How Changes In Urban Form Influences Changes In Journey To Work Mode Choice (A Case Study Of Sydney Metropolitan Region)

Bagaimana Perubahan-Perubahan Bentuk Perkotaan Akibat Pengaruh Perubahan Pilihan Perjalanan Untuk Mode Kerja (Studi Kasus Di wilayah Metropolitan Sidney)

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ABSTRACT

Suburbanization of employment and decentralization of residential workers experienced by most cities has contributed to more dependence on the car and a decreasing trend in public transportation share, leading to a less sustainable city over time. In order to overcome this condition, it is important to understand how changes in urban form influenced changes in mode choice of the residents. By using 1981-1996 Journey to Work Data for Sydney Metropolitan Region and applying multiple regression, this study investigates the relationship between changes in urban form and changes in commuting mode choices. The results indicated that the outer ring residents experienced a significantly higher increase in bus modal share compared to that of the inner and middle ring. On the other hand, the inner ring residents experienced a significantly greater increase in the proportion using train than that of the other regional rings. Local Government Areas (LGAs) with a greater increase in accessibility to jobs by bus and a greater increase in average job distances are associated with greater decrease in the proportion using car. Increasing the ratio of residential workers to jobs and accessibility to jobs by car was associated with decreases in the proportion using bus. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train.
Keywords: Urban form, mode choice, multiple regression

ABSTRAK

Sub-urbanisasi pekerja dan desentralisasi pekerja permukiman yang dialami oleh lebih banyak kota telah memberikan kontribusi lebih tergantung pada mobil dan menurunnya penggunaan angkutan umum, yang mengarah pada berkurangnya keberlanjutan kota dari waktu ke waktu. Untuk mengatasi kondisi ini, perlu memahami bagaimana perubahan-perubahan perkotaan sebagai pengaruh perubahan-perubahan perjalanan untuk pilihan moda pada wilayah permukiman. Dengan menggunakan Data Journey 1981-1996 untuk wilayah Metropolitan Sidney dan mengaplikasikan regresi bergamda, penelitian ini menyelidiki hubungan antara perubahan-perubahan bentuk perkotaan dan perubahan-perubahan pilihan-pilihan moda masyarakat. Hasilnya menunjukkan bahwa daerah sekitar perumahan mengalami peningkatan yang signifikan lebih tinggi menggunakan ankutan umum bus dibandingkan dengan daerah dalam permukiman dan di tengah-tengah permukiman. Pada sisi lain, di daerah permukiman mengalami peningkatan secara signifikan lebih besar proporsinya menggunakan kereta daripada daerah lain sekitarnya. *Local Government Areas* (*LGAs*) dengan peningkatan yang lebih besar dalam aksesibilitas bekerja menggunakan bus dan peningakatan lebih besar dalam jarak rata-rata pekerjaan yang dikaitkan dengan proporsi penggunaan mobil mengalami penurunan besar. Peningkatan ratio pekerja-pekerja permukiman ke tempat kerja dan aksesibiltas pekerjaan menggunakan mobil dikaitkan dengan proporsi penggunaan bus. Rata-rata peningkatan jarak pekerjaan, proporsi pekerja yang bekerja dalam CBD dan proporsi pekerja permukiman dikaitkan dengan proporsi penggunaan kereta mengalami peningkatan.
Kata-kata kunci: bentuk perkoataan, pilihan mode, regresi berganda

INTRODUCTION

Suburbanization of employment and decentralization of residential workers experienced by most cities has contributed to more dependence on the car and a decreasing trend in public transportation share, leading to a less sustainable city over time. In addition to the growth of vehicle numbers, the social development of more complex travel patterns (based on the car) have been seen as major limitations for the achievement of sustainable urban development (Newman and Kenworthy, 1999). Travel patterns are one component of environmentally sustainable transportation (EST) indicators. It has been suggested that travel patterns such as Vehicle Kilometer of Travel (VKT), trip length and mode choice might be used as a proxy for energy consumption and transportation emissions (Stead, 2001).

