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Urban form, level of service and bus patronage in eastern Sydney

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Abstract
The relative importance of urban form; the quality of public transport and personal socio-economic characteristics is a recurrent theme in a debate about the factors affecting the mode of travel people use. This question has obvious relevance for urban planning policies and for increasing implementation of measures aimed at raising the use of public transport. This study considers the effect of population density (an urban form variable), bus service frequency (a level of service variable) and the socio-economic variables of age, low income and low vehicle ownership on bus service use in the eastern half of Sydney.

The study employs two measures of bus service use — Census data on journey to work travel and counts of boarding passengers supplied by Sydney Buses. Analysis involved the use of multiple regression techniques. The final model for the boarding data comprised frequency and income variables. While the final model for the journey to work data comprised frequency, density and income. In the initial models with all variables density was not statistically significant. There were statistically significant correlations between density and age and density and income.

Previous studies suggest that socio-economic characteristics are less important in mode use than in generating the need to travel in the first place. The results suggest that socio-economic variables have a greater effect on mode use than previously expected. Also the popular maxim that increased population density increases public transport use, may disregard the effect of socio-economic variables or the strong effects of service quality. This study raises doubts about the effectiveness of simple planning priorities such as increasing population density in generating greater bus service patronage and shows that service quality may be critical.

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GO BACK TO START SCREEN GO BACK TO INDEX

Introduction

There is wide acceptance that land use planning can influence travel behaviour. At the city wide level the urban policy for Sydney for example, is based among other principles on acceptance of a link between higher population densities and higher public transport use (Department of Urban Affairs and Planning 1999).

The development of guidelines specifying local planning practices to encourage the development and use of public transport services occurred steadily through the last decade. In North America, a significant number of public transport and local planning authorities had adopted "transit-oriented guidelines" for suburban planning by the early to mid 1990's (Cervero 1993). In Australia, Queensland, Western Australia and New South Wales have adopted suburban planning guidelines aimed at reducing reliance on private vehicle travel (NSW Department of Urban Affairs and Planning and NSW Department of Transport 2001, Queensland Department of Transport 1997, Western Australian Planning Commission 1997). In these guidelines the emphasis on density is supported by advocacy for urban design to encourage public transport use, walking and cycling.

At the same time some researchers have expressed doubts about the reliance on urban planning as the primary or a major means of reducing car dependence. Urban planning may not act strongly or quickly enough to address the environmental and social problems of increasing private car use (De Villiers 1997, Moriarty 1996, Troy 1995, Brindle 1992). Emphasising higher population density as the predominant factor in the use of public transport services is particularly criticised as poorly based in research and over simplistic (Pund 2001, Brindle 1992, Kirwan 1992).

Both city wide and local planning approaches to generating greater public transport use emphasise urban form impacts (particularly density) over service quality aspects in promoting greater use of public transport. Mees argues that service planning — coordinating all modes of public transport operations into an integrated network for the city provides the required service quality to attract and sustain high levels of usage of public transport. Mees is sceptical about urban planning policies such as 'compact cities' as a sole response (Mees 2000).

Brunton and Brindle (1999) in a study of Melbourne, found that accessibility to activities and income were the significant factors in car use. As accessibility to activities increased car travel declined. Other urban form variables seemed to play a relatively minor role in determining car travel. Brunton and Brindle found that the apparent relationship between density and car travel diminished when a larger number of variables were studied. Density was a proxy for variables initially not included in the analysis and was not significant with these variables included. The researchers also found that provided a low level of public transport service

was reached increased service levels played a more limited role in affecting travel behaviour.

While Brunton and Brindle considered car travel the study reported in this paper focuses on bus services. The purpose of this study was to investigate the relative impact of certain socio-economic, suburban form and service quality variables on bus service use in eastern Sydney. Understanding the relative impact of these factors is critical for developing effective policies to encourage public transport use.

