

URBAN FORM AND COMMUTING BEHAVIOR CHANGES (A LESSON TO BE LEARNED FROM THE CITY OF SYDNEY, AUSTRALIA)

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Abstrak

Peningkatan ketergantungan pada pemakaian kendaraan pribadi merupakan salah satu permasalahan utama yang dihadapi oleh banyak kota di dunia. Sudah banyak kota yang menyusun target untuk mengurangi Kendaraan-Kilometer Perjalanan. Untuk mencapai target tersebut, sangat penting untuk mengetahui bagaimana sebenarnya perubahan perilaku perjalanan penduduk mengikuti perubahan lokasi antara permukiman dan aktivitas (struktur kota) sepanjang waktu. Paper ini meneliti perubahan struktur kota sepanjang waktu dan bagaimana perubahan tersebut diikuti oleh perubahan perilaku perjalanan komuter. Fungsi Keinginan (preference functions) dipergunakan untuk mengukur perilaku perjalanan komuter. Kota Sydney dipilih sebagai lokasi kasus studi. Ditemukan bahwa perubahan struktur kota diikuti oleh perubahan perilaku perjalanan komuter. Peningkatan aksesibilitas ke tempat kerja yang dialami oleh sebagian besar zona yang berada pada lingkaran luar kota Sydney tidak diikuti dengan perubahan perilaku perjalanan komuter kearah meminimalkan jarak perjalanan, tetapi sebaliknya justru memaksimalkannya. Hal tersebut telah meningkatkan ketergantungan pada penggunaan kendaraan pribadi. Pengembangan model prediksi tata guna lahan dan transportasi perlu untuk memperhatikan variasi perilaku perjalanan tersebut dan perubahannya sepanjang waktu. Model distribusi perjalanan menggunakan satu parameter global saja tidak cukup akurat dengan adanya perubahan perilaku tersebut.

Kata Kunci: fungsi keinginan, perilaku komuter, Struktur kota.

Abstract

Increasing car dependence is one major problems faced by many cities in the world. Many cities have set a target in the reduction of Vehicle Kilometer Traveled (VKT). To achieve this target, it is essential to understand how resident commuting preferences have changed following the change in the relative housing-job location (urban form) over time. This paper investigates the change in urban form over time and how this change has been followed by the change in the resident commuting preferences. A preference function was used to measure this commuting behavior. Sydney metropolitan region was selected as a case study area. It was found that as the urban form has changed over time, the resident commuting preferences have also changed. The increase in the accessibility to jobs experienced by most LGAs located in the outer ring of Sydney was not followed by the shift in the commuting preferences towards distance minimization instead it was followed by distance maximizing behavior. This has increased car dependency. Development of predictive land-use and transportation models need to consider this variation in behavioral response and how it changes over time. A trip distribution model with one global parameter is unlikely to give sufficient accuracy given changing patterns.

Keywords: reference functions, urban form.

1. INTRODUCTION

The reduction in vehicle kilometer traveled (VKT) is one of the policy objectives adopted by many cities in order to achieve environmentally sustainable transportation [1], [2], [3], [4]. 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) [5]. Calibration of model prediction using census data for a certain year might lead to inaccurate prediction if the parameter is not stable over time [6]. It is essential to understand how journey-to-work travel behavior contributes to either longer or shorter journeys. One way of doing this is to examine the commuting preferences of residents, and to establish how they have changed over time since the redistribution of employment and residential workers. Preference functions can be used to

evaluate the behavioral response change of the residents following the change in urban form over time at the zonal level [5], [7].

Intuitively, a more convenient location of employment relative to housing is expected to reduce the length of trips. A preference function – the inverse of the intervening opportunities concept (Stouffer, 1940) – is a zonal aggregate of the travel behavioral response given a particular opportunity surface surrounding those travelers [8]. Steep gradients imply a preference for shorter commuting; shallow gradients imply a preference for longer trips.

The questions posed in this paper are: (a) how has urban form changed over time in the Sydney metropolitan region? (b) is Local Government Area (LGA) aggregate journey-to-work travel behavior, as measured by the slope of preference functions,

similar across the study area once the opportunity surface of jobs is normalized for each LGA? (c) are the shapes and slopes of preference functions for each LGA stable over time?

