27th Australasian Transport Research Forum, Adelaide, 29 September – 1 October 2004

Paper title: **Urban form impacts on travelling choices: a study of four suburbs in metropolitan Adelaide, Australia**

Author(s) name(s): Ali Soltani and Andrew Allan

Organisation(s): University of South Australia

Contact details:
Postal address: University of South Australia, City East Campus, North Terrace, GPO Box 2471, Adelaide, SA 5000
Telephone: +61 08 830-22043, +61 08 830 21476
Facsimile: +61 08 830-22252
email: Ali.soltani@postgrads.unisa.edu.au Andrew.allan@unisa.edu.au

Abstract (200 words):
Creating better designed suburban communities with less car-dependency is one of the main challenges among Australian planners and urban designers, particularly in light of the fact that Australian cities are second only to US cities in their degree of automobile dependence. Metropolitan Adelaide is faced to the dominance of low-density suburbs with a large road supply, which facilitates a car-dependence lifestyle. This paper presents the results from a study of travel characteristics of residents of four suburbs: *Norwood, Unley, Para Hills and Golden Grove* in metropolitan Adelaide. The key research argument presented is how physical planning and policies could be used to affect the extent and modal choice of travelling. It is assumed that the residences of traditionally designed suburbs with mixed land uses, higher density, and more pedestrian oriented layouts could be expected to choose the sustainable patterns of travelling such as walking and bicycling. Walking and cycling clearly decrease as worker live farther from the CBD of Adelaide. In fact, decentralization impacts significantly the modal split of workers. The research findings have policy implications for the suburban development of Adelaide. The development patterns that can contribute to induce sustainable modes of transport are favourable when evaluated against a broader set of criteria of an environmentally sustainable urban development.

Introduction

Adelaide is a city with low density and a large road supply, which results in a lot of vehicle kilometers of travel and a car-dependant suburban lifestyle. According to Australian Bureau Statistics (ABS), only 4.9% of employed people in Adelaide chose walking or cycling for journey to work in 1990 which gradually declined to 3 % by the 2002 census. Therefore, integrating transport and land use planning have been identified as a key objective in the South Australian Planning Strategy by the state government, to be achieved by reducing the need for motorised travel and promoting walking and cycling (Government of South Australia 2003).

This paper was based on a comparison of four Adelaide suburbs using two data sets including metropolitan Adelaide household travel survey (MAHTS99) and Australian Bureau of Statistics (ABS) census data. A descriptive approach has been applied to finding the travel pattern differences and their possible causes. Then using a multiple regression modelling, the effects of urban form variables on commuting modal choice was analysed, with controls for socio-demographic economic factors.

Background studies

An increasing amount of literature continues to highlight the links between urban form and travel behaviour, especially in North American cities. It is generally believed that the urban form and its urban design quality do affect significantly the travel behaviours of residents, although the extent and direction of the relationship remains uncertain (Cervero and Kockelman 1997; Handy 1996; Crane and Crepeau 1998).

Some scholars claim that there is a strong relationship between urban form and travelling parameters such as choice mode, travel distance, trip generation, and car ownership. McNally and Ryan (1993) used a simulation approach, which determined that the grid-layout of street network reduces vehicle mile travelled (VMT), travel distance and average travel speeds, assuming that trip frequencies remained fix. Holtzclaw (1990) compared five neighbourhoods with different characteristics to explore relationship between density and vehicle miles travelled (VMT). He expanded (1994) on his work considering VMT and automobiles per household as dependent variables to get their non-linear relationship with density and transit accessibility. The Frank and Pivo (1994) study using socio-economic characteristics as control variables indicated that there was a positive significant relationship between walking and public transport with urban form variables. Additionally, the land use mix at trip origins was found to be related to modal choice for work and shopping trips. And the effect of density on modal choice for shopping trips was more significant than for work trips. Finally, they concluded that the relationship between travel choice mode and land use mix should be incorporated in urban policy making.

The amount and direction of impacts of urban form on travel patterns may vary by the research approach and methodology. All past approaches are *ad hoc* constructions based on the data at hand. Using aggregated data enables the exploration of the effects of the regional context in explaining travel patterns. Handy (1992) analysed the link between urban form and travel behaviour in four neighbourhoods with similar socio-economic characteristics in the San Francisco Bay Area. She also applied a multivariate analysis of variance technique to test between-versus within-group variation for both household types and the neighbourhood. According to her findings, the variation between neighbourhoods was significantly greater than the variation within neighbourhoods. Also, the regional context was found to play a considerable role, sometimes overriding the effect of urban form in the neighbourhood especially for trips through region. Schimek (1996) used multivariate regression analysis of the 1990 American Nationwide Personal Transportation Survey (NPTS) data which analysed vehicle travel, that included vehicle ownership as an intermediate factor, and which treated a household's pick of neighbourhood density and the amount of travel as a simultaneous relationship. He concluded that with all else being equal, households in denser areas travelled less in their own cars. Also, local density is a less significant factor for households' automobile trips compared to overall density as a determinant for total vehicle travel. He explained that a 10% increase in local density led to only a 0.7% reduction in households' car trips. In contrast, a 10% increase in household income led to a 3% increase in automobile travel. The study also found differences in households' travel by public transport to be associated with lower rates of vehicle ownership. This means that some households locate close to transit routes to minimise their car ownership needs. In addition, *Discrete Choice models* have been notified especially in the recent decade in respect to exploring the interaction between city form and modal split. These models predict the probability of an individual or a household as a decision-maker choosing a particular alternative based on the utility of that alternative relative to others. This method contains a stronger theoretical basis than the previous approaches and comes closer to directly testing casual relationships. Cervero (2002) applied a normative model that weighted the three core dimensions of built environment-diversity, density, and design- in addition to factors related to the generalized cost and socio-economic attributes of trip makers. His study illustrated that intensity and mixture of land use significantly influenced decisions to choose a mode, while the effect of urban design tended to be more modest.

