JOURNEY-TO-WORK PREFERENCE FUNCTIONS: TEMPORAL AND SPATIAL STABILITY IN WESTERN PACIFIC RIM CITIES

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INTRODUCTION

As cities grow larger, and spread over increasing areas, then the average journey-to-work trip length tends to increase (Voorhees, 1968). Many cities around the Western Pacific rim have experienced rapid population growth and an internal restructuring, with changes in the spatial separation of land-use activities - especially homes and workplaces. The question arises as to whether journey-to-work trip lengths are a function of changes in the relative location of homes and workplaces (land-use effect), a function of commuters' general preference to travel longer, rather than shorter, distances (behavioural travel effect) relative to the location of activities, or a combination function of both effects. A methodology to unravel these effects is proposed. It is based on the intervening opportunities model (Stouffer, 1940).

For any given distribution of homes (resident workers) and workplaces, both the minimum and maximum amount of journey-to-work travel (subject to the land-use constraints) can be calculated using the Hitchcock transportation problem of operations research. As these land-use distributions change over time, the mean values for the upper and lower bounds to travel will indicate the potential effects of land-use changes. In addition, from the observed journey-to-work O-D pattern, it is straight forward to construct for each residential zone the proportion of work trips that continue on, given reaching any specified proportion of total metropolitan jobs. These theories and measurements are outlined in Section 1 of the paper. Whether these zonal preference functions remain stable with time, shift to the left, to the right, or change their gradients, reflects a behavioural travel response, controlling for land-use effects (Section 1.5). Zonal preference functions across different cities may be compared.

The methodology is tested in Section 2 using data from Sydney, Australia (1961-1981), Sapporo, Japan (1972 to 1983), and Shanghai, People's Republic of China (1986). This allows a comparison of the preference functions in three cities of very different urban structure and transport development. An interpretation of the reasons influencing the changes in the preference functions over time, and differences across cities are given (Section 2.5). The practical implications for transport modelling and on levels of model accuracy are addressed in the conclusions.

1. THEORIES AND MEASUREMENTS

1.1 Preference Function

A journey-to-work preference function is a curve of the relationship between the proportion of travellers from a designated origin zone who reach their workplace destination zone, given that they have passed a certain proportion of total metropolitan jobs. Proportions of zonal totals and metropolitan totals are used for standardisation purposes, rather than raw 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. As defined here, the raw preference function is the inverse of Stouffer's (1940) intervening opportunities model which related the proportion of migrants (travellers) *continuing* given reaching various proportions of opportunities reached.

Stouffer's hypothesis formed the basis of operational models of trip distribution in some early US land-use and transport studies (for example, Chicago), and some Australian applications (Miller 1969; Ogden, 1970). Several studies have evaluated the model's performance with gravity models (Heanue and Pyers, 1965; Jarema, *et al*, 1967). 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., and the research reported here has implications for transport model calibration.

1.2 Preference Function Boundary Conditions

An aggregate zonal raw preference function is based on the outcome of the relative spatial distribution of homes and workplaces, and on the propensity of travellers to take up "nearer" or "further away" job opportunities. Zonal functions with steep gradients will imply a preference of those resident workers for shorter commuting, whereas, those with shallow gradients will imply a preference for longer trips. The relationship between the actual travel outcome - as measured from a journey-to-work survey, for example - and the theoretical upper and lower bounds of the preference function may be explored by the Hitchcock transportation problem of operations research.

Blunden and Black (1984, pp. 100-107) have formulated this as a mathematical programme. The objective function is either to minimise or to maximise the total amount of travel in the system subject to the resultant origin-destination travel satisfying the land-use constraints of the correct zonal origin trip productions and destination trip attractions. An additional constraint excludes negative trip flows in the optimal solution. The relationship between these boundary conditions of the preference function are explored in the next sub-section.