Research questions

It is generally accepted that socio-economic characteristics are a major determinant of overall travel activity. An important question then becomes the extent to which socio-economic factors affect the generation of trips as opposed to the mode used. Researchers see travel activity involving decisions about whether to travel, when, where and how often to travel (trip generation) and then decisions about mode use. Results show that social, economic and demographic characteristics strongly affect trip generation, but that other factors also affect mode use (Pund 1999). One of the factors affecting mode use is urban form. Studies suggest that urban form accounts for a limited but statistically significant share of effects on mode use (Handy 1997). Generally this impact is seen as independent of socio-economic effects. The *first question* for this study was whether the finding about urban form affecting mode use is replicated in the study of bus service use in eastern Sydney. The *second question* was does urban form have an effect on mode use independent of socio-economic characteristics.

The level of service (or quality) of public transport generally is seen as having a major effect on mode use. The *third question* was what is the relative importance of service level and suburban form on bus service use in eastern Sydney.

It is possible that population density (particularly when measured at the city level), is a proxy variable for a range of other variables (socio-economic and urban form) that have an effect on mode use. One of these urban form variables might be accessibility to public transport. The general issue with the variable population density is that it is a crude measure and any association between density and public transport patronage needs an explanation of the process by which density change leads to improved patronage. Population density may not be the critical aspect (or catalyst) in any impact on patronage. The study tests whether accessibility to bus services may have an effect on bus service use and questions whether this may be masked by the use of density as the measure of suburban form. The *fourth question* therefore was whether any association between density and bus service use is likely to include the effect of other suburban form variables that may impact on bus service use.

Method

Variables and measurement

Bus service use is the dependent variable in this study. Two measures of bus service use were employed – patronage counts from ticket machine records provided by Sydney Buses and Census data. Census data provides information on the method of travel to work for the 24 hours of the Census day 1996 (journey to work data).

Patronage counts include trips for all purposes, however, in the morning peak period (between 6.00 am and 9.00 am) the major proportion of travel is to work. Patronage data for the peak period has some relationship to journey to work data, but the two measures do not provide the same result. The patronage data was extracted from the Sydney Buses management information system and was the average weekday morning peak period passenger boardings for the week commencing 15th March 1999.

Personal socio-economic characteristics cover a large range of variables, three well accepted as affecting travel are – age, income and household vehicle ownership. The age, income and car ownership variables were measured using 1996 census data (Australian Bureau of Statistics 1997). The bus routes were mapped using TRANSCAD transport planning software and the values calculated from Census collector district data using the banding and overlay tools in TRANSCAD. The area within 400m either side of the bus route was taken as the area accessible to bus services. This standard is included in the regulatory arrangements that govern bus operations in NSW.

People too young to hold a driver's license and older people are generally more dependent on public transport. The age variable was the proportion of the population within 400m of each bus route who are aged less than 19 and over 65 years of age. Households without a private car also tend to be dependent on public transport. The' no car' variable was the proportion of households within 400m of each of each bus route with no car. People with limited incomes also tend to be dependent on public transport. The 'low income' variable was the proportion of households within 400m of each route group where household income was less than $500 per week.

Bus service quality is composed of a number of variables – frequency of service is of critical importance to passengers and was the variable chosen for the study. Frequency was calculated for the morning peak period (6:00 am to 9:00 am) along each bus route, using the Sydney bus timetables current at 15th March 1999. The

frequency is the number of buses in the peak period operating in the direction of peak passenger movement – most commonly to the Sydney central business district.

The concept of urban form also includes numerous variables and as researchers (Pund 1999, Steiner 1994) have noted is not a well defined concept. Urban form refers to:

> the type and location of land uses, connections between these uses, circulation and layout. It also includes the environment (urban spaces) created by buildings and other structures and how these affect the people who use them (adapted from Handy 1997).

I use the term suburban form to refer to the form of smaller urban areas or suburbs, but urban form is the more generic term. The urban form variables used in this study are population density and accessibility to bus services. The measure for density is the population of the area 400m either side of each route, divided by the total area within 400m of the bus route. The TRANSCAD program calculates density in the same way as socio-economic characteristics.