On the other hand, a few studies show that individual attitudes and lifestyle variables have much more significant effects on travel behaviour than urban form variables (Bagley & Mokhtarian 2001, Simma and Axhausen 2003). Kitamura et al (1997) found that individual attitudes were more significant predictors of travel behaviour than either urban form or other socio demographic factors. They did an empirical test on travel demand using regression models and factor analysis to investigate the impact of land use and attitudinal orientation. Respondents from five neighbourhoods in California region were surveyed on some aspects of urban life. The case areas were different on several dimensions including density, transit access, and sidewalk and bike trail availability. The results showed that urban and attitudinal variables contributed significantly to model explanatory power. Also personal attitudes are more strongly and directly associated with travel behaviour and demand than are urban form. The similar study was done by Prevedours (1992) based on the data set formed from a household survey of suburban residents in Chicago who had moved between 1987 and 1989. An ANOVA test with the dependent variable being location decision, and five explanatory variables including income and number of household workers, was conducted in the study. Different travel related models including non-work trip distances done by car as dependent variable, were estimated using the personality factors as explanatory variables. The analysis resulted that the personality of respondents was significantly associated with type of suburb chosen for the residence location of their household. Moriarty and Beed (1992) found that the expected relationship between density and travel volume was found to apply in Australian cities in 1986, where higher-density cities had much more travel than the smaller, less dense cities. They mentioned also that despite the shortening of the separation between residential areas and employment, activity centres etc, per capita travel increased greatly. They concluded that travel convenience was found to provide a better fit to the data than did land use differences.

Some have believed that urban form variables, especially density plays a role of proxy for lots of missed factors. Garnahan et al (1974) described population density as a *"composite of several different measures on land use"* including population per room, dwelling size, number of dwelling per structure, number of structures per residential area, and percentage of area used for residential land. Two different areas with the same residential density may have completely different household types or other detailed measures. The study of Brinton &Brindle (1999) concluded that accessibility to activities and income was the significant factors in car use, while other urban form factors have relatively little effect on the amount of car travel. When a broader range of factors is considered the relationship between density and car using becomes weaker. They criticized the use of urban planning for addressing car dependency problems because it is not enough strong and quick. In fact, density was a proxy for factors initially not including in the analysis and was not significant with these variables included. The other Australian study showed that density has little effect on bus service boarding or public transportation. Density has a significant effect on the proportion of journey to work travel. But density becomes significant after excluding socio-demographic variables. The correlation between density and social variables show that density is a proxy of other socio-eco variables (Black and Suthanaya 2002). The proxy role of density for other factors including socio-demographic factors shows that it is not possible to dismiss density as a factor in mode use.

It concluded from the previous studies that first; the urban form and urban design do affect significantly the travel behaviours of residents, although the extent and direction of the relationship remains uncertain. Secondly, the conditions such as the database, research approach or method, definition of case studies or variables limit the research outcome. Thirdly, because of interface many non urban form factors including personal attitudes; lifestyle; social or cultural factors the results are going to be more diversified in different geographical areas. Finally, such study should be accompanied with necessary cautious, especially when it is applied to make a policy link between urban form and travel behaviour. In fact the policies that extract from the research for any planning application should be strongly supported with the relevant empirical study to be more reliable.

Study data and methodology

A database was created using different data sets including the Metropolitan Adelaide Household Travel Survey (MAHTS99), Australian Bureau of Statistics (ABS) Census 2001, and Journey to Work (JTW) 2001 data for both urban form and socio-demographic economic characteristics. For the purpose of undertaking analysis in a GIS environment, digital maps from Digital Cadastral Data Base (DCDB) were imported. In the database, every tract or census collection district (CCD) was considered as a data record, which totalled 47 tracts for four neighbourhoods. The analysis was done on a CCD level because choosing a CCD as a unit of analysis helps to reduce the risk of aggregation bias.

Two approaches were applied: *Descriptive approach* for exploring the relationship between urban form figures and travel characteristics with emphasis on non-work trips, and *Step-wise Multiple Regressions* for analysis of the effects of urban form variables on modal split of commuting trips when socio-demographic factors are controlled.

Four case studies

From the findings of previous research studies, urban form features including density; land use diversity and urban design impact travelling choices. In fact, it is assumed that the residences of mixed land use with higher density, and pedestrian oriented design are expected to contribute to lower rates of private car use for both commuting and non-work trips. For the purpose of testing this hypothesis, four residential suburbs were purposefully selected. The two mixed land use suburbs including *Unley* and *Norwood* were selected for the study, because they had traditional suburban design characteristics while two other suburbs; *Para Hills* and *Golden Grove* developed in new era and exhibit relatively contemporary suburban design characteristics. Unley and Norwood are based on grid street patterns that are more pedestrian oriented environments with higher density and accessibility. Figure 1 shows the locations of the four case studies within metropolitan Adelaide.

