. J., Farmer, M. J. B., Lee, B. H., & Brooks, C. G. (1997). Vehicle travel speeds and the incidence of fatal pedestrian crashes. *Accident Analysis & Prevention, 29*(5), 667-674.

Antov, D., Abe, K., Surje, P., & Rõuk, H. (2009). Speed reduction effects of urban roundabouts. *The Baltic Journal of Road and Bridge Engineering, 4*(1), 22-26.

Archer, J., Fotheringham, N., Symmons, M., & Corben, B. (2009). The impact of lowered speed limits in urban and metropolitan areas: Monash University Accident Research Centre.

Australian Transport Council. (2011). National Road Safety Strategy 2011-2020: http://www.atcouncil.gov.au/documents/files/NRSS_2011_2020_15Aug11.pdf accessed September 2012.

Ballesteros, M. F., Dischinger, P. C., & Langenberg, P. (2004). Pedestrian injuries and vehicle type in Maryland, 1995–1999. *Accident Analysis & Prevention, 36*(1), 73-81.

Baruya, A. (1998). *Speed-accident relationships on European roads.* Paper presented at the 9th International Conference on Road Safety in Europe.

Berke, E. M., Koepsell, T. D., Moudon, A. V., Hoskins, R. E., & Larson, E. B. (2007). Association of the Built Environment With Physical Activity and Obesity in Older Persons. *American Journal of Public Health, 97*(3), 486-492.

BITRE. (2010). Information Sheet: Effectiveness of measures to reduce road fatality rates: Bureau of Infrastructure, Transport and Regional Economics, Department of Infrastructure and Transport, http://www.bitre.gov.au/publications/2010/files/is_039.pdf, accessed February 2013.

Blows, S., Ivers, R. Q., Woodward, M., Connor, J., Ameratunga, S., & Norton, R. (2003). Vehicle year and the risk of car crash injury. *Injury Prevention, 9*(4), 353-356.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2006). Neighborhood design and vehicle type choice: Evidence from Northern California. *Transportation Research Part D: Transport and Environment, 11*(2), 133-145.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2009). The relationship between the built environment and nonwork travel: A case study of Northern California. *Transportation Research Part A: Policy and Practice, 43*(5), 548-559.

Carlin, J. B., Stevenson, M. R., Roberts, I., Bennett, C. M., Gelman, A., & Nolan, T. (1997). Walking to school and traffic exposure in Australian children. *Australian and New Zealand journal of public health, 21*(3), 286-292.

Cervero, R., & Murakami, J. (2010). Effects of built environments on vehicle miles traveled: evidence from 370 US urbanized areas. *Environment and Planning A, 42*(2), 400-418.

Cervero, R., & Radisch, C. (1996). Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy, 3*(3), 127-141.

Cho, G., Rodríguez, D. A., & Khattak, A. J. (2009). The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety. *Accident Analysis & Prevention, 41*(4), 692-702.

Clifton, K. J., Burnier, C. V., & Akar, G. (2009). Severity of injury resulting from pedestrian-vehicle crashes: What can we learn from examining the built environment? *Transportation Research Part D: Transport and Environment, 14*(6), 425-436.

Clifton, K. J., & Kreamer-Fults, K. (2007). An examination of the environmental attributes associated with pedestrian-vehicular crashes near public schools. *Accident Analysis & Prevention, 39*(4), 708-715.

Corben, B., Senserrick, T., Cameron, M., & Rechnitzer, G. (2004). Development of the Visionary Research Model:Application to the Car/Pedestrian Conflict: Monash University Accident Research Centre.

Department of Transport. (2012). Planning and Designing for Pedestrians: guidelines: Department of Transport, Western Australia, http://www.transport.wa.gov.au/mediaFiles/AT_WALK_P_plan_design_pedestrians_guidelines.pdf accessed July 2013, .

Dumbaugh, E., & Rae, R. (2009). Safe Urban Form: Revisiting the Relationship Between Community Design and Traffic Safety. [Article]. *Journal of the American Planning Association, 75*(3), 309-329.