1.3 Preference Function Estimation

The estimation of the shape of the zonal raw preference functions requires data for the zonal number of resident workers, the zonal number of job opportunities, the origin-destination pattern of traffic, and the inter-zonal transport impedance matrix (distance, travel time, generalised cost). Typically, such information may be extracted from Census data for the journey-to-work or from metropolitan land-use/transport studies.

A simple example with hypothetical data is outlined to show the basis of calculating raw preference functions and defining their upper and lower bounds.

A study area is partitioned into two residential zones, labelled 1 and 2, and three employment zones, labelled 3, 4, and 5. Table 1 combines the journey-to-work origin-destination matrix with the transport impedance (distance in km) matrix, where the top left of each element of the matrix is the traffic flow and the bottom right is the inter-zonal distance. (Note, this is set up as the classical transportation tableau for the optimisation problem.) The zonal trip productions are 300 and 700 for zones 1 and 2, respectively, and the zonal trip attractions for zones 3, 4, and 5 are 550, 200, and 250, respectively.

Table 1
Origin - Destination Data and Transport Impedance Matrix for Worked Example

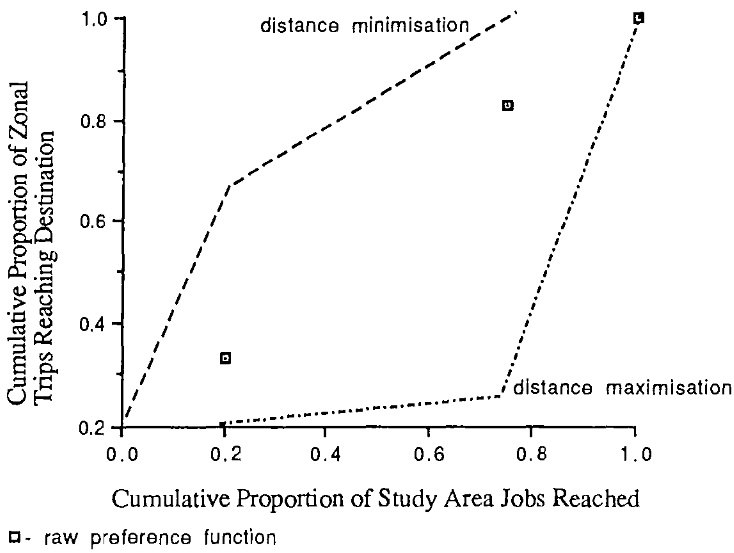
Origin Zone	Destination Zone		
	3	4	5
1	150 3	100 2	50 5
2	400 3	100 5	200 4

Consider zone 1, and the estimation of its raw preference function as set out in the following five steps. (1) Destination zones are ranked in order of increasing distance from the origin zone. (2) The cumulative number of jobs at increasing distance from the origin zone are calculated and these are expressed as a proportion of the metropolitan total (row 3). (3) From the O-D data, the number of jobs with destinations at increasing distance from the origin zone are set out (row 4). (4) The O-D flows are expressed as a proportion by destination of the total zonal trip productions - 300 in this case (row 5). Finally, the proportions are plotted as a graph (Figure 1). These steps are repeated to produce the preference function for zone 2.

(1)	Ranking of destination zones	4	3	5
(2)	Cumulative number of jobs reached	200	750	1000
(3)	Cumulative proportion of jobs reached	0.20	0.75	1.00
(4)	Cumulative origin zone trips by increasing distance	100	250	300
(5)	Cumulative proportion of zonal trips	0.33	0.83	1.00

The distance minimisation solution for the problem in Table 1 - using the standard transportation tableau method, or the simplex algorithm - yields the following desire line pattern (zero inter-zonal trips are excluded): 1 - 3 = 100; 1 - 4 = 200; 2 - 3 = 450; and 2 - 5 = 250. If we substitute this minimum origin-destination pattern of trips for the survey trips in row 4 above, the cumulative proportion can be calculated in row 5, and the results plotted in Figure 1 as "distance minimisation". Similarly, "distance maximisation" leads to the other boundary condition illustrated in Figure 1.