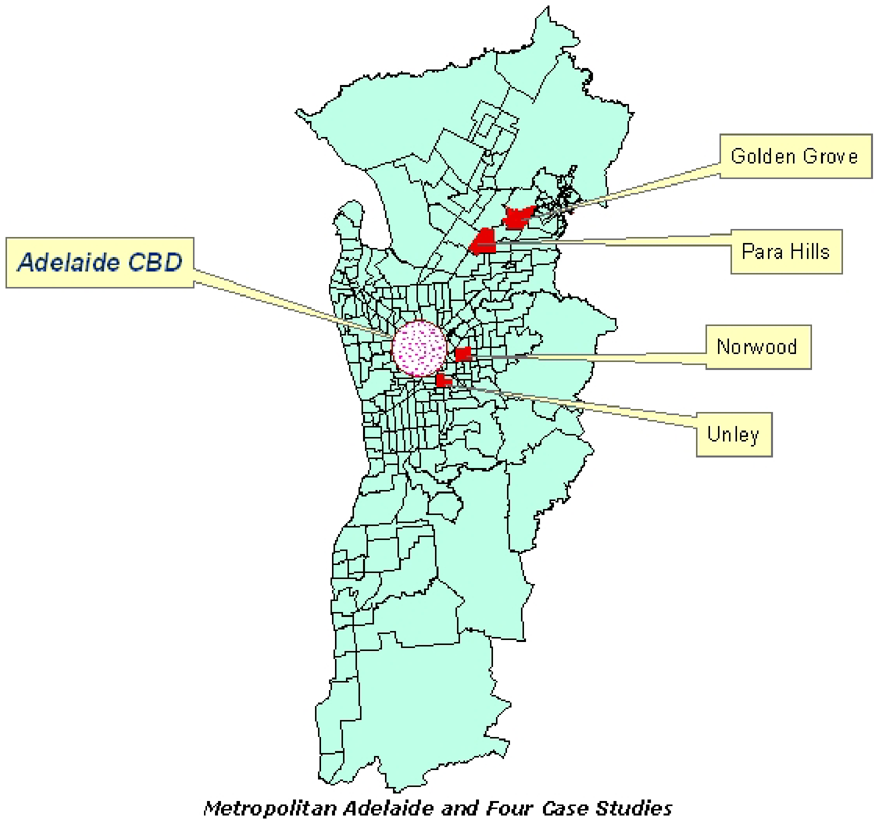

Figure 1 Metropolitan Adelaide and Four case studies.

Unley is a suburb dating back to the 1900s on the south side of Adelaide with the street pattern of a rectangular design. And it is the one of the closest suburbs to Adelaide CBD being approximately 2 km from the CBD. The study area is around 145 ha, and is supported with a busy shopping street called *Unley Road* with diverse business units. It also has a few multi-family apartments, a few town houses and small parks and offices as well.

Norwood is another traditional neighbourhood located approximately 3 km east of the Adelaide CBD. The study area covers about 222 hectares. The relatively high mix of land use can be seen along *Parade Norwood*. A variety of retailing, offices, local parks and playgrounds are established within this neighbourhood. The local street network follows a grid pattern with a few dead-end streets. The street space appears to be pedestrian oriented with a considerable proportion of paved sidewalks, cycle lanes, and on-street parking. A significant proportion of this area has two or three storey apartment buildings. The street design pattern and land use mix of Unley and Norwood is illustrated in Figure 2.

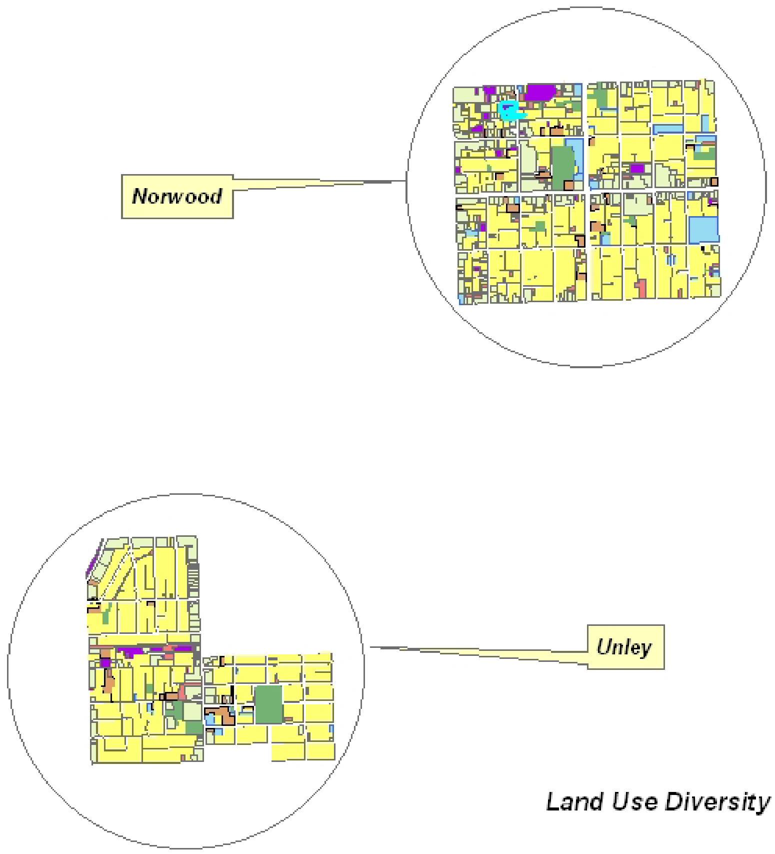

Figure 2 the street pattern and land use mix of Unley and Norwood.