Accessibility is the ease with which a person can join a bus service. It is in part affected by the connectivity of the street network (urban form) and is also an attribute of bus services and depends on the bus route network. In this study, the radial distance from a bus route was the (rudimentary) measure of accessibility. A value for each of the other variables measured by Census data was obtained using TRANSCAD for the following distance bands from each bus route: 0 – 200, 200 – 400m, 400 – 600m and 600 – 800m. This was in addition to the measure within 400m of each from each bus route.

Issues

Five issues that affect the interpretation of results from this study are discussed below.

The bus network

All data was available by Census collector area except for patronage counts. Patronage counts were available by route. This required the linking of bus patronage to a particular geographical area, otherwise the comparison of patronage data with other variables would be flawed. Sydney Buses operates a network of over 200 bus routes services in the eastern half of Sydney. However, due to the way that routes are planned and numbered there is considerable overlap of some routes making it difficult to identify the geographical coverage of any particular route. The overlapping routes were grouped, resulting in 71 route

groups. The route groups were relatively free of infiltration from routes outside the route group.

An analysis of the 71 route groups identified 25 that were subject to very minimal overlap from other route groups and competing public transport services. The tests were designed to identify route groups where the patronage data could confidently be compared with the Census data. The analysis involved comparing boarding data with journey to work data. The 71 route groups were subjected to three tests. The first requirement was that within the 400m area around route groups the use of train for the journey to work was less than 20% of bus only journey to work. This means that train travel did not generate much additional bus patronage and was unlikely to provide a significant alternative to bus travel. This could be identified in the Census data. The second test was that boardings were greater than the bus only journey to work, indicating that more people used the bus than those travelling to work. This would be the case as the boardings data would include school trips, personal business, etc. This means that there was a good chance that the boardings data were capturing close to the total bus travel for those residences within the 400m area. The third test was that boardings were no more than (approximately) one and a half times the total journey to work by public transport accounting for people not travelling to work, but indicating that there was little or no other public transport use not captured by the boardings data.

The tests were not applied with absolute rigour because there will not be an exact match between journey to work data and boarding data for a number of reasons. Boarding data may include some return trips in the morning peak period. The data are from different years and times during the year – March is traditionally the busiest time on public transport in the commuter peak perod. The Census journey to work data are collated by 'main mode' where journeys are allocated to certain mode categories based on a hierarchy. For example a journey by bus and train is recorded as 'train and one other', as is a journey by train and ferry. Assumptions need to be made to identify journeys in the Census data that include use of bus. The journey to work data are related to place of residence in the same way as socio-economic data. Patronage data may include trips by people residing beyond 400m of route groups.

Assumption of uniform spread

The TRANCAD program calculates the variable score from the count in each collector district. The collector district was the most disaggregated level of Census data available. Where collector districts did not wholly fall within the 400m buffer around a route group, the TRANCAD program estimated the result for the appropriate proportion of the collector district. The estimated result is based on the proportion of the collector district within the 400m buffer. While this is the conventional approach, the implicit assumption is that people and households

within the collector district are uniformly spread. This is not like to be the case and while a necessary approach, it introduces error into the results.

Sample

A convenience sample was used in this study, mainly because of the availability of patronage data from Sydney Buses. Bus companies are generally reluctant to release patronage data for commercial reasons. The routes within the Sydney Bus network are appropriate because data was available and the routes cover a wide area of Sydney. However, the use of a convenience sample reduces the validity of generalising results beyond eastern Sydney.

The general characteristics of the Sydney Buses network are somewhat unique in regard to the rest of Sydney. While there is variation in the areas that Sydney Buses serves the route network is predominantly radial with the Sydney CBD as the main hub. The size of the Sydney CBD as an employment, service and entertainment centre means that it is a major destination for travel in the eastern Sydney metropolitan area. The levels of congestion and the cost and limited availability of parking along with the historical high use of public transport to access the CBD benefit bus patronage. This study does not assess the effect of destination on bus service use, but the predominance of the Sydney CBD is a factor that should raise caution in applying results to other areas. Also differences in a range of other factors such as fares, average speed and length of trips should be considered in generalising from the study results.

Frequency: a factor or a consequence

The measure of bus service levels in this study is frequency. For the bus operator there is a close relationship between frequency and patronage. Operators adjust service frequency to levels of demand as part of the financial imperative to balance revenue and cost. However, the level of frequency is likely to be a strong determinant of patronage demand. There is an historical process occurring that a point in time view (as taken by this study) will miss. This also suggests caution in interpreting results.