Using journey-to-work (JTW) Census data over a 35-year period from 1961 to 1996 in Sydney, this research investigates the change in the urban form and journey-to-work commuting preferences by all transportation modes. Descriptive statistics is applied to evaluate the trends in the commuting preferences over time. Historical patterns of development and the policies associated with them that may help to explain low (or high) performance is beyond the scope of this paper.

2. THEORY OF PREFERENCE FUNCTIONS

Several studies have reported the use of preference functions to evaluate residents' travel behavioral response to a normalized distribution of land-use opportunities. Black (1993) identified the varying values of the slopes of journey-to-work preference function across different cities [9]. Female workers were found to have steeper functions than males [10]. Masuya and Black (1992) claimed that the slope is influenced by the improvements in transportation technology, with lines of high-speed urban transit inducing shifts in the preference function [11]. Black and Katakos (1987) reported that the system upper bound of journey-to-work travel (distance maximization) increases substantially although the lower bound (distance minimization) remains much the same as a result of employment decentralization [12]. This approach determines the boundary conditions to the steepest and shallowest preference functions. This paper studies preference functions for all transportation modes over time following the change in the urban form in the Sydney metropolitan region.

Preference function is an aggregate of individual travel behavioral responses by a zonal grouping given a particular opportunity surface distribution of activities surrounding those travelers. Operationally, a journey-to-work preference function is the relationship between the proportion of travelers from a designated origin zone who reach their workplace destination zones, given that they have passed a certain proportion of the total metropolitan jobs. To derive such functions information is contained in O-D matrices. Proportion of zonal totals and metropolitan totals are used for standardization purposes, rather than absolute numbers, to facilitate comparison of the shape of preference functions across origin zones within a city, across different cities, and within the same city over time. Conceptually, the raw preference function is simply the inverse of

Stouffer's intervening opportunity theory that relates the proportion of migrants (travelers) *continuing* given reaching various proportion of the opportunities reached – or more technically-correct the *l*-factor parameter in the intervening opportunities model of trip distribution [13].

Stouffer's hypothesis formed the basis of operational models of trip distribution in some early land-use and transportation studies in the United States of America (for example, the Chicago Area Transportation Study during the late 1950s), and is expressed as:

$$P(dv) = (1-P(v) f(v))dv \quad (1)$$

Where:

$P(dv)$ = probability of locating within the dv opportunities, $P(dv) = dp$;

$P(v)$ = probability of having found a location within the v opportunities;

$1-P(v)$ = probability of having found a location within the v opportunities; and

$f(v).dv$ = probability of finding a suitable location within the dv opportunities given that a suitable location has not already been found.

The term $f(v)$ is often called the *l* parameter, or calibration parameter. It is the ordinate of a probability density function for finding a suitable location given that a location has not already been found. So, equation (1) may be rewritten as:

$$dP = (1-P) \cdot l \cdot dv \quad (2)$$

If *l* is a constant and the initial conditions are $P=0$ when $v=0$ then:

$$lv = -\ln(1-P) \quad (3)$$

Hence,

$$P = 1 - e^{-lv} \quad (4)$$

Whereas equation (4) is used to derive trip distribution models, equation (3) is the mathematical expression for the preference function. The relationship between the cumulative total number of opportunities passed, v , and the natural logarithm of the cumulative total number of opportunities taken, $\ln(1-P)$, is assumed to be linear. One of the issues was calibrating the *l*-factor parameter (Ruiter, 1967), and whether there was a break of slope to justify different parameters for "short" and "long" trips. There is little evidence in the literature that operational models based on Stouffer's hypothesis were developed, and transportation engineering practice generally favored the gravity model as a mechanism for forecasting future trip O-D tables.

The manual approach for studying the shifting trend of the preference function for a given zone is to superimpose all the preference functions at

different points in time onto the same graph and the shifting trend is obtained by visual inspection. However, the visual inspection tends to be difficult when the shift is not significant (e.g. all the curves are close to each other) and when there are many curves to compare. Therefore, the logarithmic curve of the preference function might be linearized using natural logarithmic transformation. The shifting trend of the preference function can then be evaluated by analyzing the change in the slope of preference instead of using visual inspection on the superimposed curves. This is in line with the theory of the intervening opportunities model, where it is stated that the preference functions should have linear form in which $X_{i,t}$ being transformed to $-\ln(X_i, t)$. The shape of the observed preference functions is transformed as follows using regression analysis:

$$Y = a [-\ln(X)] + b \quad (5)$$

where:

Y = cumulative proportion of zonal metropolitan jobs taken from each origin zone,

X = cumulative proportion of zonal jobs reached from each origin zone,

a = regression coefficient,

b = regression constant.