Figure 1
Raw Preference Function for Zone 1 in an Hypothetical Example



1.4 Curve Fitting

Unlike the worked example in sub-section 1.3, cities contain many destination zones and a procedure to estimate the parameters of the preference function is required. The shape of the raw preference function illustrated in Figure 1 is transformed as follows using regression analysis:

$$Y = \alpha[- ln(X)] + \beta$$

where,

Y = cumulative proportion of total metropolitan jobs taken from an origin zone;
X = cumulative proportion of zonal jobs reached from each origin zone;

α = regression coefficient;

β = regression constant; and
ln = natural logarithm.

Lotus 123 spreadsheets have a number of built-in functions and may be used to estimate the above parameters. Unlike the raw preference function illustrated in Figure 1 these are the transformed preference functions with negative gradients, as in the above formula.

1.5 Temporal and Spatial Stability of Preference Functions

There are five possibilities for change over time for the shape of the raw zonal preference function. Referring to Figure 1:

(a) it shifts completely to the left towards the Y-axis implying that travellers are tending towards a distance minimisation behaviour;
(b) it shifts completely to the right away from the Y-axis implying travellers are tending more towards a distance maximisation solution;
(c) the lower portion of the function shifts to the left whereas the upper portion shifts to the right (more shorter trips and more longer trips);
(d) the lower portion of the function shifts to the right whereas the upper portion shifts to the left (nearby trips are being extended whereas the longer distance trips are shortening)
(e) there is no change.

Spatial interaction modelling, as applied in transport planning practice, implicitly assumes spatial and temporal stability of parameters and would consider only the latter possibility. When considering the above changes in the transformed preference function (Section 1.4) the gradient tends towards zero in (a); the value of the gradient increases for (b); and the gradient remains constant for (e). Cases (c) and (d) are impossible to distinguish from the gradient alone and visual inspection of the raw preference function is required.

Spatial stability of the preference function implies that all zones have an identically shaped preference function. That is, once the different pattern of zonal job accessibilities are taken into account, there is a uniform travel behaviour in terms of the propensity to take up jobs. This assumption is convenient in the gravity and intervening opportunities models, for example, because it leads to the specification of one global parameter in the transport impedance function.

2. EMPIRICAL ANALYSIS

The three case study cities located along the Western Pacific rim - Sapporo (Japan), Shanghai (The People's Republic of China) and Sydney (Australia) - were selected as case studies because of their differences in population size and density (Table 2), transport technology and land-use/transport policies. Sapporo is the fifth major city in Japan in terms of population and is the smallest in area of the three case studies - one twelfth the area of Sydney yet with half the population. There has been major additions to transport infrastructure. Road planning in the City of Sapporo has undergone several alterations since the 1936 plan of 60 routes totalling 247 km. The 1965 plan, which forms the basis of the present road network, implemented one ring road, 5 large-scale radial roads and a by-pass, and as of March 1988, there are 190 designated routes of 754 km. A subway covers 14 km along the Nanboku (North-South) Line, completed in 1971, and 17 km along the Tozai (East-West) Line, completed in two stages in 1976 and 1982 (City of Sapporo, 1988). A new connecting line of 8 km opened in 1989.

Shanghai represents a marked contrast: the 900 km of roads that exist within the old central city boundary (with about 6 million people in an area of 149 square km) are

Table 2
Western Pacific Rim Case Study Cities, Population and Density

Study Area	Year	Population (millions)	Area (sq km)	Gross Density (persons/sq km)
Sapporo	1986	1.6	1,118	1431
Shanghai	1986	13.0	6,180	2104
Sydney	1986	3.4	12,5000	272

"a product of another time" (Pisarski and Pratt, 1987, p. 5). Shanghai's unique characteristic is a lack of motorised vehicles: about 130,000 - of which passenger cars are 13 per cent, buses are 6 per cent, trucks are 39 per cent, motorcycles are 13 per cent and tractors are 29 per cent. There are about 4 million bicycles, increasing at a rate of some 300,000 per year. The Shanghai metropolitan area given in Table 2 includes a hinterland beyond the city proper and this contains many factories and farms, with some 33 country towns and 100 smaller towns. The Shanghai Comprehensive Transportation Planning Team was formed in 1986 to make the first systematic, comprehensive, and coordinated urban transport plan and project evaluation for the region.