Para Hills is a newly developed suburb on the north east of metropolitan Adelaide 14km from Adelaide. The study area is about 531 hectares. The street design of this suburb is curvilinear pattern with a large number of curved streets and cul-de-sacs. The local facilities are more dispersed than those in Unley and Norwood. Two major arterial roads: *McIntyre Road* and *Main North Road* bond the area, although the core area is serviced by local narrow streets. The design of the streets, street furniture and landscaping may encourage more walking/cycling activities but steep terrain acts as an obstacle. The forms of buildings are relatively similar and are on large allotments.

Golden Grove is the fourth case located 18 km north east of the Adelaide CBD. The study area is around 508 hectares. The street layout follows a curvilinear pattern with a few cul-de-sacs. The *Delfin Land Management Corporation* and the South Australian State Government developed Golden Grove jointly in the mid 1980s as a planned suburb with the purpose of establishing a liveable residential community. Figure 3 shows the street pattern and land use diversity of the newly developed suburbs of Para Hills and Golden Grove. There are obvious physical differences between the four suburbs' urban form as summarized in Table1. In the two traditional suburbs; Norwood and Unley, mixed land use in them promotes local trips due to the presences of commercial establishments nearby decreasing the need to drive. Commercial streets such as *Norwood Parade* and *Unley Road* provide goods and services used on a routine basis, including grocery stores, restaurants, cafes and pharmacies. The Land Use Mix (LUM) index shows this difference (the LUM index is calculated using the Entropy formula given by Cervero and Kockelman (1997).

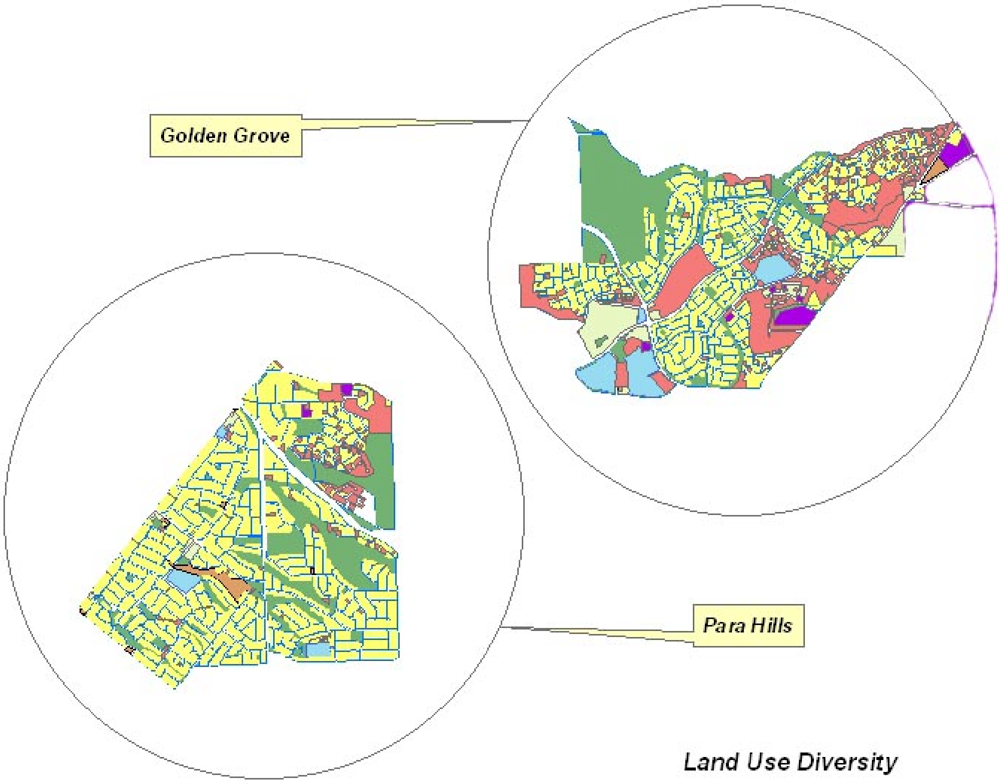

Figure 3 The street pattern and land use mix of Para Hills and Golden Grove.

More details are provided in Table 2. The other physical difference between traditional and newly developed suburbs is in having different levels of street network permeability. This factor facilitates easier walking or cycling activity within a suburb. The Mean Block Area (MBA) was considered as an index of permeability. The MBA of Golden Grove (a MBA of 71833 m^2) is around four times that for Unley (a MBA of 18206 m^2) or Norwood (a MBA of 18652 m^2). The MBA of Para Hills (a MBA of 52697 m^2) is about 3 times more that of Unley and Norwood.

Table 1: Some Physical Specifications of four case studies.