Unlike the raw preference functions these are the transformed preference functions with negative gradients, as in the above formula, where small (absolute) values of parameter a are associated with a preference for shorter trips and large (absolute) values are associated with a preference for longer trips, everything else being equal. The slope of these empirically determined preference functions tells us much about travel behavior as a pure response to opportunities, and not to transport impedance (distance, time or cost) as in the gravity model of trip distribution.

3. METHODOLOGY

Sydney has been selected as a case study area for this study. Sydney is characterized as a low-density, sprawling, car-dependent city, very like many North American cities. It has a high density CBD and several other regional sub-centers of high employment and residential density. Medium density housing is found in pockets especially in the inner suburbs. Sydney comprises about 50 local government areas (LGAs), however only 44 LGAs are considered in this study. Time-series journey-to-work census data over a 35-year period from 1961 to 1996 are available. The configuration of the 44 LGAs is shown in Figure 1. This analysis uses time-series journey-to-work (JTW) census data over a 35-year period from 1961 to 1996 for the analyses of preference function by all transportation modes. Inter-zonal (LGA) distances over the road network

were provided by the NSW State Transport Study Group, now the Transport Data Centre.

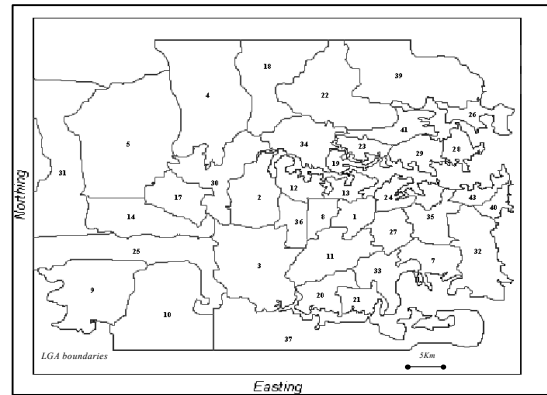


Figure 1 Sydney Zoning System

Note:

Zone 1(Ashfield), 2(Auburn), 3(Bankstown), 4(Baulkham Hills), 5(Blacktown), 6(Blue Mountain), 7(Botany), 8(Burwood), 9(Camden), 10(Campbelltown), 11(Canterbury), 12(Concord), 13(Drummoyne), 14(Fairfield), 15(Gosford), 16(Hawkesbury), 17(Holroyd), 18(Hornsby), 19(Hunter's Hill), 20(Hurstville), 21(Kogarah), 22(Ku-ring-gai), 23(Lane Cove), 24(Leichardt), 25(Liverpool), 26(Manly), 27(Marrickville), 28(Mosman), 29(North Sydney), 30(Parramatta), 31(Penrith), 32(Randwick), 33(Rockdale), 34(Ryde), 35(South Sydney), 36(Strathfield), 37(Sutherland), 38(Sydney), 39(Warringah), 40(Waverley), 41(Willoughby), 42(Wollondilly), 43(Woollahra) and 44(Wyong). Zones 15 (Gosford), 16 (Hawkesbury), 42 (Wollondilly) and 44 (Wyong) not in map.

4. RESULTS AND DISCUSSION

Urban Form Changes

Population in Sydney has continued to increase over time. The NSW Department of Transport (1999) reported that the total population during the 1991-1997 period increased by about 7.1 percent from 3,569,000 persons in 1991 to 3,822,000 persons in 1997 [14]. The number of travelers also increased during the 1991-1997 period by about 11.6 percent from 2,901,000 in 1991 to 3,236,000 in 1997. Similarly, the number of households has increased by about 8.9 percent from 1,293,000 in 1991 to 1,408,000 in 1997 with a decreasing average household size of about -1.6 percent (NSW Department of Transport, 1999). The location of population and jobs has changed over time followed by the change in the relative housing-jobs distances. Several measures of urban form are used here including job and housing distance from the CBD, dispersal index, and accessibility to jobs.

