TRANSPORTATION INFRASTRUCTURE DEVELOPMENT AND JOURNEY-TO-WORK PREFERENCE FUNCTIONS IN SAPPORO

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This paper presents the methodology to examine whether there is a general preference for travel longer, rather than shorter, distances once changes in the relatives location of homes and workplaces have been accounted for. The methodology exploits Stouffer's hypothesis and relates zonal preference functions to their upper and lower bounds, as determined mathematically by optimisation techniques. Its specific application in this paper has been to study changes in journey-to-work preference functions in Sapporo using person trip data for 1972 and 1983. The influence of transport infrastructure on travel behaviour is examined by contrasting the findings for the Nanboku Subway Line and the Tozai Subway Line.

1. INTRODUCTION

The impact of land use on transport is relatively well understood: there are established techniques to calculate travel demand (trip generation, distribution, mode choice, and assignment) as a mathematical function of land use (Blunden and Black,1984). The reverse interaction - that of the impact of transport on land-use - is less well understood. It is generally accepted that the provision of high capacity transport infrastructure in urban areas, such as freeways or subway, encourages, among other things, people to travel longer distances, especially for journey- to-work. One theory is that people have a constant "travel time budget" and that commuters trade off increase distances for the same travel time afforded by substituting faster modes of transport.

There are methodological problems in unravelling such relationships. Major urban transport infrastructure takes a long time to plan and implement (and is often staged in construction). The temporal aspect of locational decisions - where people choose to live and to work, and how these change over time - and the impacts over time of transport investment on peoples' travel patterns, especially commuting distances, are still only imperfectly understood. Much land-use and transport analysis is undertaken on cross-sectional data, and there is a need to understood changes over time - the dynamic aspects of urban structure and travel. Research in the Department of Transport Engineering, University of New South Wales, is aimed to studying some of these dynamics (Black,et. al,1982; Black and Katakos 1987; Black, 1987; Ton, 1989; Cheng and Black, 1992; and Black, et . al, 1992)

This paper reports on part of this research that involves a comparison of cities with different urban structure and travel patterns: Sydney (Australia) ;Shanghai (The People's Republic of China), and Sapporo (Japan). Sapporo provides a suitable case study city because journey-to-work origin destination travel data is available for 1972 and again for 1983, and a major subway line - the 17 km long Tozai (East-West) Line - was opened between dates of these surveys, with the first stage in June, 1976, and the second stage, in March, 1982. The data allow journey-to-work preference functions (which may be contrasted with the calibration parameter of the intervening opportunities model of trip distribution) to be constructed for 53 zones in 1972 and 1983. The behaviour of the shape of the these functions over time is analysed. Specifically, we ask whether those zones adjacent to the Tozai Subway Line have changing preference functions that indicate commuters are by-passing closer opportunities and are travelling further afield, when compared with those zones adjacent to the Nanboku (North-South) Line that was opened in December, 1971.

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keywords : Journey-to-work, Preference function, Transport investment, Travel behaviour, Subway, Sapporo

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The paper is organised in the following way. Section 2 defines a journey-to-work preference function as the relationship between the proportion of commuters from a designated origin zone who reach their workplace destination given that they have passed a certain proportion of total metropolitan jobs. With changing urban structure over time - more people and jobs and a different spatial distribution of land-use activities -this is a powerful way of comparing two time periods. In Section 2, the similarity to the Stouffer(1940) intervening opportunity model is indicated. Also, the preference function's relationship with the standard gravity model and with mathematical programming approaches is demonstrated with a simple worked example. Curve fitting is also explained. Section 3 indicates the data sources from the first and second personal trip surveys and set out the results of the empirical analyses of the 1972 and 1983 zonal preference functions. Major land-use and transport infrastructure developments in the Sapporo region are described in Section 4, and the impact of the Tozai Subway Line on journey-to-work travel behaviour is examined. The conclusions speculate both on the relationship between transport infrastructure development and travel behaviour, and on implications for land-use and transport modelling.