	LUM	MBA (m^2)	Employment density (employee/ha)	Residential gross density (People/ ha)	Distance from CBD(km)	Street Pattern
Golden Grove	**0.505**	**71833.29**	**1.208**	**30.313**	**18.513**	**Curvilinear**
Para Hills	**0.477**	**52697.53**	**2.118**	**30.189**	**14.335**	**Curvilinear**
Unley	**0.72**	**18205.85**	**22.537**	**43.707**	**2.370**	**Grid**
Norwood	**0.731**	**18651.58**	**28.42**	**53.814**	**3.049**	**Grid**

Table 2 variable description

Variable	Description
Residential gross density	population per residential area (hectare)
Employment density	employee per developed area(hectare)
Land use mix (LUM)	mean entropy for land use categories within a tract(CCD) LUM for each CCD, computed as: $\{\sum_k [\sum_j P_{jk} Ln(p_{jk})]/Ln(j)\}/k$, where: P_{jk} = proportion of land use category j within a CCD; j = number of land use categories; and k = number of actively developed hectares in CCD. The mean LUM ranges between 0(where in all land uses area of a single type) and 1(where in developed area is evenly distributed among all land use categories)
Proportion of cul-de-sac	proportion of cul-de-sac or dead end streets within a tract
Distance from CBD	Average straight distance between centroids of a tract and Adelaide's CBD (kilometre)
Median block area (MBA)	average area of blocks within a tract MBA for each CCD, computed as: $\{\sum B_i\} / n$, where: i= number of each block; and n= total number of blocks within a CCD.
Dwelling structure	proportion of dwelling with three categories: separate house(SH), semi-detached, row or terrace house, townhouse(SD), flat, unit or apartments(FA)
Level of service (transit)	LOS according to transit service
Income	Mean household income(weekly)
Housing loan repayment	monthly housing loan repayment (purchased dwellings)
Home rent	weekly home rent(rented dwellings)
Car ownership	number of available cars for adult
Family type	couple family with children, couple family without children, one parent family, other type family
Household size	mean household size(no. of members)
Age	proportion of people aged between 15 years and 65 years
Sex	male status
Employment	full time or part time
Occupation (employed persons)	professional, assistance professional, administrative, manager, supply workers, labour worker
Level of education	Education more than 12 years, education less than 12 years, still at school, never at school
Car-base trips	Percentage of work trips done by car as a driver or passenger within a CCD
Walking/cycling trips	Percentage of work trips done as walking or using a bike within a CCD

Urban form impacts

It is believed that the impacts of density, both residential and employment density are important. The probability of using a car by residents declines in denser suburbs, while the probability of transit use and walking/cycling by residents increases. The effect of the street design pattern is noticeable. The grid pattern may ease walking and cycling whereas a large number of cul-de-sacs in an area might make walking/cycling difficult due to a circuitous road network resulting in longer routes. For exploring the impact of urban form on travelling characteristics, first a descriptive comparison was done between four cases. Then step-wise multiple regression models were used to explain the modal choice of travelling for work trips by both urban form variables and socio-demographic economic factors. Different observed travel behaviour in four suburbs was compared to determine the probability of relationship between urban form characteristics and travel patterns. Travel mode choices including walking/cycling (walking and cycling), car-based (using car as driver or passenger), and public transport (bus, tram, and train) were calculated for all four case studies.

Modal choices for non-work trips

Usually it is expected traditional designed neighbourhoods with grid street network would encourage walking and cycling for non-work trips (Crane and Crepeau 1998, Badoe and Miller 2000). This finding appears to be supported by the findings for the case studies, with regard to walking and cycling. As Figure 4 shows, in Unley and Norwood, 21% and 20% respectively of all non-work trips were by walking or cycling. Para Hills and Golden Grove had fewer walking/cycling trips with 8% and 6% of all trips respectively. The non-work trip purposes were shopping, social or recreation and show that the most common purposes for walking/cycling were personal.