Sufficient variation in density

To properly investigate density in public transport use in relation to other variables, it is important that there be sufficient variation in the population density of the routes studied. Within the 400m around the 25 route groups the range in population density is from 2,703 people per square kilometre to 7108 people per square kilometre. These densities are at or above the point where Cevero (1998) reports public transport use will sustain a significant increase over use in lower density areas.

Analysis

Multiple regression is a statistical tool for investigating the effects of each of a range of variables on another variable. It is therefore an appropriate tool for the research questions in this study. Three analyses were performed on the data with patronage as the dependent variable. In the first analysis, boardings was the dependent variable and in the other two analyses the proportion of journey to work was the patronage measure. The third analysis is a variation of the standard multiple regression technique allowing the analysis of accessibility. Statistical analysis was undertaken using SPSS 9.0 and Minitab 13 computer software statistical packages.

Results

Analysis 1: Boardings as the dependent variable

The first multiple regression was performed with patronage being measured by boardings. The plot of frequency against boardings shows a strong relationship which is slightly curved, violating the assumption that the relationship between variables can be described by a straight line. Consequently the data on frequency of bus services were transformed by squaring the values. This made the relationship between frequency and boardings more linear. The results of the Pearson correlations between variables are shown in Table 1 below.

Table 1 Correlations — patronage measured by boardings

	Boardings	Frequency	Frequency squared	Density	Age	Vehicles	Income
Boardings	1.000	.949 (.000)	.894 (.000)	.202 (.334)	-.290 (.160)	.179 (.393)	-.114 (.588)
Frequency		1.000	.970 (.000)	.168 (.421)	-.290 (.159)	.093 (.660)	-.254 (.221)
Frequency squared			1.000	.103 (.625)	-.193 (.355)	.077 (.716)	-.137 (.512)
Density				1.000	-.566 (.003)	.589 (.002)	-.110 (.602)
Age					1.000	-.753 (000)	.368 (.071)
Vehicles						1.000	.224 (.282)
Income							1.000

Notes: N=25

figures in parenthesises are the p value – the result of a two-tailed test of significance

The correlations that are significant at the .05 level or better are: boardings with frequency and frequency squared, age and density, density and household vehicle ownership; and age with vehicle ownership. The high correlation coefficient between frequency and frequency squared is to do with the transformed data and

can be ignored. The moderate but significant relationships between age and density and vehicle ownership and density raise the possibility of density being a proxy for socio-economic variables.

Along with the significant relationship between age and vehicle ownership the significant relationships with density raise the possibility of multicollinearity that could affect multiple regression results. Multicollinearity arises when two independent variables are highly correlated. The most problematic effect is that the regression shows the variables as having no effect on the dependent variable in the presence of the other variables when in fact they have a strong effect.

The negative correlation of boardings with age arises because boardings are measured in the peak travel period when the majority of those people travelling will be going to work. The measure of age used excludes those older than 19 and younger than 65 years of age – what are generally considered the working years. The same effect is the most plausible explanation of the negative relationships with income. The positive relationships between income and vehicle ownership and income and age are clearly to do with poorer households being less likely to own vehicles and likely to be composed of younger and older people who are outside the workforce. The moderate relationship of age with vehicles and its direction is also no surprise. Younger people and older people are less likely to own cars.

The relationship of density with age and vehicle ownership is interesting. It could be that the common connection between the variables – population is being reflected in the correlation score. An explanation is that younger and older people may tend not to own vehicles and live in multi-unit housing which tends to be concentrated to give areas of higher population density. However, following this explanation the relationship with density and age should be positive.

Undertaking a multiple regression analysis with boardings as the dependent variable showed an R^2 value of .953 indicating that the model from the analysis explains a high proportion of the variation in boardings. The analysis of variance shows a significance level of .000 meaning that the model as a whole is significant.

The model showed that frequency and frequency squared were highly significant. All the other variables were not significant.