Elvik, R., Christensen, P., & Amundsen, A. (2004). Speed and road accidents. *An evaluation of the Power Model. TØI report, 740*, 2004.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal of the American Planning Association, 76*(3), 265-294.

Ewing, R., & Dumbaugh, E. (2009). The built environment and traffic safety. *Journal of Planning Literature, 23*(4), 347.

Ewing, R., Schieber, R. A., & Zegeer, C. V. (2003). Urban sprawl as a risk factor in motor vehicle occupant and pedestrian fatalities. *American Journal of Public Health, 93*(9), 1541.

Ewing, R., Schmid, T., killingsworth, R. E., Zlot, A., & Raudenbush, S. (2003). Relationship Between Urban Sprawl and Physical Activity, Obesity, and Morbidity. *American Journal of Health Promotion, 18*(1), 47-57.

Feng, C. (2001). Synthesis of studies on speed and safety. *Transportation Research Record: Journal of the Transportation Research Board, 1779*, 86-92.

Fitzpatrick, K., Carlson, P., Brewer, M., & Wooldridge, M. (2001). Design factors that affect driver speed on suburban streets. *Transportation Research Record: Journal of the Transportation Research Board, 1751*(-1), 18-25.

Fleury, D., Peytavin, J. F., Alam, T., & Brenac, T. (2010). Excess accident risk among residents of deprived areas. *Accident Analysis & Prevention, 42*(6), 1653-1660.

Forsyth, A., Hearst, M., Oakes, J. M., & Schmitz, K. H. (2008). Design and destinations: factors influencing walking and total physical activity. *Urban Studies, 45*(9), 1973.

Frank, L. D., & Engelke, P. O. (2001). The built environment and human activity patterns: exploring the impacts of urban form on public health. *Journal of Planning Literature, 16*(2), 202.

Frank, L. D., & Pivo, G. (1994). Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking. *Transportation Research Record*, 44-44.

Gårder, P. E. (2004). The impact of speed and other variables on pedestrian safety in Maine. *Accident Analysis & Prevention, 36*(4), 533-542.

Gattis, J., & Watts, A. (1999). Urban street speed related to width and functional class. *Journal of Transportation Engineering, 125*, 193.

Graham, D., Glaister, S., & Anderson, R. (2005). The effects of area deprivation on the incidence of child and adult pedestrian casualties in England. *Accident Analysis & Prevention, 37*(1), 125-135.

Hadayeghi, A., Shalaby, A. S., & Persaud, B. N. (2003). Macrolevel accident prediction models for evaluating safety of urban transportation systems. *Transportation Research Record: Journal of the Transportation Research Board, 1840*(-1), 87-95.

Hadayeghi, A., Shalaby, A. S., & Persaud, B. N. (2007). Safety prediction models: Proactive tool for safety evaluation in urban transportation planning applications. *Transportation Research Record: Journal of the Transportation Research Board, 2019*(-1), 225-236.

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). How the built environment affects physical activity. *American journal of preventive medicine, 23*(2S), 64-73.

Ivers, R., Senserrick, T., Boufous, S., Stevenson, M., Chen, H.-Y., Woodward, M., & Norton, R. (2009). Novice Drivers' Risky Driving Behavior, Risk Perception, and Crash Risk: Findings From the DRIVE Study. *American Journal of Public Health, 99*(9), 1638-1644.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention, 9*(3), 205-209.

Khan, F. M., Jawaid, M., Chotani, H., & Luby, S. (1999). Pedestrian environment and behavior in Karachi, Pakistan. *Accident Analysis & Prevention, 31*(4), 335-339.

Kim, K., Brunner, I. M., & Yamashita, E. Y. (2006). Influence of land use, population, employment, and economic activity on accidents. *Transportation Research Record: Journal of the Transportation Research Board, 1953*(-1), 56-64.

Kloeden, C. N., McLean, A., Moore, V., & Ponte, G. (1997). Travelling Speed and the Risk of Crash Involvement (CR 172) *Volume 1: Findings*: NHMRC Road Accident Research Unit, University of Adelaide.

Kloeden, C. N., Ponte, G., & McLean, A. (2001). Travelling Speed and The Risk of Crash Involvement on Rural Roads (CR204): Road Accident Research Unit, Adelaide University.