The Sydney metropolitan region has by far the lowest population density of the three case studies. In the post-war period, there has been rapid population growth fuelled by immigration, a continued sprawl of residences, and a suburbanisation of employment (encouraged by the 1951 County of Cumberland Plan, the 1968 Sydney Region Outline Plan, and the 1988 Sydney into its Third Century Strategy). Unlike American cities the freeway system is modest in extent, and various ring-radial plans - such as County of Cumberland Planning Scheme - or suburban grids - such as the 1971 Sydney Area Transportation Study proposals - have not been implemented. An extensive commuter rail network has been in place since the 1920s, and recent small additions have been limited to the East Hills line and to the Bondi Junction line. The use of private transport for the journey-to-work is higher than for Sapporo.

2.1 Data Source and Analysis

The Sapporo study area is controlled by the Sapporo Municipal Government. The main sources of data are the 1972 urban area personal trip survey (The First Do-oh Central Hokkaido) and the 1983 personal trip surveys (The Second Do-oh Central Hokkaido). The population increased from 1.1 million in 1972 to 1.5 million in 1983. The study area was divided into 53 zones and the matrix of inter-zonal distances were calculated from the location of zone centroids and the configuration of the highway network. Shanghai's metropolitan region has from 12 to 13 million people. There are 18 zonal districts defined for the inner area plus an additional 12 for the rest of the metropolitan region (Baogang, Minhang, Shanghai, Jiading, Baoshan, Chuansha, Nanhui, Fengxian, Qingpu, Jinshan, Songjiang, and Chongming). The Shanghai Comprehensive Transportation Planning Team conduced a home interview survey in

1986. Inter-zonal road distances were used for this analysis. The Sydney study area is the Sydney Statistical Division defined by the Australian Bureau of Census. It comprises the 40 local government areas (LGA) in the County of Cumberland plus four adjacent areas of Wollondilly, the Blue Mountains, Gosford and Wyong. This analysis used journey-to-work census data for 1961 (a 10 per cent sample), 1971, 1976 and 1981. During this twenty-year period, the population of the region increased from 2.4 million to 3.2 million. Inter-zonal (LGA) distances over the road network were provided by the State Transport Study Group of New South Wales.

A micro-computer program called PREFER was written in the Department of Transport Engineering, University of New South Wales. Its main functions are: to read in an origin-destination matrix; to read in a transport impedance matrix; to use the impedance matrix to rank in order of increasing distance all possible destination zones; to set up (and plot) all raw preference functions, as in Section 1.3; to transform the appropriate variables and to use regression analysis to estimate the function's parameters (Section 1.4); and to tabulate the value for the gradient obtained.

2.2 Sydney, 1961-1981

Results from Sydney are the most comprehensive, involving curve fitting of 176 data sets (44 LGAs x 4 Census Years), and have been fully documented (Ton, 1989, pp. 77-111 and Appendices). The spatial stability of transformed preference functions was tested by comparing gradients across all 44 zones at each census period. The range of gradients for the preference function in each year are:

	1961	1971	1976	1981
Zonal Minimum	-0.042	-0.047	-0.055	-0.080
Zonal Maximum	-0.284	-0.296	-0.300	-0.309

It is clear that the gradients of the preference functions vary over a wide range in each of the four years - a factor of nearly seven for the gradients in 1961 decreasing to almost four in 1981.

In addition to testing for spatial stability, temporal stability were checked by visually inspecting the shape of the preference function for each of the 44 zones over twenty years, and by calculating the minimum and maximum values for the gradients over three time periods (Table 3). The gradients for the transformed preference functions changed by less than 0.01 for twelve zones, by from 0.01 to 0.02 for twelve zones, from 0.02 to 0.03 for eleven zones and more than 0.03 for nine zones.