Basically, the characteristics of urban form can influence population activities through trip behavior. Space form is an aggregate of various concepts and urban elements depicted in physical structure of the urban area. According to Kusumantoro et.al (2009), fringe area development or sprawl is a phenomenon that will continue to go on in the process of urban development. Un-readiness of spatial planning instruments in dealing with the problem has exacerbated the transportation problem in is connecting corridor, such as the problem of congestion. One effort that can be done is to conduct 'internalization of the orientation of the trip in the fringe area' so that the interaction of the fringe area with its core city can be reduced. However, before using urban form as a tool the first step in achieving sustainable transportation is to understand how urban form influences travel patterns.

At a macro level study, Giuliano and Dargay (2006) conducted international comparative analysis of relationships between car ownership, daily travel and urban form. Using travel diary data for the US and Great Britain, they estimated models of car ownership and daily travel distance. Both a structural model with daily travel conditional upon car ownership and a reduced form model for daily travel, excluding car ownership, were estimated. They found that differences in travel were explained by differences in demographics between the two countries, a lower household income in Great Britain, and differences in costs of car ownership and use and transport supply.

Gordon, et.al (2004) conducted a micro level study and he argued variations in public transit commuting were influenced by neighborhood type. They found a statistical link over a sample of all census tracts in the four largest California metro areas. They used statistical cluster analysis to identify twenty generic neighborhood types. The variables used in the analysis included broad indicators of location and population density, street design, transit access and highway access. They identified that the denser neighborhoods had higher transit use, whilst other things equal.

In Germany, Vance and Hedel (2007) focused on individual automobile travel. They applied econometric models on a panel of travel-diary data collected in Germany between 1996 and 2003. They employed the two-part model (2PM): a procedure involving probit and OLS estimators. They found that urban form has a causative impact on car use. In Italian, Montis, et al. (2010) also found that similar commuting networks emerge in similar geographical settings.

Yang and Gakenheimer (2007) assessed the accessibility and mobility consequences of urban land transformation in expanding Chinese cities. They pointed out that appropriate accessibility and mobility objectives were not well considered in land development, and current development themes tend to lengthen trips and lead to increased congestion in the context of growth and motorization. Based on GIS modeling, Tang and Wang (2007) investigated the ways that four urban forms in the Macao Peninsula influenced vehicle transport and street environment. They stated that the urban forms in historical areas with narrower roads, complex road networks and a higher density of intersections lead to lower traffic volumes and thus lower noise pollution.

A research conducted in the fringe area of the Bandung City, Indonesia, by Kusmantoro et.al (2009) found that the compactness in an area does not have direct influence to the community pattern in having internal movement. Only several activities have direct influence, i.e. education and shopping trip. Not all of education and shopping trip have direct influence, they are only elementary school movement, junior high school movement, shop and supermarket. The rest of activities, such as working trip and health facility access do not show the relation of compactness and movement pattern. Another fringe area study was conducted by Kawabata et.al (2009) who analyzes travel behavior by car passengers and community buses in a mountainous under-populated region, Yamakoshi in the city of Nagaoka, Niigata in Japan. They estimated travel mode choice models using travel diary data to reveal the constraint factors of mobility for elderly people. They found that 'walking distance from home to a bus stop' influenced elderly people to shift travel mode from car passengers into an exclusive club bus system.

The strength of the relationship between urban form and mobility behavior is a longstanding question within the field of transportation demand management. Although several studies have identified a strong correlation between these variables, there is as yet scant evidence to support policy interventions that target land use as a means of influencing travel. For non-work trips, Zhang (2005) applied an activity-based time-use analysis of the relationship between urban form and non-work travel. Using data from the 1991 Activity–Travel Survey in Boston, he tested the role of spatial accessibility as a composite measure of urban form in explaining individuals' non-work activity participation, travel times, and travel frequencies. The results showed varying effects of modifying spatial accessibility on non-work activity participation and travel among different activity categories. However, according to Pooley and Turnbull (2000), the journey to work is one of the most commonly experienced forms of every-day travel, encompassing almost all transport modes, and making a substantial contribution to urban traffic congestion.