The limited importance of not owning a vehicle in relation to boardings is surprising. It may be necessary to measure the number and type of trips to rule out vehicle ownership as having no effect in this sample. After all the boardings measure is for a particular time period in which most trips would be for work or education. Many of these trips would be to the Sydney CBD where parking is limited and expensive. Alternatively, the association of vehicle ownership and age

with each other and with other variables (notably density) may be the reason for these variables not showing the expected effects on boardings. The multicollinearity diagnostics reported in SPSS showed that there was multicollinearity between age and vehicle ownership variables.

A step-wise deletion of non-significant variables was used to derive the simplest regression model. The R^2 is .952 almost the same as the regression involving all the variables. The results are presented in Table 2 below.

The coefficient for frequency remained almost unchanged indicating that deleting density, age and vehicles has no effect on frequency. Given that bus operators adjust frequency against boardings, the relationship between these two variables may well apply independent of other variables.

After deletion of other vehicles the coefficient for income increased substantially providing further evidence of the relationship between socio-economic variables. When age and vehicle ownership are deleted the measurement of socio-economic factors is by income only.

Density is not significant. The relationships between density and age and density and vehicle ownership (see Table 1), may be a component of the effect of income, but it may be slight. In comparison to frequency, density has little effect on bus service boardings.

Table 2 Step-wise multiple regression — Dependent variable is boardings

Independent Variables	Unstandardised regression coefficient	Standardised regresssion coefficient	t value	Significance
Frequency	160.293	1.838	8.150	.000
Frequency squared	.562	.856	-3.888	.001
Income	134.810	.235	4.209	.000
Constant	-5907.087		-4.497	.000
Density	deleted			
Age	deleted			
Vehicles	deleted			

Note: N=25

Analysis 2: Journey to work as the dependent variable

The second multiple regression was performed with the proportion of journey to work trips taken by bus as the measure of patronage. The outcomes are similar to using boardings as the measure of patronage. Again the frequency data needed to be transformed and frequency and frequency squared were the key variables.

The results of the Pearson correlations between variables are shown in Table 3 below.

Table 3 Correlations — Patronage measured by proportion of journey to work travel by bus

	Journey to work	Frequency	Frequency squared	Density	Age	Vehicles	Income
Journey to work	1.000	.651 (.000)	.553 (.004)	.567 (.003)	-.578 (.010)	.542 (.007)	-.059 (.779)
Frequency		1.000	.970 (.000)	.168 (.421)	-.290 (.159)	.093 (.660)	-.254 (.221)
Frequency squared			1.000	.103 (.625)	-.193 (.355)	.077 (.716)	-.137 (.512)
Density				1.000	-.566 (.003)	.589 (.002)	-.110 (.602)
Age					1.000	-.753 (000)	.368 (.071)
Vehicles						1.000	.224 (.282)
Income							1.000

Notes: N=25
figures in parenthesises are the results of a two-tailed test of significance

The correlations that are significant at the .05 level or better are: journey to work and frequency (also significant at the .01 level); journey to work and density; journey to work and age; journey to work and vehicles; along with correlations also appearing in Table 1 — age and density, density and household vehicle ownership; and age with vehicle ownership.

The multiple regression has an R^2 value of .794 showing that the result explains a moderate to high proportion of the variance. The analysis of variance shows a significance level of .000 meaning that the model as a whole is significant. In this analysis the independent variables account for less of the variance in travel to work than did boardings in relation to all travel purposes. Travel to work is in large measure a sub-set of boardings but there are some differences. For example the coefficient for age is negative with travel to work, but positive with boardings. Unsurprisingly travel to work is associated with people of workforce age.

The model from the multiple regression analysis shows that frequency is highly significant but all other variables are significant. The multicollinearity diagnostics for this model show the same issues as in the first analysis with boardings as the dependent variable. A backwards deletion of non-significant variables produces a simplified regression model with a moderate R^2 value of .755. The results are presented in Table 4 below.