Housing Distance from the CBD

Like cities in other developed countries, Sydney has experienced the decentralization of housing location towards the outer areas over time. The change in the average housing distances from the CBD is used to measure this decentralization. Table 1 shows the change in the average housing distances from the CBD in Sydney over a 35-year period from 1961 to 1996. Because the 1986 JTW census data was not

published, the value for 1986 is obtained from the extrapolation based on 1981 and 1991 census data. It is shown that over this 35-year period the average housing distance from the CBD has increased by about 7.1 km (or 41.6 percent) from 16.9 km in 1961 to 24.0 km in 1996. This indicates that on the metropolitan average, people lived 16.9 km away from the CBD in 1961 and this increased to 24.0 km in 1996.

Although decentralization of housing still continues, the rate of change has decreased constantly. This might be an indication of some success in the urban consolidation policy of attracting more people to live in the inner areas of Sydney in order to achieve a more compact city. Overall, the average increase in the mean housing distance from the CBD is about one km per 5 year during the 1961-1996 periods.

Employment Distance from the CBD

The average employment distance from the CBD has also increased over time as shown in Table 2. The highest increase was experienced during the 1961-1966 period (as with housing) by about 1.6 km from 10.9 km in 1961 to 12.5 km in 1966. Although the average job distance from the CBD has continuously increased over time, the rate of increase has decreased consistently from 1.6 km during the 1961-1966 period to only 0.3 km in the 1991-1996 period. Over the 35-year period from 1961 to 1996, the average job distance from the CBD has increased by about 7.2 km (or 66.5 percent) from 10.9 km in 1961 to 18.1 km in 1996. The average change per 5 years during the 1961-1996 period is about 1.0 km. This increasing trend in the average job distance from the CBD confirms that decentralization of jobs has taken place in Sydney.

Table 1. Average Housing Distances from the CBD in Sydney (1961-1996)

Year	Average housing distance from CBD (km)	5-year change	Average housing distance change per 5 year	
			Absolute	(%)
1961	16.93	1961-1966	1.63	9.62
1966	18.56	1966-1971	1.20	6.46
1971	19.76	1971-1976	1.26	6.39
1976	21.02	1976-1981	1.26	5.99
1981	22.28	1981-1986	0.74	3.32
1986	23.02	1986-1991	0.73	3.20
1991	23.75	1991-1996	0.24	0.99
1996	23.98			
		1961-1971	2.83	16.70
		1961-1981	5.35	31.59
		1961-1991	6.81	40.24
		1961-1996	7.05	41.64

Relative Employment and Housing Location

Following the changes in the distribution of residential workers and employment location over time, the relative jobs and housing distance has also changed. In order to measure this change at the

metropolitan level, the dispersal index based on Brothie *et al.* (1996) is calculated [15]. Dispersal index is a measure of the relative dispersion of jobs to housing. Table 3 shows the average jobs and housing distance from the CBD in Sydney and the dispersal index over the 35-year period from 1961 to 1996. The difference between the average housing distance and the average job distance from the CBD is also presented. It is identified that although the location of housing on the average is further away from the CBD compared to the location of jobs, the average job distance from the CBD has increased at a greater rate than the average housing distance. This is shown by the change in the difference value which is closer to zero. When the difference is zero, it is an indication that, on average, the distance of jobs and housing from the CBD is equal. The dispersal index further indicates that the value has moved toward unity over time. The dispersal index of 1 indicates that the average job distance from the CBD is the same as the average housing distance. It is clearly shown that as the dispersal index approaches unity, jobs are decentralized at a faster rate than housing.

Table 2. Average Job Distance from the CBD in Sydney (1961-1996)

Year	Average job distance from the CBD (km)	5-Year Change	Average job distance change from the CBD	
			Absolute	(%)
1961	10.88	1961-1966	1.63	14.96
1966	12.50	1966-1971	1.21	9.66
1971	13.71	1971-1976	1.58	11.51
1976	15.29	1976-1981	0.77	5.02
1981	16.06	1981-1986	0.86	5.35
1986	16.92	1986-1991	0.86	5.08
1991	17.78	1991-1996	0.32	1.81
1996	18.11			
		1961-1971	2.84	26.07
		1961-1981	5.18	47.64
		1961-1991	6.91	63.51
		1961-1996	7.23	66.47

Accessibility to Jobs

Accessibility to jobs is calculated based on Hansen's accessibility index [16]. Figure 2 shows the job accessibility in Sydney by increasing LGA distance from the CBD over a 35-year period from 1961 to 1996. Accessibility to jobs tends to decrease by increasing the distance from the CBD. The Sydney LGA has the highest accessibility to jobs, about 179,933 in 1961. It reached 180,938 in 1996. Mosman has the lowest accessibility in the inner ring about 60,682 in 1961 and up to 84,537 in 1996. On average for the inner ring LGAs, the accessibility to jobs has increased from 90,706 in 1961 to 103,641 in 1966, followed by an unstable figure and it reached 110,216 in 1996. The average increase in the accessibility to jobs for the inner ring LGAs is about 2,787 per 5 year or 557 per year.