2. THEORIES AND MEASUREMENTS

2.1 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 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. 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 is expressed as:

$$\mathbf{P(dv) = (1\text{-}P(v)) \cdot f(v)dv} \qquad (1)$$

where,

- $\mathbf{P(dv)}$ = probability of locating within the dv opportunities, $\mathbf{P(dv)=dP}$;
- $\mathbf{P(v)}$ = probability of having found a location within the v opportunities;
- $\mathbf{1\text{-}P(v)}$ = probability of not having found a location within the v opportunities;
- $\mathbf{f(v)dv}$ = 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. Equation (1) may be rewritten as:

$$\mathbf{dP = (1\text{-}P) \cdot L \cdot dv} \qquad (2)$$

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

$$\mathbf{Lv = -ln(1\text{-}P)} \qquad (3)$$

Hence

$$\mathbf{P = 1\text{-}e^{-Lv}} \qquad (4)$$

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. Several studies have evaluated the intervening opportunities 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.

2.2 Preference Function Boundary Condition

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 (Hitchcock, 1941).

Blunden and Black (1984, pp.100-107) have formulated this as a mathematical programming problem. The objective function in the primal 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 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 with a simple worked example.

2.3 Preference Function Estimation

The purpose of this sub-section is to explain, with an hypothetical worked example, how to estimate the shape of the raw preference. Its relationship to the upper and lower bounds based on optimisation techniques is demonstrated. The approach is contrasted with calibrating a fully-constrained gravity model.

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 home-interview surveys conducted as part of metropolitan land-use/transport studies. The same information could be used to calibrate a gravity model of trip distribution, or to solve Hitchcock' s transportation problem.

Assume that 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

(a) Raw Preference Function

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).

Zone 1

(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

These steps are repeated to produce the preference function for zone 2.

Zone 2

(1)Ranking of destination zones
3 5 4
(2)Cumulative number of jobs reached
550 800 1000
(3)Cumulative proportion of jobs reached
0.55 0.80 1.00
(4)Cumulative origin zone trips increasing distance
400 600 700
(5)Cumulative proportion of zona trips
0.57 0.86 1.00

(b) Mathematical Programming

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 interzonal trips are exclude): 1-3=100;1-4= 200;2-3=450; and 2-5=250. Note that there are (m+n-1) basic solutions, where m is the number of origin zones (m=2) and n is the number of destination zones (n=3). 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.

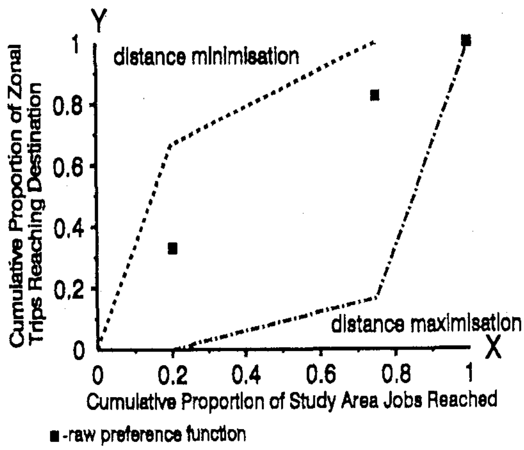

Figure 1 Raw Preference Function for Zone 1 in a Hypothetical Example

(c) Gravity Model Calibration

Assume that we wish to calibrate the fully constrained gravity model with a power function of transport impedance given in equation 5 using the data in Table 1.

$$Q_{ij} = x_i y_j P_i A_j D_{ij}^{-\alpha} \quad i=1,2 \; j=3,4,5 \qquad (5)$$

where

Q_{ij} = an estimate of the number of trips from zone i to zone j;

x_i, y_j = mathematical balancing factors;

P_i = total number of zonal trip productions in zone i;

A_j = total number of zonal trip attractions in zone j;

D_{ij} = inter-zonal distance in Km ; and

α = calibration parameter.

The calibration criterion is for the model mean trip length to equal the survey mean trip length, which, in this example, is 3.4 Km. Calibration is achieved by adjusting α until the correct value is found. Here, α equals approximately unity (1) with the following set of balancing factors:

$x_1 = 0.002996$; $y_3 = 0.8957$;
$x_2 = 0.003501$; $y_4 = 1.0644$; and
$y_5 = 1.2619$

The gravity model yields mxn solutions and the estimate of the desire line pattern traffic (with rounding to give integer values) is : 1-3=148; 1-4=96; 1-5=57; 2-3=402; 2-4= 104, and 2-5=193.

2.4 Curve Fitting

Unlike the worked example in subsection 2.3, 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:

$$Y = \alpha[-\ln(X)]+\beta \qquad (6)$$

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.

This transforms the function into a form more commonly encountered in transport planning practice.