Table 4 Step-wise multiple regression — dependent variable is journey to work

Independent Variables	Unstandardised regression coefficient	Standardised regresssion coefficient	t value	Significance
Frequency	.280	2.083	3.854	.001
Frequency squared	-1.484	-1.465	-2.794	.011
Density	1.760	.401	3.453	.003
Income	.276	.312	2.422	.025
Constant	-8.676		-1.774	.091
Age	deleted			
Vehicles	deleted			

Note: N=25

The final regression model shows two important results. Both frequency (at the 0.1 level) and density (at the 0.5 level) have a statistically significant effect on the proportion of journey to work travel as the dependent variable. Secondly density only becomes significant with the deletion of socio-economic variables. This indicates that there are relationships between density and the socio-economic variables that are hidden when the vehicles and age variables are included. This is supported by the results of correlations in Table 3 showing a significant relationship between density and age and density and household vehicle ownership. Table 3 also shows significant relationships between journey to work and age and journey to work and vehicles. These relationships are not as strong as those with density. The effect of density on journey to work travel appears (at least in part) to rest on the effect of age and vehicle ownership on journey to work travel.

Test 3: Analysis of Accessibility

This analysis includes accessibility as measured by four distance bands from the bus routes. As the distance bands are categories and the other independent variables are continuous measures, multiple regression cannot be performed without the use of dummy variables. The need to use dummy variables is overcome by using a variant of multiple regression analysis known as the general linear model. The results of the analysis are presented in Table 5.

The results in Table 5 follow from removing data from one route group that dramatically affected results. This route group is in an area with a dominant non-residential facility with unusual operating times and generating unusual travel patterns.

Table 5 **Effect of variables on the proportion of journey to work travel by bus on 24 route groups in eastern Sydney**

Independent Variables	Adjusted SS	Coefficient	t value	Significance
Frequency	155.98	0.040121	6.62	0.000
Density	0.60	0.000100	0.41	0.683
Income	2.90	0.06648	0.90	0.369
Age	83.73	-0.45979	-4.85	0.000
Vehicles	6.40	0.08912	1.34	0.184
Accessibility	44.71			0.008
Constant		21.148	6.73	0.000

Note: N=96

The general linear model results show that frequency, age and accessibility are statistically significant. As with analysis 2 density was not significant when all variables were included. Unlike the previous two analyses a socio-economic variable — age is significant in the initial model.

The deletion in turn of the non-significant variables from the analysis gives the results shown in Table 6.

Table 6 **Step-wise general linear model — dependent variable is journey to work**

Independent Variables	Adjusted SS	Coefficient	t value	Significance
Frequency	157.14	0.039667	6.68	0.000
Density	deleted			
Income	deleted			
Age	172.67	-0.39781	-7.01	0.000
Vehicles	55.44	0.14172	3.97	0.000
Accessibility	53.21			0.003
Constant		20.358	7.70	0.000

Note: N=96

Density as the least significant variable was deleted first. With density deleted income was the next least significant variable. With the deletion of income, vehicles became significant as expected given the relationship between income and car ownership discussed above. This then becomes the final model.

Multiple regression analysis rests on an assumption that the independent or predictor variables do not have a strong effect on each other. Testing of interaction effects between bands and the other variables in the final model found that the relationship between bands and each variable in turn was not significant. In this analysis, accessibility has an effect on bus service usage independent of the socio-economic, level of service and other urban form variables.

The major finding of this analysis was that accessibility as measured by the radial distance from bus routes affects the use of bus services. This is not a new finding, it is clearly important to ensure that bus routes are close to potential passengers. The interesting aspect of this research is the consideration of accessibility (radial distance from bus routes) with the other urban form variable density (resident population per unit of urban area). There is no interaction effect in the general linear model between accessibility bands and density, indicating that the impact of distance from the bus route is not inadvertently measuring a change in density which is affecting bus service use.

Conclusion

Question 1: Suburban form and mode use

Density (as measured by population per square kilometre) was the primary suburban form variable used in this study. The result of the effect of density on bus service use was counter to the predominant view amongst transport planners. Density was not a significant variable in analysis 1 where boardings was the dependent variable and also not significant in analysis three where the accessibility variable was included. Density was only significant in analysis two when the socio-economic variables were removed. However, the relationships between density and socio-economic factors mean that it is not possible to dismiss density as a factor in mode use. The study results question the existence of a simple and direct relationship such that higher density equals higher bus (or public transport) use. In this respect this study supports a similar finding by Brunton and Brindle (1999) mentioned earlier.