When supplemented by additional information on changes in the spatial pattern of resident workers and jobs, the following main conclusions may be drawn from the results in Table 3. There are a group of outer LGAs - Liverpool, Camden, Campbelltown, Penrith, Hawkesbury, Blacktown, Baulkham Hills, Hornsby, Blue Mountains and Gosford - where the raw preference functions have shifted to the right, implying a trend in travel behaviour towards distance maximisation. These are areas where there has been substantial growth in the number of resident workers, and, to a lesser degree, the number of locally available job opportunities. In all of these zones, the gradient of the transformed preference function changed by more than 0.03. Five of the six zones where the raw preference function has shifted to the left, implying a trend in travel behaviour towards distance minimisation, are found in the middle ring of

Table 3
Change in Zonal Preference Function Gradients, Sydney, 1961 to 1981

LGA	Minimum	Maximum	Range	Change
City of Sydney	-0.222	-0.170	0.052	Fluctuates
North Sydney	-0.221	-0.210	0.011	Fluctuates
South Sydney	-0.218	-.0.199	0.019	Fluctuates
Woollahra	-0.188	-0.182	0.006	Fluctuates
Waverley	-0.198	-0.185	0.013	Fluctuates
Randwick	-0.224	-0.201	0.023	Fluctuates
Botany	-0.180	-0.157	0.023	Fluctuates
Marrickville	-0.231	-0.219	0.012	Fluctuates
Leichhardt	-0.210	-0.197	0.013	Shift Right
Drummoyne	-0.199	-0.193	0.006	Shift Right
Ashfield	-0.236	-0.216	0.020	Shift Left
Burwood	-0.226	-0.209	0.017	Fluctuates
Concord	-0.217	-0.192	0.025	Fluctuates
Strathfield	-0.231	-0.224	0.007	Fluctuates
Canterbury	-0.272	-0.255	0.017	Shift Left
Rockdale	-0.231	-0.228	0.003	Fluctuates
Kogarah	-0.232	-0.217	0.015	Shift Left
Hurstville	-0.253	-0.229	0.024	Shift Left
Sutherland	-0.217	-0.188	0.029	Fluctuates
Bankstown	-0.268	-0.239	0.029	Shift Left
Auburn	-0.212	-0.198	0.014	Fluctuates
Holroyd	-0.217	-0.197	0.020	Fluctuates
Fairfield	-0.207	-0.199	0.008	Fluctuates
Liverpool	-0.180	-0.122	0.058	Shift Right
Camden	-0.087	-0.044	0.043	Shift Right
Campbelltown	-0.156	-0.105	0.051	Shift Right
Penrith	-0.170	-0.091	0.079	Shift Right
Hawkesbury	-0.086	-0.042	0.044	Shift Right
Blacktown	-0.217	-0.189	0.028	Shift Right
Parramatta	-0.252	-0.215	0.037	Shift Right
Baulkham Hills	-0.216	-0.131	0.085	Shift Right
Hornsby	-0.219	-0.201	0.018	Shift Right
Ryde	-0.225	-0.214	0.011	Shift Right
Hunters Hill	-0.185	-0.178	0.007	Fluctuates
Lane Cove	-0.210	-0.203	0.007	Fluctuates
Willoughby	-0.208	-0.199	0.009	Fluctuates
Ku-ring-gai	-0.236	-0.228	0.008	Fluctuates
Warringah	-0.167	-0.160	0.007	Shift Left
Manly	-0.180	-0.176	0.004	Fluctuates
Mosman	-0.191	-0.183	0.008	Fluctuates
Wollondilly	-0.080	-0.055	0.025	Fluctuates
Blue Mountains	-0.309	-0.284	0.025	Shift Right
Gosford	-0.088	-0.053	0.035	Shift Right
Wyong	-0.057	-0.040	0.017	Fluctuates

suburbs to the west and southwest of the city centre - Ashfield, Canterbury, Bankstown, Hurstville and Kogarah. These areas are characterised by a relative decline in resident workers and jobs. The outer northern suburb of Warringah experienced growth but the raw preference function shifted to the left. Of the remaining zones, no consistent trend in the preference function was discernible, with the gradients fluctuating one way then the next over time, or changing relatively little over time.