Lotus 123 spreadsheets have a number of built-in functions that may be used to estimate the above parameters and software called PREFER has been developed at the University of New South Wales, Department of Transport Engineering (Ton,1989). Unlike the raw preference function illustrated in Figure 1, these are the transformed preference functions with negative gradients, as in the equation (6). In the hypothetical example of the two origin zones and three destination zones, the parameters are estimated to be α=-0.404 and β=0.975.

3. CASE STUDY, SAPPORO, 1972 TO 1983

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 survey (The Second Do-oh Central Hokkaido). The population increased from 1.1 million in 1972 to 1.5 million in 1983. Commenced 1971, the subway system comprises a 14 Km north-south line (Nanboku Line) and a 10 Km east-west (Tozai Line) offering services eighteen hours daily with four-minutes headway in the peak. The study area was divided into 53 zones illustrated in Figure 2. The matrix of inter-zonal distances were calculated from the location of zone centroids and the configuration of the highway network.

This section presents the results of a comprehensive investigation of the shapes of zonal preference functions. Sub-section 3.1 outlines all possible changes in shape of these functions over time. Changes from 1972 to 1983 are classified according to this schema. Sub-section 3.2 presents the results of the curve fitting exercises for the zonal preference functions.

3.1 Temporal Change in Preference Functions, 1972 to 1983

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 (called "shift left");

(b)it shifts completely to right away from the Y-axis implying travellers are tending more towards a distance maximisation solution (call "shift right");

(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 (called "cross, L, R");

(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 long distance trips are shortening (called "cross, R, L"); or

(e)there is no change.

Raw preference functions were drawn for the 53 zones of the Sapporo study area using the origin-destination data for 1972 and 1983. The results of the visual change in shape of the preference function over time are summarised in Table 2. The X-ordinate - the proportion of total metropolitan jobs - is divided arbitrarily into two sections - less than 0.6 and greater than 0.6 - and the columns give the changing position of the 1983 preference function for these two sections. Of the 53 preference functions, 20 have shifted to the left (distance minimisation behaviour), 17 have moved to the right, 10 have crossed (left, right) - more shorter trips but more longer trips - and 6 have crossed (right ,left) - shorter trips are extending and the further ones shortening.

One way of quantifying this change over time is to calculate the area under the curve of the preference function bounded by the X-axis and the ordinate X=1. By subtracting the area obtained for each zone in 1983 from that obtained for 1972 provides an overall indication of the direction of change. Negative values indicate the function has shifted towards the right from 1972 to 1983. 26 of all 53 zones, had negative changes in area and 27 of the zones had positive changes in area. Because some of the changes in area are small, zones have been grouped into three categories by change of area(dA):

$$dA < -0.01 \quad \text{(18 zones);}$$
$$-0.01 < dA < 0.01 \quad \text{(15 zones); and}$$
$$dA > 0.01 \quad \text{(20 zones).}$$

Table 2 Temporal Trend of Raw Preference Functions, Sapporo, 1972 to 1983

0.0<x <0.6	0.6<x <1.0	Shifting Trends	Zone No.
SL	SL	Shift Left	2, 7,18,21,22,23,24, 25,26,28,29,30,33,40, 41,43,45,47,52,53
SR	SR	Shift Right	1, 4, 5,10,11,14,15, 17,31,32,34,36,37,46, 48,50,51
SL	SR	Cross (L,R)	3, 6, 8, 9,12,19,20, 38,39,49
SR	SL	Cross (R,L)	13,16,27,35,42,44