The weakness in most of the journey-to-work trip studies was the use of a static approach (i.e. the analysis was done at one point in time). This cross-sectional analysis using data at one point in time did not explain whether the changes in travel behavior of residents in a zone can be explained by the changes in urban form variables in that zone. There were substantial variations in travel behavior, urban form and socio-economic changes across the Sydney region. These variations provide a potential means of identifying the characteristics of urban form and socio-economic factors that are associated with changes in travel behavior. Using 1981-1996 Journey to Work data for the Sydney Metropolitan Region, the objective of this study is to investigate the relationship between changes in urban form and changes in travel behavior, especially mode choice. The average change per 5 year of each variable for every zone (Local Government Area or LGA) over the period 1981 to 1996 is calculated and used in the analysis. Several statistical analyses are employed including descriptive statistic, analysis of variance, correlation and multiple regression analysis.

DEFINITION OF URBAN FORM

Despite many factors influencing travel behavior, this research focuses on the influence of urban form on travel behavior. This section describes briefly the definition of urban form and archetypal urban form. Anderson (*et al*., 1996) defined urban form as 'the spatial configuration of fixed elements within metropolitan region'. According to Brunton and Brindle (1999) urban form is 'the generalized shape of an urban region, and the disposition of its major components (especially regional centers and major employment areas)'. In this study, urban form refers to physical arrangement of jobs-housing location. Urban form variables considered include density of population and employment, accessibility to jobs, average job distances, jobs-housing balance and distance from the CBD. Urban interaction is explained by the flow of goods, people and information across a city. However, the flow of people (commuters, shoppers, etc.) is regarded as the most important movement in relation to the reduction of energy use and environmental emissions although the movement of goods also has significant impact.

Urban development is the result of many factors. Apart from geographical factors (rivers, mountains), the development of transportation infrastructure has influenced the size and the shape of cities. In Europe, before 1800, the physical expansion of a city was defined by the maximum distance people could comfortably walk to work. In that time, walking was the dominant mode of transportation. With the introduction of the new technology, passenger transportation modes (railways, trams) started replacing the walking mode and encouraged expansion outside the city (Hass-Klau, 1990). A similar situation was also experienced in Sydney with a steady progression from a compact "walking city" to a sprawling, car dependent city with low residential housing densities by world standards (Black, 1993). In addition to the influence of new technology, Newman and Kenworthy (1999) stated that the change in urban form is a result of a combination of factors including the market, government, and civil society.

The urban form is not simply determined by planners (Anderson, *et al.*, 1996): the shape of the city has evolved over a long term period as a results of both public policies and free market forces. The construction of new transportation infrastructure leads to a more dispersed and inefficient pattern of land use development. Increasing numbers of people living in the outer areas requires more infrastructure to be developed. In turn, good infrastructure attracts more people to live in the outer ring.

METHODOLOGY

In order to analyze urban form change and travel patterns change across zones in Sydney Metropolitan Region, Journey to Work (JTW) census data and centroid to centroid distance matrix are used as input data. However, the values of the variables used are not the values for one point in time data but the average change per 5 years. Descriptive statistic is used to explain the change in urban form and mode choice across zones in Sydney over time. Following this descriptive analysis, analysis of variance (multiple comparison using Benferroni method) is used to compare the change in urban form and mode choice amongst LGAs located in the inner, middle and outer rings. Scatter-plot matrix is employed to visually inspect the relationship between independent and dependent variable and to check the linearity of the relationship. Correlation analysis is then used to examine the

relationship between variables. A multiple regression analysis is conducted to predict the change in travel mode choice. The change in urban form variables is used as independent variables. The analysis is also stratified into three regional rings – inner, middle and outer rings. The results are then used to draw policy implications on land-use development. Figure 1 and Table 1 shows Sydney zoning system.