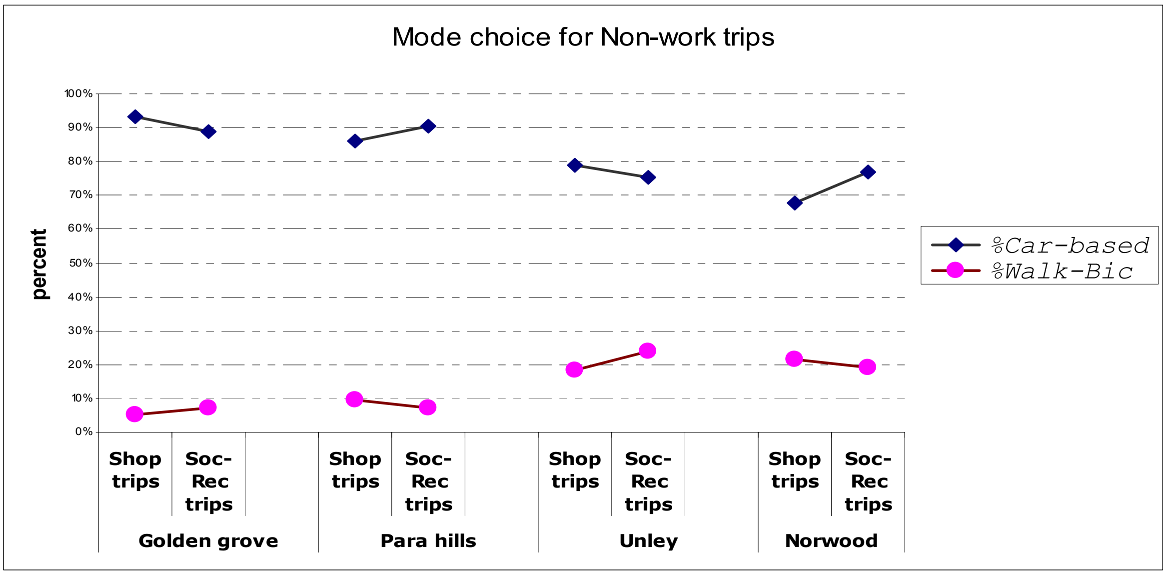

Figure 4 Mode choices for non-work trips.

The use of public transport for work and non-work trips was compared in the case study areas. All the areas had a public transport level of service (LOS) A, when the method of Kittelson & Associates, Inc (1999) was applied to the metropolitan bus services in these areas. Figure 5 shows the public transport used difference for four case studies. Those living in Norwood and Unley had a slighter higher percentage of public transport using, whereas the percentage of public transport users in Para Hills was similar to Golden Grove both of which areas outer suburbs. This comparison may suggest that neighbourhood form might not be the most influential factor affecting public transport use.

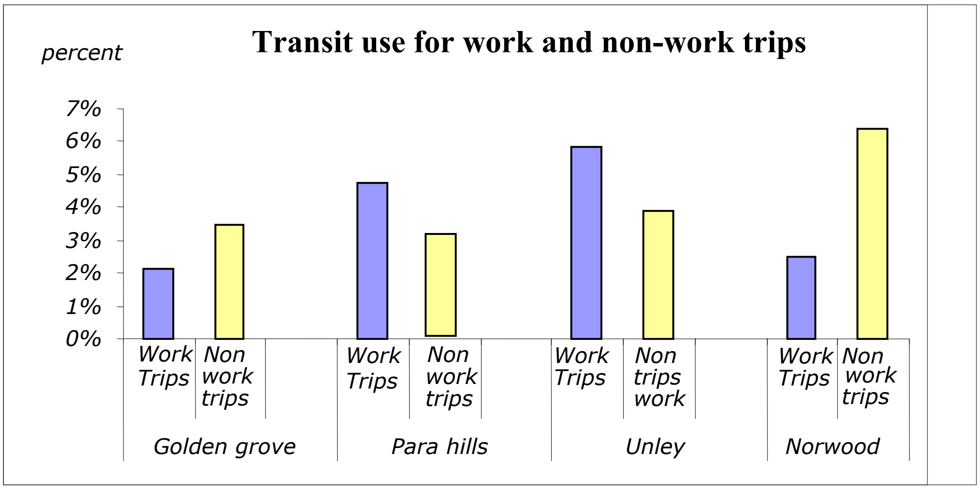

Figure 5 Transit use for work and non-work trips.

These different features of modal split might be related to urban form specifications in addition to socio-demographic characteristics. Furthermore, this difference could be influenced by the different geographical location of the four case studies and their interaction with their regional context.

Multiple regressions modelling

Multiple regressions modelling were used for predicting the value of modal choice for a given set of socio-demographic and urban form variables. From a statistical viewpoint, it is desirable to explain whether any of the independent variables (urban form and socio-demographic economic variables) have a statistically significant effect on the dependent variable (choice mode), and whether the dependent variable is explained by independent variables. Two types of data were used in regression modelling: socio-demographic and economic specifications of people living in case areas; and data of urban form measures. The list of variables representing both groups is detailed on Table 2.

Bi-variate Correlation test

Correlation test was done to find out whether a significant linear relationship exists between the percentages of work trips by car or walking/cycling modes originating in each CCD and for each of independent variables. In the multiple regression models, only the variables that were found to have relatively higher correlation coefficients were considered. The list of these variables and their basic statistics are provided in Table 3. All spatial measures for computing physical variables were done using Arc GIS and Map Info environment with high precise.

Only statistically significant variables related to travel mode choice were considered as predictors in the regression models. The method using here is Stepwise. (Stepwise is method of analysis where variables are systematically added to the regression equation depending on the significance of their predictability to the dependent variable. Variables can be repeatedly added and subtracted from the equation).