Kuhlmann, A. K. S., Brett, J., Thomas, D., & Sain, S. R. (2009). Environmental Characteristics Associated With Pedestrian-Motor Vehicle Collisions in Denver, Colorado. [Article]. *American Journal of Public Health, 99*(9), 1632-1637.

Lang, C. P., Tay, R., Watson, B., Edmonstion, C., & O'Connor, N. E. (2003). *Drinking walking: An examination of the related behaviour and attitudes of young people.* Paper presented at the 2003 Road Safety Research, Policing and Education Conference-From Research to Action.

LaScala, E. A., Gerber, D., & Gruenewald, P. J. (2000). Demographic and environmental correlates of pedestrian injury collisions: a spatial analysis. *Accident Analysis & Prevention, 32*(5), 651-658.

LaScala, E. A., Johnson, F. W., & Gruenewald, P. J. (2001). Neighborhood Characteristics of Alcohol-Related Pedestrian Injury Collisions: A Geostatistical Analysis. *Prevention Science, 2*(2), 123-134.

Leaf, W., & Preusser, D. F. (1999). *Literature review on vehicle travel speeds and pedestrian injuries*: US Dept. of Transportation, National Highway Traffic Safety Administration.

Lightstone, A., Dhillon, P., Peek-Asa, C., & Kraus, J. (2001). A geographic analysis of motor vehicle collisions with child pedestrians in Long Beach, California: comparing intersection and midblock incident locations. *Injury Prevention, 7*(2), 155.

Loukaitou-Sideris, A., Liggett, R., & Sung, H. G. (2007). Death on the Crosswalk. *Journal of Planning Education and Research, 26*(3), 338.

Lovegrove, G. R., & Sayed, T. (2006). Macro-level collision prediction models for evaluating neighbourhood traffic safety. *Canadian Journal of Civil Engineering, 33*(5), 609-621.

Marshall, W. E., & Garrick, N. W. (2010). Considering the role of the street network in road safety: a case study of 24 California cities. *Urban Design International Journal 15*(3), 133-147.

Marshall, W. E., & Garrick, N. W. (2011). Does street network design affect traffic safety? *Accident Analysis & Prevention, 43*(3), 769-781.

Miranda-Moreno, L. F., Morency, P., & El-Geneidy, A. M. (2011). The link between built environment, pedestrian activity and pedestrian-vehicle collision occurrence at signalized intersections. *Accident Analysis & Prevention*.

Mohan, D. (2002). Road safety in less-motorized environments: future concerns. *International Journal of Epidemiology, 31*(3), 527-532.

Mok, J. H., Landphair, H. C., & Naderi, J. R. (2006). Landscape improvement impacts on roadside safety in Texas. *Landscape and Urban Planning, 78*(3), 263-274.

Newstead, S. V., Watson, L. M., & Cameron, M. (2012). Vehicle safety ratings estimated from police reported crash data: 2012 update Australian and New Zealand crashes during 1987-2010: Monash University Accident Research Centre, Report No. 313.

Ossenbruggen, P. J., Pendharkar, J., & Ivan, J. (2001). Roadway safety in rural and small urbanized areas. *Accident Analysis & Prevention, 33*(4), 485-498.

Pasanen, E. (1992). Driving speeds and pedestrian safety: a mathematical model.

Potoglou, D. (2008). Vehicle-type choice and neighbourhood characteristics: An empirical study of Hamilton, Canada. *Transportation Research Part D: Transport and Environment, 13*(3), 177-186.

Priyantha Wedagama, D. M., Bird, R. N., & Metcalfe, A. V. (2006). The influence of urban land-use on non-motorised transport casualties. *Accident Analysis & Prevention, 38*(6), 1049-1057.

Retting, R. A., Ferguson, S. A., & McCartt, A. T. (2003). A review of evidence-based traffic engineering measures designed to reduce pedestrian–motor vehicle crashes. *American Journal of Public Health, 93*(9), 1456.

Rifaat, S., Tay, R., & De Barros, A. (2010). Effect of Street Pattern on Road Safety. *Transportation Research Record: Journal of the Transportation Research Board, 2147*(-1), 58-65.