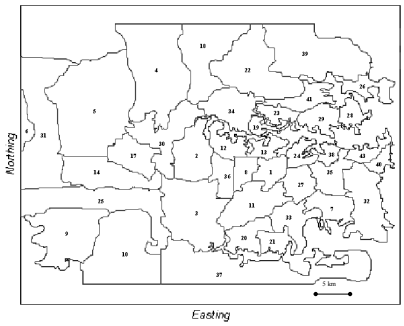

Figure 1. Sydney Zoning System

The primary data source for this level of analysis were the 1981, 1991, and 1996 Journey-to-Work data for the Sydney Metropolitan Area. The Australian Bureau of Statistics (ABS) conducted the Census. The data are provided at the travel zone levels that have been aggregated from census tracts for the Statistical Local Area (SLA) levels and cover 44 Local Government Areas. The data that forms the basis for this research are the National Census of Population and Housing Journey-to-Work tabulations provided by the NSW Department of Transport, Transport Data Center (TDC).

Dependent variables describing LGA zonal travel behavior when stratified by transport mode were of three kinds: the proportion of journey-to-work travel by the three major modes (car, bus and train); the total amount of travel, also stratified by mode; and the mean trip length, again also stratified by mode. Table 2 lists urban form as independent variables used in this study.

Tabel 2. Lists of urban form variables

No	Urban Form Variables
1	Proportion residential worker (%)
2	Proportion job (%)
3	Worker density (prs/km^2)
4	Job density (prs/km^2)
5	Ratio of residential worker to job
6	Proportion employed in CBD (%)
7	Proportion employed locally (%)
8	Average job distance (km)
9	Job accessibility by all mode
10	Job accessibility by car
11	Job accessibility by bus
12	Job accessibility by train
13	Separate dwelling (%)
14	Semi-detached dwelling (%)
15	Flat 1-3 storey (%)
16	Flat 4+ storey (%)
17	Road length per 1000 workers (km/1000workers)

Table 1. Local Government Areas in Sydney and Zone Number

Innerring				Midle ring				Outer ring			
Region	SLA	Zone number	SLA code (ABS)	Region	SLA	Zone number	SLA code (ABS)	Region	SLA	Zone number	SLA code (ABS)
Central core	South Sydney	35	7070	Midle South	Hurstville	20	4150	Outer South	Sutherland	37	7150
	Sydney (inner)	38	7201		Kogarah	21	4450	Outer South-West	Firefield	14	2850
	Sydney (remainder)	38	7202		Rockdale	33	6650		Camden	9	1450
Inner East	Botany	7	1100	Midle South-West	Canterbury	11	1550		Campbelltown	10	1500
	Randwick	32	6550		Bankstown	3	350		Wollondilly	42	8400
	Woollahra	42	8500	Midle West	Auburn	2	200		Liverpool	25	4900
	Waverley	40	8050		Parramatta	30	6250	Outer West	Blacktown	5	750
Inner West	Leidhardt	24	4800		Concord	12	1900		Blu Montains	6	900
	Marickville	37	5200		Burwood	8	1300		Penrith	31	6350
	Ashfield	1	150		Strathfield	36	7100		Holroyd	17	3950
	Drummoyne	13	2550	Midle North	Ryde	34	6700		Howkesbury	16	3800
Inner North	Lane Cove	23	4700		Ku-ring-gai	22	4500	Outer North	Warringah	39	8000
	Mosman	28	5350		Manly	26	5150		Baulkham Hill	4	500
	North Sydney	29	5950		Willoughby	41	8250		Hornsby	18	4000
					Hunters Hill	19	4100	Central Coast	Wyong	44	8550
									Gosford	15	3100

RESULTS AND DISCUSSIONS

Changes in Urban Form in Sydney

Table 3, 4 and 5 show changes in urban form variables in the inner, middle and outer ring of Sydney, respectively. The highest increase in the total number of jobs occurred in the outer ring (by about 3,664 persons per 5 years on average), whilst the middle ring LGAs experienced an increase of about 1,401 persons per 5 years but only 886 persons per 5 years for the inner ring. As with the total number of jobs, the outer ring LGAs also experience the greatest increase in total number of workers by about 4,658 persons per 5 years, in contrast to only 165 persons per 5 years in the inner ring. In spite of the absolute increase in total number of jobs and workers in the inner and middle ring, their metropolitan share of both jobs and residential workers has decreased. As jobs have continuously decentralized towards the outer ring, the inner ring LGAs have experienced the greatest increase in average jobs distances (by about 1.05 km per 5 years). Middle ring LGAs experienced an increase of about 0.77 km per 5 years. The increase is only 0.16 km in the outer ring.