Table 3 Descriptive statistics

	Variable	Mean	Standard Deviation	Min	Max	Cases
Dependent Variables	**%Car Based Work Trips**	81.67%	6.90%	59.66%	93.23%	47
	%Walking/cycling Work trips	5.53%	5.72%	0.00%	19.89%	47
Socio-economic Variables						
Age	**Age between 15 and 35**	30.19%	6.97%	16.25%	50.46%	47
	Age between 35 and 65	39.82%	5.46%	27.85%	52.50%	47
Car ownership	**with zero car**	16.23%	12.13%	0.00%	47.45%	47
	with two cars and more	45.52%	22.35%	18.57%	81.48%	47
Education level	**High_Education**	32.95%	13.96%	20.29%	57.73%	47
	%Still at School	3.34%	2.07%	0.00%	6.39%	47
Employment status	**%Emp_FT**	45.75%	6.07%	33.16%	58.63%	47
Family type	**% Cf (couple family with children)**	12.45%	3.41%	6.06%	19.27%	47
Weekly Income($)	**INC<500**	56.57%	12.38%	41.14%	75.96%	47
Median Weekly Rent($)	**Median_W_Rent**	162.500	41.458	75	325	47
Median Monthly Loan Repay($)	**Med_M_Hsg Ln_Rpy**	875.000	214.573	500.000	1300.000	47
Household size	**Median_hh_Size**	2.419	0.472	1.6	3.5	47
Occupation	**Wrkrs**	56.81%	19.05%	28.32%	82.05%	47
Urban Form Variables						
Density	**Employment Density**	11.45	12.13	0.56	28.42	47
	Res-Gross-Dens	41.863	11.468	16.769	70.758	47
Dwelling structure	**SH(separated houses)**	76.38%	26.04%	21.16%	100.00%	47
	SD(semi-detached or townhouses)	14.46%	17.08%	0.00%	77.23%	47
	FA(flat, unit and apartment)	10.06%	15.67%	0.00%	54.73%	47
Median block area (m square)	**MBA**	36802.5	37758.1	4209.14	233744	47
Land use mix entropy	**LUM**	0.476	0.194	0.085	0.822	47
Proportion of cul-de-sac	**Cul-de-Sac**	0.387	0.304	0	1	47
Distance from CBD (km)	**Distance-CBD**	10.560	6.604	1.674	20.019	47

In the first model, the car-based mode (the percentage of trips done by using car as passenger or driver) was taken as dependent variable.

Model one: car-based mode as the dependent variable

According to correlation test result, 17 variables entered to regression analysis. With a stepwise method, only three variables out of 17 variables including the percentage of people with zero cars, the percentage of adults between 15 and 35, and the proportion of semi-detached, and town houses were found to be highly significant ($p < 0.05$). The significant model emerged (Adjusted R square = 0.835).The following display summarizes the regression fitness (for a CCD area):

$Y=1.008 - 0.292\times X_1 - 0.423\times X_2 - 0.085\times X_3$ *where;*

Y= the percentage of trips originated using car-based mode;
X_1=*the percentage of people with zero cars;*
X_2=*the percentage of adult with age between 15 and 35;*
X_3= *the proportion of semi-detached and townhouses.*
Therefore, the regression model provides a reasonable fit to the available data. The coefficient of determination, R-square shows that the model explained the 83% of the variation in the percentage of work trips done with car-based mode in a CCD per day.

Model Two: walking/cycling mode as the dependent variable

Similarly, according to correlation test result, 18 variables entered to regression analysis. With a stepwise method, only three variables out of 17 variables including the distance between a CCD and CBD, the percentage of adults between 15 and 35, and the proportion of separated houses were found to be highly significant ($p < 0.05$). A significant model emerged (Adjusted R square = 0.887). The summarized model can be written as follow (for a CCD area):

$Z = 0.119 + 0.162 \times X_2 - 0.003 \times X_4 - 0.106 \times X_5$ *where;*

Z = the percentage of trips originated using walking/cycling mode;
X_2 = *the percentage of workers with Age between 15 and 35;*
X_4 = *distance from CBD;*
X_5 = *the proportion of separated houses.*

Also this regression model provides a reasonable fit to the available data. The R-square indicates the model explained the 89% of the variation in the percentage of work trips done with walking/cycling mode in CCD tracts per day.
The regression models assumptions were validated. There was no clear evidence of no-normality, or auto-correlation; there was no major colinearity.

Interpretation

The multiple regression models and correlation test can be used to estimate, interpret and predict. Briefly, the effects of independent variables on travel mode choices can be summarized as follows:

According to bi-variate correlation test, among the neighbourhood form variables, land use mix entropy, distance from CBD, residential gross density, employment density, and dwelling type have significant linear relationships with the percentage of car-based trips, whereas median block area, and proportion of cul-de-sac are not significant. In addition, the correlation test showed that more land use mix results in increased walking/cycling trips. Both residential and employment density have negative linear relationships with the percentage of car-based trips. In contrast, higher density results in an increasing the proportion of walking or cycling trips. Further, employment density is more significant than residential density in influencing travel modal choice. The amount of distance between a CCD and Adelaide CBD has a negative impact on walking/cycling trips. In other words, the residents of outer suburbs prefer to do more car-based trips rather walking or cycling. The type of dwelling also has significant relationship with modal choice. People living in flats, units or apartments are more likely to walk to work or use their bikes than those living in

separate houses. Median block area as a determinant of permeability has significant relationship only with walking/cycling mode. The area with a smaller average of block is associated with lower rates of walking/cycling. The proportion of cul-de-sacs within neighbourhoods does not have significant linear relationship with the percentage of trips done by walking/cycling, although the relationship between them is negative.
According to the regression results, 'type of dwelling' and 'distance from CBD' are most important physical variables to regressing modal choice. The distance from the CBD variable may be interpreted as a measure of the effect of 'sprawl'. The workers live farther from CBD are less likely to walk or use their bike for journey to work. Socio-demographic characteristics play a significant role in choosing a mode for travel. Owning at least one car for adults in a household or being in an older age group leads to more car-based commuting trips including being a driver or as a passenger. On the other hand, being in a younger age group is a more significant determinant of people choosing walking or cycling for the journey to work.