Table 3. Dispersal Index for Sydney (1961-1996)

Year	Average job distance from CBD (km)	Average housing distance from CBD (km)	Difference (km)	Dispersal index (DI)
1961	10.88	16.93	6.05	0.642
1966	12.50	18.56	6.06	0.674
1971	13.71	19.76	6.05	0.694
1976	15.29	21.02	5.73	0.727
1981	16.06	22.28	6.22	0.721
1986	16.92	23.02	6.10	0.735
1991	17.78	23.75	5.97	0.749
1996	18.11	23.98	5.87	0.755

The accessibility to jobs in the middle ring increased sharply mainly during the 1961-1966 and the 1991-1996 period. Based on 1996 census data, the accessibility to jobs in the middle ring ranged from 61,694 (Manly) to 101,611 (Burwood). Unlike unstable values experienced in the inner ring LGAs, the average accessibility to jobs in the middle ring LGAs has increased consistently from 56,305 in 1961 to 82,364 in 1996. On average, the accessibility to jobs in the middle ring has increased at about 3,723 per 5 year or 745 per year.

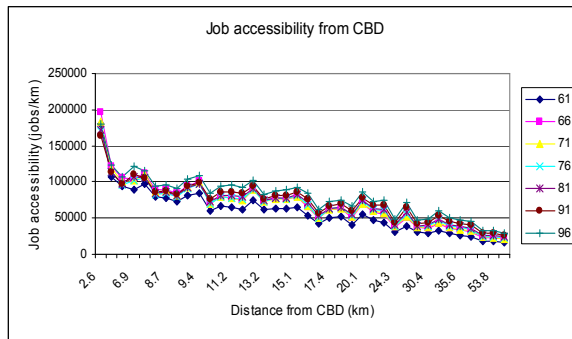


Figure 2. Accessibility to Jobs and Distance from the CBD in Sydney (1961-1996)

In the outer ring, Camden has the lowest accessibility to jobs over time whilst Holroyd has the highest. In 1996, the accessibility to jobs ranged from 29,256 (Camden) to 71,065 (Holroyd) with the average of 46,497. The accessibility to jobs in the outer ring LGAs has increased at a much steeper rate than that in the inner and middle rings as a result of job decentralization. On average, the accessibility to jobs in the outer ring has increased significantly from 26,812 in 1961 to 46,497 in 1996 with a rate of increase of 2,812 per 5 year or 562 per year – very similar to the inner ring that has the advantage of centrality.

5. COMMUTING PREFERENCES CHANGES

Preference function is applied to measure the commuting preferences in the Sydney metropolitan area. On average, for the inner ring LGAs, the positive (absolute value of the slope has decreased slightly during the 1961-1976 period from 0.207 in 1961 to 0.200 in 1976. It then increased constantly

to 0.210 in 1996. This indicates that, on average, the inner ring residential workers experienced a movement towards shorter trip preferences during 1961 to 1976 and then for longer trip preferences during the 1976-1996 period, although the differences are relatively small.

The middle ring residents, on average, experience a relatively stable slope over this 35 years period ranging narrowly from 0.218 in 1976 to 0.224 in 1961. In contrast to the inner and middle ring residents, the outer ring residents experienced a constant increase in the absolute slope from 0.150 in 1961 to 0.194 in 1996, which indicates a constant trend towards distance maximization behavior, yet with values slightly below those experienced in the inner two rings.

Furthermore, Figure 3 and Tabel 4 show that the mean slope (absolute value) for 38 LGAs in Sydney increased very slightly during 1961-1976 period from 0.197 in 1961 to 0.199 in 1976 and was then followed by a slightly steeper increase reaching 0.210 in 1996.