Table 3. Urban form variables changes per 5 years in the inner ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-494.36	138.71	13
CarAccess	2520.06	530.15	13
trainAccess	241.91	377.03	13
JobAccess	3874.32	1079.74	13
JOBDIS	1.05	0.09	13
TOTJOB	885.56	5881.22	13
TOTWRK	1088.46	2601.08	13
PROPJOB	-0.14	0.68	13
PROPWRK	-0.03	0.19	13
RATIOWJ	-0.05	0.13	13
WRKDEN	16.74	335.07	13
JOBDEN	-169.88	1194.13	13
%WRKCBD	-2.88	1.15	13
%WRKLOCAL	-0.13	1.22	13
%FLAT1+	-4.52	2.96	13
%SEMI	4.03	3.78	13
%Separate	0.48	1.26	13

Table 4. Urban form variables changes per 5 years in the middle ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-395.36	77.45	15
CarAccess	2748.60	438.53	15
TrainAccess	257.97	163.87	15
JobAccess	3931.18	519.46	15
JOBDIS	0.77	0.19	15
TOTJOB	1401.13	2111.90	15
TOTWRK	165.40	629.56	15
PROPJOB	-0.03	0.12	15
PROPWRK	-0.12	0.11	15
RATIOWJ	-0.04	0.07	15
WRKDEN	9.80	19.68	15
JOBDEN	43.05	68.72	15
%WRKCBD	-2.13	0.63	15
%WRKLOCAL	-0.35	1.20	15
%FLAT1+	-1.81	1.36	15
%SEMI	1.45	0.77	15
%Separate	0.36	1.44	15

A constant decrease in job density of about 170 persons per square kilometers per 5 years is experienced in the inner ring. On the other hand, the middle and outer ring experience increase by about 43 and 14 persons per square kilometers per 5 years, respectively. The average density of residential workers increased in these three regional rings. In terms of dwellings, all of the regional rings experienced a decrease in the proportion of high-density dwellings and an increase in the proportion of semi-detached and separate dwellings. Moreover, the proportion of workers employed in the CBD and locally has decreased in all of these three regional rings indicating an increase in the suburb to suburb trips.

Table 5. Urban form variables changes per 5 years in the outer ring of Sydney (1981-1996)

Variables	Mean	Std. Deviation	N
BusAccess	-148.91	64.42	16
CarAccess	1849.72	724.03	16
trainAccess	135.13	53.35	16
JobAccess	2676.81	961.11	16
JOBDIS	0.16	0.34	16
TOTJOB	3663.85	2532.24	16
TOTWRK	4657.50	3661.59	16
PROPJOB	0.14	0.16	16
PROPWRK	0.14	0.27	16
RATIOWJ	-0.01	0.11	16
WRKDEN	12.80	13.90	16
JOBDEN	13.92	17.15	16
%WRKCBD	-1.01	0.80	16
%WRKLOCAL	-1.19	2.39	16
%FLAT1+	-1.58	1.53	16
%SEMI	1.33	0.74	16
%Separate	0.25	1.07	16

Comparison in the Travel Mode Choice Changes

It has yet to be established whether significant differences exist in travel behavior between inner, middle and outer ring LGAs. This section compares travel behavior between these three regional rings in Sydney using analysis of variance, Benferroni method. Firstly, the comparison is performed using 1996 data only, it is then followed by the comparison of the average changes per 5 years. Table 6 shows the results of analysis of variance using 1996 data whilst Table 7 presents the results based on the average change per 5 years (during the 1981-1996 period).