Policy implications

The findings provide some clues to the interaction between urban form and modal choice. They have implications for both current policy and the practice of strategic planning in the suburban development of Adelaide. The suburban development patterns that can contribute to reducing the amount of motorized transport in urban areas are more likely to be favourable due to inducing sustainable transport modes such as walking; cycling and public transport.

Conclusion

The results of the analysis confirmed findings of the earlier studies that urban form characteristics are statistically associated with travelling choices. First, it is observed that walking and cycling clearly decrease as worker live farther from the CBD of Adelaide. In fact, decentralization impacts significantly the modal split of workers. Secondly, although density and land use mixing measures did not make a statically significant contribution to the regression models, the correlation tests showed that mixed use suburbs a with higher density are associated with increased walking, and cycling, thus suggesting that an improvement in the density and diversity of land uses in a residential area can decrease the proportion of car-dependent travelling. The evidence supports the contention that density and diversity have many advantages related to transport. The effect of neighbourhood design was found to be an important factor in encouraging walking and cycling. The designs with fewer cul-de-sacs or with smaller block areas have positive effects on inducing trips with walking or cycling modes. From a transport viewpoint, it is preferred to design grided neighbourhoods with lower number of cul-de-sacs and smaller block areas to more easily facilitate walking or cycling. Thirdly, little strong evidence was found that income level was an effective factor for workers to choose walking or cycling modes for journey to work, although car ownership was found to be important for using private car for commuting. Also, being in an older age group leads to more car-based journey to work trips. On contrast, being in a younger age group is a more significant determinant of people choosing walking or cycling for commuting.

For doing further research, panel data needs to be provided to better examine the causality between urban form and transportation variables. Definition of variable, the method used to statistically analysis could improve the explanatory powers of regression models for predictive purposes. Using discrete choice models can be more efficient to understanding the interrelationship between urban form and travel choice mode. Extending the analysis to other Adelaide's suburbs could be useful. The other aspects of neighbourhood design such as sidewalk quality, landscape, and topography could have some effects, although they have not been included in this study.

Acknowledgment

The authors are grateful to Dr. Sekhar Somenahalli for his kind advice on this study.

References

Badoe, D A and Miller, E J (2000) Transportation-land-use interaction: empirical findings in North America, and their implications for modelling *Transportation Research Part D 5*, 235-263

Bagley, M N and Mokhtarian, P L 2002, 'the impact of residential neighbourhood type on travel behaviour; a structural equations modelling approach', *Annual Regional Science 36*, pp. 279-297

Banister, D 1992, Energy use, transport and settlement patterns, pp160-181 of M J Breheny (ed), *Sustainable Development and Urban Form* London: Pion Limited

Black, J and Suthanaya, P (2002) Sustainable and spatial modeling of VKT of travel by car for the journey to work in Sydney, 1981-1996: implications for sustainable transportation targets *Papers of the 25th Australian Transportation Research Forum*

Brunton, P and Brindle, R (1999) The relationship between urban form and travel behaviour *ARRB Research Report* ARR No. 335, Australian Road Research Board

Cervero, R (2002) Built environments and mode choice: toward a normative framework *Transportation Research Part D 7*, 265-284

Cevero, R and Kockelman, K (1997) Travel demand and the 3D's: density, diversity, and design *Transportation Research D 2* (3), 199–219

Crane, R and Crepeau, R (1998) Does neighbourhood design influence travel? a behavioural analysis of travel diary and GIS data *Transport Research Digest 3* (4), 225-238

Frank, L and Pivo, G (1994) The impacts of mixed use and density on the utilization of three modes of travel: the single occupant vehicle, transit, and walking *Transportation Research Record 1466*, 44-52

Garnahan, D et al (1974) ongestion, concentration and behaviour: research in the study of urban population density *The Sociological Quarterly 15*, 488-506

Handy, S (1996) Understanding the link between urban form and non-work travel behaviour *Journal of Planning Education and Research 15* (3), 183-98

Handy, S (1992) *How Land Use Patterns Affect Travel Patterns* Council of Planning Librarians, Chicago.

Holtzclaw, J (1994) Residential Patterns and Transit, Auto Dependence, and Costs *Resources Defence Council*, San Francisco.

Holtzclaw, J (1990) *Explaining urban density and transit impacts on auto use* Presented by the Natural Resources Defence Council for *California Home Energy Efficiency Rating Systems*, June.

Kitamura, R et a. (1997) *A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay area* University of California at Davis report prepared for the California Air Resources Board

Kittelson and Associates (1999) *Transit Capacity and Quality of Service Manual* A report prepared for Transit Cooperative Research Program, National Research Council

McNally, M G and Ryan, S (1993) A comparative assessment of travel characteristics for neo-traditional development *Transportation Research Record 1117*, 45-68

Prevedours, P (1992) Association of personality characteristics with transport behaviour and residence location decisions *Transportation Research 26A*, 381-391

Schimek, P (1996) Household motor vehicle ownership and use: how much does residential density matter? *Transportation Research Record 1552*, 120-125

Simma, A and Axhausen, K W (2003) Interactions between travel behaviour, accessibility and personal characteristics: the case of the Upper Austin Region, Working paper.

The Government of South Australia (2003) *Planning Strategy for Metropolitan Adelaide*, January.