2.3 Sapporo, 1972 to 1983

The spatial stability of preference functions in Sapporo was tested by comparing gradients across all 53 zones for the survey years of 1972 and 1983. The range of gradients in the two years are:

	1972	1983
Zonal Minimum	0.364	0.091
Zonal Maximum	0.300	0.330

Again, the preference functions were found to vary by a large factor - five fold in 1972 reducing to a little under four fold in 1983. Over a nine-year time period, 41 of the 53 zones were found to have increasing gradients - that is 80 per cent of zones had raw preference functions shifting to the right, implying commuters were travelling further afield than the distribution of jobs would indicate. In comparison, in Sydney, from 1971 to 1981, a little over one half of the zones were found to have increasing gradients, or raw preference functions shifting to the right.

2.4 Shanghai

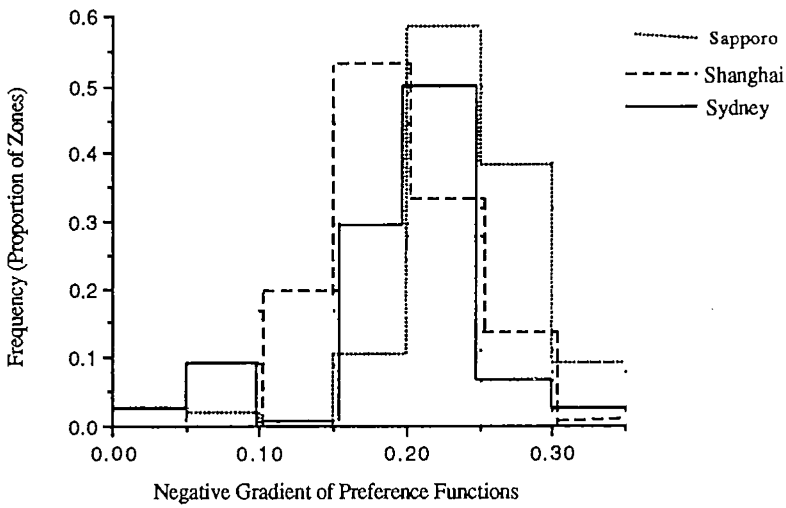
There is no time series data available for journey-to-work travel in Shanghai, and so the analysis was restricted to comparing gradients across the 30 zones of the metropolitan region. A clear distinction was found between the gradients of the city and suburbs (zones 1 to 18) and the gradients of the metropolitan hinterland. The values for the city and suburbs range from -0.105 to -0.261, but for the fringe and remote areas, from -0.00096 to -0.0681. The lowest value is recorded for Chongming (zone 30) which is an island at the mouth of the Huangpu River from which very few commuting trips are made (by ferry).

2.5 Interpretation

The analysis of the three case studies allows some general observations to be made. The zonal preference functions vary within a study area at any point in time. There is a discernible geographical pattern, with peripheral zones having much steeper raw preference functions. This is especially noticeable with the outer local government areas of Sydney, and with the twelve peripheral zones around Shanghai. Changes over time were examined for Sapporo and Sydney and the preference functions were found to be unstable over time. In Sydney, over a twenty-year period, 24 zones had fluctuating functions, 14 had raw preference functions shifting to the right, and 6 zones had raw preference functions shifting to the left. Only in these latter six zones were travellers moving consistently towards "distance minimisation" given the re-distribution of job opportunities. In Sapporo, 80 per cent of the raw zonal preference functions had shifted to the right over a nine-year period.

A comparison of the zonal gradients for Sapporo (1983), Shanghai (1986) and Sydney (1981) - using the most recent data for each city - is given in the frequency distribution of Figure 2. For Shanghai, only those 18 zones which can correctly be described as contiguously urban are included in this analysis. In general, the distribution is skewed on the left for Shanghai, and skewed to the right for Sapporo, although there are similar values for all three cities in the range from -0.15 to -0.25.