Table 6. Comparison of Travel Behavior Between Groups of LGAs in Sydney (1996)

Dependent Variables	(I) Ring	(J) Ring	Mean Difference (I-J)
%Car	1	2	-10.4*
		3	-21.3*
	2	1	10.4*
		3	-11*
%Bus	1	2	14.9*
		3	18.7*
	2	1	-14.9*
		3	3.8
%Train	1	2	-4.5
		3	2.6
	2	1	4.5
		3	7.1
	2	1	90237
		3	-439449*

1=inner, 2=middle, 3 =outer ; The mean difference is significant at 0.05 level

Based on 1996 data, Table 6 shows that the proportion using car for inner ring residents is significantly lower by about 10.4 and 21.3 percent than that of middle and outer ring residents, respectively. The proportion using car for middle ring residents is significantly lower (by about 11 percent) than those in the outer ring. The inner ring residents have a significantly higher bus modal share by about 14.9 and 18.7 percent than that of middle and outer ring residents, respectively. However, there is no significant difference in the proportion using bus between the middle and outer ring residents. In terms of the proportion using train, there is no significant difference between the three regional rings.

Furthermore, based on the average change per 5 years, Table 7 shows that there is no significant difference between the three regional rings in terms of proportion using car. The outer ring residents experienced a significantly higher increase in bus modal share (by about 1.43 percent) than the inner ring residents. On the other hand, the increase in the proportion using train in the inner ring is significantly higher by about 0.97 and 1.17 percent than the middle and outer ring, respectively.

Table 7. Comparison of Travel Behavior Between Groups of LGAs in Sydney (Average Change per 5 Years Data)

Dependent Variables	(I) Ring	(J) Ring	Mean Difference (I-J)
%Car	1	2	7.3E-03
		3	0.26
	2	1	-7.3E-03
		3	0.25
%Bus	1	2	-0.98
		3	-1.43*
	2	1	0.98
		3	-0.45
%Train	1	2	0.97*
		3	1.17*
	2	1	-0.97*
		3	-0.20
	2	1	-2005
		3	-75339*

1=inner, 2=middle, 3 =outer

* The mean difference is significant at 0.05 level

Changes in the Mode Choice

For changes in mode choice, three transportation modes were considered – car, bus and train. The average change in the urban form variables per 5 years was expected to be associated with a change in the proportion using car and public transportation.

Changes in the Proportion Using Car as Dependent Variable

Table 8 shows the result of multiple regression analysis for the average change in the proportion using car as the dependent variable. In the inner ring, only the average change in accessibility to jobs by bus entered the model with a negative association. The LGAs in the inner ring that had a greater

increase in the accessibility to jobs by bus experienced a significant decrease in the proportion using car. The average change in accessibility to jobs by bus explains 38 percent of variation in the average change in proportion using car.

Two urban form variables entered the regression model for the middle ring, i.e. the average change in total number of residential workers (with a negative association) and the ratio of residential workers to jobs (with a positive association). This indicates that increasing the number of workers by about 1000

In the outer ring, only job density entered the regression model. The outer ring LGAs that had a greater increase in job density experienced a greater increase in the proportion using car. This finding suggests that increasing job density in the outer ring where there are plenty of parking spaces available, less congestion and a lack of public transportation services is not likely to reduce the use of car. The regression coefficient is statistically significant. However, the average change in job density only explains 39 percent of variation in the average change in the proportion using car.

When all LGAs are included, the average change in accessibility to jobs by bus and average job distances entered the model with a negative association. This indicates that LGAs with a greater increase in accessibility to jobs by bus and a greater increase in average job distances are associated with greater decrease in the proportion using car. A combination of these two variables explains only 27 percent of variation in the average change in the proportion using car.

Changes in the Proportion Using Bus as Dependent Variable

Table 9 presents the result of multiple regression analysis using stepwise procedure between the average change in proportion using bus as the dependent variable and urban form change as the independent variable. The model is developed for all rings, and also for the inner, middle and outer rings.

For each model, the regression coefficients, t-statistics, standar-dized coefficients (beta) and the significance are reported in-cluding collinearity test as given by tolerance and variance inflation factor (VIF) values. Tolerance values of less than 0.1 or VIF more than 10 indicate a collinearity problem. Acceptable tolerance value is 0.1 or over while VIF value is less than 10. The beta coefficients reflect the relative importance of the association of the independent variable with the change in the proportion using bus. A beta coefficient may be interpreted as the effect of one standard error change in the independent variable on the dependent variable measured in unit equals to its standard error. A variable with a larger beta coefficient has a greater effect on the dependent variable than one with a smaller coefficient.