Analysis 3 suggests that urban form has some effect on bus service use in eastern Sydney. Analysis 3 is an initial look at the effect of accessibility on bus service use. This analysis shows that there is a clear relationship between bus service use and the distance from a bus route in eastern Sydney. This finding supports the general acceptance that urban form has a limited but significant effect on mode use (Handy 1997). In the above study urban form seems to be less important than level of service in affecting the use of bus services.

The answer to the question whether the study replicated findings about urban form affecting mode use, is that the study tends to support the view that urban form does affect bus service use, but questions the concentration on density as the key urban form variable.

Question 2: Suburban form and socio-economic variables

Both the first and second analyses showed socio-economic variables particularly income having an effect on mode use. Analysis three showed age and vehicle

ownership as affecting mode use. The interrelation of socio-economic variables made the independent effect of each variable difficult to determine. For example income was included in the final models from analyses one and two only after the deletion of the other socio-economic variables. In neither analysis was income significant in the full models. In the general linear model in analysis 3 vehicle ownership became significant only in the final model after the deletion of income.

The results show that density was related to socio-economic characteristics, but the other urban form variable accessibility was not. The relationship between urban form and socio-economic variables is often not tested in research on the effect of urban form on mode use. Analysis 2 showed that the effect of density on the proportion of journey to work travel by bus became significant only when the socio-economic variables were removed. Studies that show an effect of density on public transport use and do not control for the effect of socio-economic factors may produce results that mask any relationship between urban form and socio-economic variables. The tendency is to see the urban form as static and having an effect independent of other factors. While this is likely the case to some extent, it appears that the characteristics of people will mitigate and perhaps override the effect of urban form.

Question 3: Bus service levels and suburban form

The three analyses show that level of bus services as measured by frequency is strongly associated with use. This is a clear conclusion from the study, but is contrary to the results obtained by Brunton and Brindle (1999) using a different method.

The suburban form variable common to all three analyses was density. Results suggest that density is a crude measure of urban form and is closely correlated with socio-economic factors. It is likely that in studies seeking to test the impact of urban form where socio-economic factors are not included that density may be a proxy for the effect of variables such as income, age and vehicle ownership. Analysis 3 indicates that accessibility might have an effect on bus service use.

Question 4: Density and proxies for other suburban form variables

Analysis three showed that accessibility affected bus service use independent of population density. There was no evidence that population density acted as a proxy for the other suburban form variable. However, if the concept of accessibility was measured differently to include effects such as the street network then there may be some interaction effect with population density. This issue of definition and the need to test more urban form variables means that interrelations between population density and other suburban form variables is an open question.

Implications

The results of the study support the view that urban form has an effect on mode use, however there are some implications for urban planning policies aimed at greater public transport use. The first of these implications is that socio-economic factors may be more important in mode use than generally accepted. The conventional view is that socio-economic factors have a major effect on trip generation – the decision or need to travel, but a more limited effect on the mode of travel. This study suggests that socio-economic factors are critical in mode use as well. It raises the use of policies with a more direct effect on travel behaviour such as parking limitations and charges and road pricing.

A second implication for urban planning policies is the strong relationship between level of public transport services and mode use. Again the level of public transport services is not emphasised in studies that investigate the impact of urban form on transport mode use. The importance of socio-economic factors and public transport level of service suggest that urban planners policies need to work closely with public transport service providers and understand the socio-economic characteristics of the residents of areas. Planning a revitalised urban form in isolation may not be sufficient to change travel behaviour.

Related to the limitations of urban planning approaches is the emphasis on population density as a means of generating greater use of public transport. There has been much debate about whether density is such a critical factor or not. This study suggests that urban planning policies strongly underpinned by the premise of increasing population density may be less effective than previously thought.