Rifaat, S., Tay, R., Perez, A., & Barros, A. D. (2009). Effects of neighborhood street patterns on traffic collision frequency. *Journal of Transportation Safety & Security, 1*, 241-253.

Road and Traffic Authority. (2006). Road environment safety: a practitioner's reference guide to safer roads: http://www.rta.nsw.gov.au/roadsafety/downloads/road_environment_safety_practitionersguide.pdf Accessed Dec 2012.

Roberts, I., Norton, R., & Taua, B. (1996). Child pedestrian injury rates: the importance of" exposure to risk" relating to socioeconomic and ethnic differences, in Auckland, New Zealand. *Journal of epidemiology and community health, 50*(2), 162.

Rock, S. M. (1995). Impact of the 65 mph speed limit on accidents, deaths, and injuries in illinois. *Accident Analysis & Prevention, 27*(2), 207-214.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine, 25*(2), 80-91.

Schuurman, N., Cinnamon, J., Crooks, V. A., & Hameed, S. M. (2009). Pedestrian injury and the built environment: an environmental scan of hotspots. *BMC public health, 9*(1), 233.

Senserrick, T. M., Kinsman, S. B., Garcia-Espana, F., Hafner, L., Ginsburg, K. R., & Winston, F. K. (2007). Does having their own car increase teen drivers' risk? *Journal of Adolescent Health, 40*(2, Supplement), S53.

Shope, J. T. (2006). Influences on youthful driving behavior and their potential for guiding interventions to reduce crashes. *Injury Prevention, 12*(suppl 1), i9-i14.

Tester, J. M., Rutherford, G. W., Wald, Z., & Rutherford, M. W. (2004). A matched case-control study evaluating the effectiveness of speed humps in reducing child pedestrian injuries. *American Journal of Public Health, 94*(4), 646.

Thiffault, P., & Bergeron, J. (2003). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis & Prevention, 35*(3), 381-391.

Towner, E., Jarvis, S., Walsh, S., & Aynsley-Green, A. (1994). Measuring exposure to injury risk in schoolchildren aged 11-14. *BMJ, 308*(6926), 449.

Transport Research Centre. (2008). *Towards zero: ambitious road safety targets and the safe system approach*: International Transport Forum, OECD Publishing.

Turner, C., & McClure, R. (2003). Age and gender differences in risk-taking behaviour as an explanation for high incidence of motor vehicle crashes as a driver in young males. [Article]. *Injury Control & Safety Promotion, 10*(3), 123.

Tziotis, M., Roper, P., Edmonstion, C., & Sheehan, M. (2006). *Road safety in rural and remote areas of Australia*. Paper presented at the 22nd ARRB Conference-Research into Practice, Canberra Australia.

Vaez, M., & Laflamme, L. (2005). Impaired driving and motor vehicle crashes among Swedish youth: An investigation into drivers' sociodemographic characteristics. *Accident Analysis & Prevention, 37*(4), 605-611.

Wang, X., & Kockelman, K. M. (2005). Use of heteroscedastic ordered logit model to study severity of occupant injury: distinguishing effects of vehicle weight and type. *Transportation Research Record: Journal of the Transportation Research Board, 1908*(-1), 195-204.

Wier, M., Weintraub, J., Humphreys, E. H., Seto, E., & Bhatia, R. (2009). An area-level model of vehicle-pedestrian injury collisions with implications for land use and transportation planning. *Accident Analysis & Prevention, 41*(1), 137-145.

Williams, A. F., Leaf, W. A., Simons-Morton, B. G., & Hartos, J. L. (2006). Vehicles Driven by Teenagers in Their First Year of Licensure. *Traffic Injury Prevention, 7*(1), 23-30. doi: 10.1080/15389580500412044

Young, M. S., Mahfoud, J. M., Stanton, N. A., Salmon, P. M., Jenkins, D. P., & Walker, G. H. (2009). Conflicts of interest: The implications of roadside advertising for driver attention. *Transportation Research Part F: Traffic Psychology and Behaviour, 12*(5), 381-388.