Table 8. Regression Model for the Changes in Proportion Using Car as the Dependent Variable and Urban Form as the Independent Variables (Aggregate and by Rings)

Dependent Variable	Model	Unstandard-ised coeff.	Standardi-sed coeff.	t	sig	Tolerance	VIF	
%Car (Inner)	Constant	-1.56		-1.27	0.230			R=0.62
	BusAccess	-0.0063	-0.619	-2.61	0.024	1	1	R^2=0.38
								F=6.83
								Sig.=0.024
%Car (Middle)	Constant	1.91		12.49	0.000			R=0.84
	TotWrk	-7.96E-04	-0.588	-3.67	0.003	0.946	1.057	R^2=0.71
	RatioWJ	5.75	0.482	3.01	0.011	0.946	1.057	Adj. R^2=0.66
								F=14.6
								Sig.=0.001
%Car (Outer)	Constant	0.71		2.41	0.030			R=0.62
	JobDen	0.041	0.623	2.98	0.010	1	1	R^2=0.39
								F=8.9
								Sig.=0.010
%Car (All ring)	Constant	0.58		1.80	0.079			R=0.52
								R^2=0.27
								Adj. R^2=0.23
								F=7.5
								Sig.=0.002

Table 9. Regression Model for the Proportion Using Bus as the Dependent Variable and Urban Form as the Independent Variables

Dependent Variable	Model	Unstandard-ised coeff.	Standardi-sed coeff.	t	Sig	Tolera-nce	VIF	
%Bus (Inner)	Constant	1.81		1.10	0.294			R=0.58
	BusAccess	0.00076	0.577	2.34	0.039	1	1	R^2=0.33
								F=5.5
								Sig.=0.039
%Bus (Middle)	Constant	-1.19		-9.84	0.000			R=0.75
	RatioWJ	-6.039	-0.750	-4.09	0.001	1	1	R^2=0.56
								F=16.75
								Sig.=0.001
%Bus (Outer)	Constant	0.35		0.94	0.363			R=0.82
	RatioWJ	-6.42	-1.013	-5.09	0.000	0.638	1.567	R^2=0.67
	CarAccess	-4.66E-04	-0.480	-2.41	0.031	0.638	1.567	Adj.
								R^2=0.62
								F=13.28
								Sig.=0.001
%Bus (All ring)	Constant	0.21		0.70	0.491			R=0.71
								R^2=0.50
								Adj.
								R^2=0.48
								F=20.8
								Sig.=0.000

Table 10. Regression Model for the Changes in Proportion Using Train as the Dependent Variable and Urban Form as the Independent Variables

Dependent Variable	Model	Unstandard-ised coeff.	Standardi-sed coeff.	t	Sig	Tolera-nce	VIF	
%Train (Inner)	N/S (Not Significant)							
%Train (Middle)	Constant	-0.71		-6.50	0.000			R=0.73
	TotWrk	6.591E-04	0.726	3.80	0.002	1	1	R^2=0.53
								F=14.47
								Sig.=0.002
%Train (Outer)	Constant	0.64		2.63	0.022			R=0.91
	WrkCBD	1.18	0.778	5.19	0.000	0.639	1.565	R^2=0.83
	JobDen	-0.032	-0.455	-3.60	0.004	0.900	1.111	Adj. R^2=0.79
	JobDis	1.25	0.355	2.45	0.031	0.684	1.462	F=19.22
								Sig.=0.000
%Train (All ring)	Constant	-1.31		-3.87	0.000			R=0.72
								R^2=0.52
								Adj. R^2=0.47
								F=10.55
								Sig.=0.000

For the inner ring, only the average change in accessibility to jobs by bus (BusAccess) entered the model with a positive association. The LGAs in the inner ring with higher increases in their average accessibility to jobs by bus tended to have higher increases in the proportion using bus. Although the regression coefficient is statistically significant, it only explains 33 percent of variation in the average change in proportion using bus.