The unwarranted emphasis on population density should not imply a reduced emphasis on other urban form components as factors in transport mode use. Urban form is a complex concept which needs to be the subject of more sophisticated analysis. The analysis of accessibility in this study is a start, but the measure of accessibility is limited. While the importance of other factors such as socio-economic characteristics and public transport level of service must also be considered when developing policies to promote public transport, the linkages between urban form and public transport level of service might also be critical. One of the criticisms of the research on urban and form and mode use is that explanations of the mechanism by which urban form affects mode use are often lacking (Pund 1999).

The effect of accessibility on bus service use is on one level simple to conceive. The easier it is to gain access to bus services the more it is likely to be used over another mode. The more people closer to a bus route the more patronage is likely. A relevant question is why no relationship between density and

accessibility and why doesn't higher density show as significant in bus service use. The relationship is more complex. Bus operators have some control of accessibility in the routes they operate. Operating more routes is likely to increase accessibility. Accessibility is actually both an urban form and a bus level of service variable. The road layout sets limits on the bus routes that can be provided. The capacity of buses to use certain roads, whether there are through direct links or whether there are limited and indirect through roads will affect the operators route planning options. Nevertheless the operator has choices in how to plan routes and the spacing between routes affects accessibility. The effect of accessibility on bus service use in suburban areas may not be related to population density. Urban form may affect bus service usage through the level of service provided.

At present there is a strong tendency for urban planning policies to take a strong prescriptive position about the urban form required to generate greater public transport use. This study adds to others, that suggest the effect of urban form on public transport use is not as simple and direct as frequently accepted. To the extent that urban form affects mode use, urban planning has validity. It is the approach to urban planning that is questioned by this study. This study adds to the view that taking a less prescriptive position about the detail of the desired form and a wider view to include other factors that affect mode use, may be a beneficial path in urban planning.

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References

Australian Bureau of Statistics (1997) *Cdata 96* Canberra: ABS

Brindle R E (1992) Transport and land use: A 'neo-modern' approach, pp111-135 of *Proceedings 16th Australian Road Research Board Conference Part 6*, Melbourne: ARRB

Brunton, P and Brindle, R (1999) *The relationship between urban form and travel behaviour* Melbourne: ARRB Research Report ARR 335

Cervero, R (1998) *The transit metropolis: A global inquiry* Washington DC: Island Press

Cervero, R (1993) *Transit-Supportive development in the United States: Experience and prospects* Washington DC; Federal Transit Administration.

De Villiers P (1997) New urbanism: A critical review *Australian Planner* 34(1):30-34.

Handy S (1997) *Travel behavior - Land use interactions: An overview and assessment of the research* unpublished, Austin: School of Architecture University of Texas at Austin

Kirwan, R (1992) Urban form, energy and transport: A note on the Newman-Kenworthy thesis *Urban Policy and Research* 10(1), 6-23

Mees, P (2000) *A very public solution* Melbourne: Melbourne University Press

Moriarty P (996) Can Urban Density Explain Personal Travel Levels *Urban Policy and Research* 14:109-118.

NSW Department of Urban Affairs and Planning (1999) *Shaping our cities: The planning strategy for the greater metropolitan region of Sydney, Newcastle, Wollongong and the Central Coast* Sydney: Department of Urban Affairs and Planning

NSW Department of Urban Affairs and Planning and NSW Department of Transport (2001) *Integrating land use and transport: A planning policy package* Sydney: Department of Urban Affairs and Planning and Department of Transport

Pund, G (2001) City density and public transport *Australian Planner* 38 (2), 74-79

Pund G (1999) Towards a theory of suburban form and travel mode use, pp 111-126 of Papers of the 23rd Australian Transport Research Forum 22 (1) Perth: ATRF

Queensland Department of Transport (1997) *Shaping up:Shaping urban communities to reduce car dependency in Queensland* Queensland Brisbane: Department of Transport

Steiner, R L (1994) Residential density and travel patterns: Review of the literature *Transportation Research Record* 1466, 37-43
Troy P ed (1995) *Australian cities: issues, strategies and policy for urban Australia in the 1990's* Melbourne: Cambridge University Press

Western Australian Planning Commission (1997) *Liveable neighbourhoods:*

Community design code, Perth: Western Australian Planning Commission