Figure 2
Frequency Distributions of Preference Function Gradients Sapporo, Shanghai and Sydney in the 1980s



Some suggestions for these differences in aggregate journey-to-work travel behaviour may be offered. In Shanghai there are several factors that result in a more distance minimisation travel behaviour. First, national housing policy is such that the work unit (*danwei*) allocates rental apartments to employees and these are often located near to the workplace. However, in practice, this is complicated by multiple workers living in one dwelling unit, and the fact that new employees wait on housing lists and must find interim accommodation. Secondly, there is a habit amongst Shanghai residents to crowd into the central area: even suburbs are regarded as being inconvenient. Thirdly, anything above half-an-hour cycling time is regarded in Shanghai as being inconvenient. In Sapporo, transport investment in main roads and a subway system in a relatively small study area has appeared to facilitate commuters travelling further afield. Employer subsidised commuting fares encourages this.

Zonal preference functions change over time for many parts of a study area. The most dramatic shifts in the direction of "distance maximisation" are on the periphery of cities when essentially ex-urban communities that initially have a high degree of intra-zonal travel to free standing towns are "hooked" into a metropolitan commuting system. This has happened for example in Sydney where rapid suburbanisation of housing has outstripped the supply of locally available jobs. The implication for the outer zones of Shanghai are that as transport improvements are made more workers will be drawn into the central areas to work: the freeway through Jiading county is one example. In Sydney, Black (1987) has already assessed the impact of a second Sydney Harbour crossing on travel patterns, and the Sapporo analysis suggests the opening of the subway has also helped change commuters' travel preferences towards "distance maximisation" for those living adjacent to stations.

CONCLUSIONS

A methodology has been described to examine whether there is a general preference for commuters to travel longer, rather than shorter, distances once the relative location of homes and workplaces have been accounted for. It exploits Stouffer's hypothesis and relates zonal preference functions to their upper and lower bounds, as determined mathematically by optimisation techniques. From case studies of journey-to-work data in Sapporo, Shanghai and Sydney, it is concluded that these preference functions vary both spatially and temporally. Specific differences noted in the case studies have been interpreted - especially the influence of transport infrastructure investment on travel behaviour.

Comparative studies shed light not only on travel behaviour but they have implications for land-use and transport modelling. Spatial interaction models assume one global parameter for trip-length distributions. For example, in Sydney in 1981, the gradient for all zones combined (regional mean) would be -0.173 (standard deviation 0.058) but any difference between this and the correct zonal gradient would lead to estimation errors in modelling. The misallocation of predicted trips to destination zones ranges from about 11 per cent for workers from the city of Sydney, 17 per cent for a middle distance suburb of Bankstown, and 43 per cent for a peripheral area such as Gosford. Similarly, forecasting errors are introduced by not accounting for temporal changes in zonal parameters. By examining changes over time using the framework suggested in this paper model builders should have clearer idea of the direction of parameter changes rather than having to use *ad hoc* adjustment factors, which appears to be current practice (Dasgupta, 1991, p. 488).

ACKNOWLEDGEMENT

The authors thank the following who provided data: Mr K. Yamaya, Chief, Planning and Coordination Bureau, and Mr Y. Omo, Traffic Planning Section, Sapporo Municipal Government; Mr Chen Sheng Hong, Director, Shanghai Comprehensive Transportation Planning Team; and Mr R. Leavens, formerly State Transport Study Group of NSW. Associate Professor Xu Weici, Department of Road Engineering, Tongji University, Shanghai, assisted in obtaining the data. Software development was undertaken by Tu Ton and by Youzhen Cheng whilst he was a visiting honorary fellow at the University of NSW, visiting from Zhejiang Communications College,

Hangzhou, The People's Republic of China. Yuzo Masuya was also a visiting honorary fellow at the University of NSW.

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