The average change in accessibility to jobs by bus did not enter the regression model in the middle ring. Only the average change in ratio of residential workers to jobs entered the model (with a negative association). The negative association implies that increasing the ratio of residential workers to jobs in the middle ring is associated with decreases in the proportion using bus. The variable explains 56 percent of the variation in the average change in proportion using bus.

The average change in the ratio of residential workers to jobs also entered the regression model in the outer ring. In addition, accessibility to jobs by car entered the model with a negative sign. Increasing the ratio of residential workers to jobs and accessibility to jobs by car was associated with decreases in the proportion using bus. A combination of these two urban form variables explains 67 percent of variation in the average change in proportion using bus in the outer ring. When considering all LGAs in Sydney, two urban form variables entered the regression model: the average change in accessibility to jobs by bus (with a positive association); and the ratio of residential workers to jobs (with a negative association).

Changes in the Proportion Using Train as Dependent Variable

The regression model given in Table 10 indicates that none of the urban form variables entered the regression model in the inner ring and only the average change in total number of residential workers entered the middle ring model with a positive association. Three urban form variables entered the regression model in the outer ring, i.e. the average change in proportion of workers employed in the CBD, job density and average job distance. Increasing the proportion of workers employed in the CBD by 10 percent was associated with the increase in train modal share by about 12 percent in the outer ring. On the other hand, increasing job density decreases the proportion using train. This indicates that the role of train is to serve CBD work

destinations for outer ring residents and it is not a competitive mode for local or suburb to suburb travel.

Four urban form variables entered the regression model for all LGAs, i.e. the average change in average jobs distance, proportion of workers employed in the CBD, proportion of residential workers and proportion of workers employed locally. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train. On the other hand, increasing the proportion of workers employed locally decreased the use of train. A combination of these four urban form variables explains 52 percent of variation in the average change in proportion using train with no problem of collinearity identified.

CONCLUSIONS

Changes in urban form variables in Sydney indicated that the highest increase in the total number of jobs occurred in the outer ring, followed by middle and inner ring. The outer ring LGAs also experienced the greatest increase in total number of workers. In spite of the absolute increase in total number of jobs and workers in the inner and middle ring, their metropolitan share of both jobs and residential workers has decreased. As jobs have continuously decentralized towards the outer ring, the inner ring LGAs have experienced the greatest increase in average jobs distances whilst the outer ring the lowest. A constant decrease in job density was experienced in the inner ring, while, the middle and outer ring experienced constant increase. The average density of residential workers increased in these three regional rings. In terms of dwellings, all of the regional rings experienced a decrease in the proportion of high-density dwellings and an increase in the proportion of semi-detached and separate dwellings. Moreover, the proportion of workers employed in the CBD and locally has decreased in all of these three regional rings indicating an increase in the suburb to suburb trips.

Based on the average change per 5 years, analysis of variance comparing travel behavior between the inner, middle and outer rings indicated that there was no significant difference in the changes in proportion using car between these regional rings. The outer ring residents experienced a significantly higher increase in bus modal share compared to that of the inner and middle ring. On the other hand, the inner ring residents experienced a significantly greater increase in the proportion using train than that of the other regional rings.

Results of multiple regression analyses indicated that for the proportion using car as dependent variable, the average change in accessibility to jobs by bus and average job distances entered the model with a negative association. This indicated that LGAs with a greater increase in accessibility to jobs by bus and a greater increase in average job distances were associated with greater decrease in the proportion using car. Two urban form variables entered the regression model for the proportion using bus: the average change in accessibility to jobs by bus (with a positive association); and the ratio of residential workers to jobs (with a negative association). In the case of the proportion using train, four urban form variables entered the model, i.e. the average change in average jobs distance, proportion of workers employed in the CBD, proportion of residential workers and proportion of workers employed locally. Increasing the average jobs distance, proportion of workers employed in the CBD and proportion of residential workers was associated with an increase in the proportion using train. On the other hand, increasing the proportion of workers employed locally decreased the use of train.

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