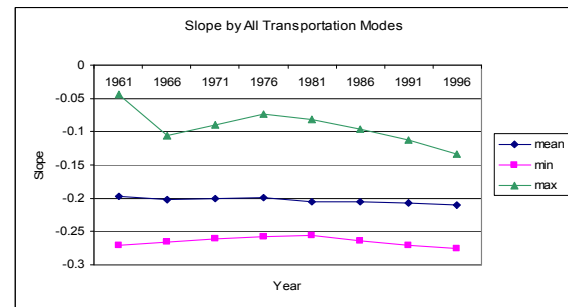


Figure 3. The Mean Slope Preferences for 38 LGAs in Sydney (1961-1996)

Table 4. Summary of Descriptive Statistics of the Slope Preferences in Sydney (1961-1996)

Statistics	1961	1966	1971	1976	1981	1991	1996
Mean	-0.197	-0.202	-0.201	-0.199	-0.205	-0.207	-0.210
Standard Deviation	0.047	0.035	0.035	0.034	0.031	0.028	0.027
Minimum	-0.270	-0.265	-0.261	-0.257	-0.256	-0.271	-0.276
Maximum	-0.045	-0.106	-0.090	-0.073	-0.082	-0.112	-0.134
Range	0.226	0.159	0.171	0.184	0.175	0.159	0.142

The slope will likely continue to increase slightly in the future if the distribution of residential workers and jobs and travel behavior follows existing trends. Continuation of decentralization trends in a scattered form will lead the behavioral preferences of residents toward longer trips or towards the distance maximization upperbound.

When plotted by the LGA's location at increasing distances from the CBD, Figure 4 shows that several LGAs in the inner and middle ring experience little change in the absolute value of the slope preferences during the 35 years period from 1961 to 1996. The slopes are relatively stable in

these areas. On the other hand, there is an increase in the slope (in absolute terms) experienced by the LGAs in the outer ring (beyond 20 km from the CBD). Despite decentralization of employment towards the outer areas experienced in Sydney during this period, the scattered location of the development may explain the change in the behavioral response of residents towards longer trip, or maximizing distance behavior. This indicates that in order to stabilize or slow the growth of resident preferences for longer trips in the outer areas, distribution of employment needs to be shaped and focused in several key areas instead of scattered evenly across the outer ring LGAs.

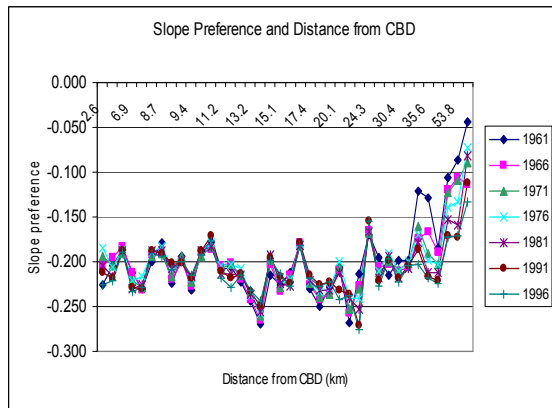


Figure 4. Slope Preferences by Increasing Distance from CBD (1961-1996)

6. CONCLUSIONS

The results of the urban form analyses indicated that urban form has changed overtime in the Sydney Metropolitan Region towards decentralization. The average job distance from the CBD has increased followed by the significant increase of the accessibility to jobs for the outer ring residents.

The results of preference function analyses for all transportation modes showed that the mean slope (positive or absolute value) for 38 LGAs in Sydney increased slightly from 0.197 in 1961 to 0.210 in 1996. This indicated the increasing preference for residents to travel for longer distances over time. There is no clear increasing or decreasing trend in the slope preferences of the LGAs by increasing distances from the CBD. The slope preferences are mostly stable in the inner and middle ring over the 35 years period from 1961 to 1996 whilst substantial increase is experienced by LGAs in the outer ring (beyond 20 km from the CBD). Despite decentralization of employment towards the outer areas experienced over time, this is not followed by the change in the commuting preference towards minimization. This may be partially explained by the scatter development of employment.

In response to the changes of the residents travel behavior, it is suggested that development of predictive land-use and transportation models for Sydney need to consider this variation in behavioral response. Several LGAs, in particular in the outer areas, experienced a dramatic increase in the preference towards distance maximization. It is clearly shown that the change in the relative location of jobs and residential workers over time was followed by a change in the preferences of residents towards shorter or longer trips. It seems that the variation in urban form across Sydney and the change over time is associated with the variation and change in travel patterns, which would lead to the variation and change in the energy consumption and transportation emissions. Further study is required to accommodate this environmental aspect.

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