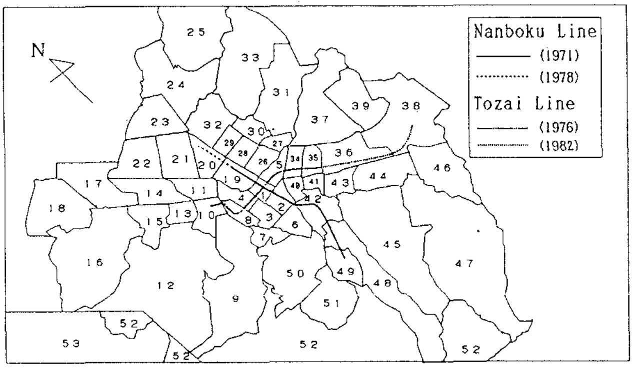

Figure 2 Zone System specified for the analysis and Subway System of Sapporo

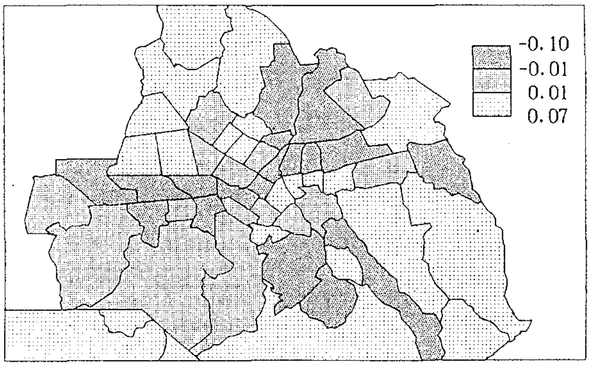

Figure 3 Map showing the Change in Area under the Zonal Raw Preference Function Curves, Sapporo, 1972 to 1983

The spatial pattern of these changes are illustrated in Figure 3. The zones where functions have shifted to the right follow largely the subway lines, and ten extend outwards beyond their reach. The zones where the functions have shifted to the left are found in outer suburban and in the middle distance suburbs.

3.2 Curve Fitting, 1972 and 1983

In sub-section 2.4 curve fitting of the transformed preference functions was explained. This approach was applied to data for each of the 53 zones in Sapporo in 1972 and 1983. The correlation coefficient was very high (between 0.84 and 0.99) in both years. Table 3 summaries the gradients (X-coefficient(α)) of transformed preference functions for 1972 and 1983 in the form of a frequency distribution. In 1972, the range was from 0.142 to 0.292; in 1983, the range had shifted upward from 0.192 to 0.330. The modal value for the gradient is 0.25 in both years, but, in 1983, 80% of the zones fell in the range 0.25 to 0.30 (compared with 68% in 1972). These gradients had increased in their negative values implying that commuters were moving towards distance maximaisation.

It may be noted that additional work on the transformed preference functions were undertaken to marginally improve curve fitting. When transformed, many of the preference functions in Sapporo are still not linear. Improved fits were obtained by segmenting the function into either two or three parts (either, X=0 to 0.1,X=0 to 0.6, and X=0.6 to 1.0). For all 53 zones, for X greater than 0.6, the logarithmic function provided the best fit. For 11 zones, a linear function was best for the range X=0 to X=0.6. For the remaining 42 zones, it was better to partition into X=0 to X=0.1, and X=0.1 to X=0.6, and use separate linear functions.

4. IMPACT OF TRANSPORT INFRASTRUCTURE

As cities grow larger, and spread over increasing areas, evidence from North American cities is that the average journey-to-work trip lengths increase (Voorhees ,1968). The question arises as to whether journey-to-work trip lengths are : (a) a function of the relative location of homes and workplaces (increasing spatial separation of complementary land-use activities); (b) a function of commuters' general preferences to travel longer, rather than shorter, distance (a behavioural travel effect of people moving away from distance minimisation to distance maximisation) relative to the location of homes and workplaces; or (c) some combination of both. A method of unravelling some of these dynamics has been described in Section 2: by considering the proportion of total job opportunities at increasing distance from the residential zone, the spatial restructuring of land-use activities can be controlled, and the behavioural travel effect isolated.

Table 3 Frequency Distribution of the Gradients of the Transformed Preference Functions, Sapporo, 1972 to 1983

Gradient	1972		1983	
α	No. of Zones	%Zones	No. of Zones	%Zones
-0.10	1	2%	1	2%
-0.15	2	4%	0	0%
-0.20	14	26%	5	9%
-0.25	20	38%	26	49%
-0.30	16	30%	17	32%
-0.35	0	0%	4	8%

Evidence from Sapporo 1972 to 1983 presented in the previous section indicates that commuters are trending to "by-pass" the nearer opportunities for those further away in some parts of the city. This section investigates the extent to which investment in high capacity transport infrastructure is a factor in these zonal raw preference functions shifting to the right. Specifically, the impact of the Tozai Subway Line is studied and contrasted with the Nanboku Line which opened in 1972. First, however, changes in Sapporo's urban spatial structure are outlined.

From 1972 to 1983, growth was accompanied by internal restructuring of homes and workplaces. The total number of jobs increased from 335,218 to 498,434 - an extra 163,216 jobs. There was a relative decentralisation of workplaces, with the five inner share falling from a half of all metropolitan jobs in 1972 to about 40% in 1983. The number of jobs in many of the outer suburban zones, doubled between 1972 and 1983 (zones 41 and 53 being an exception), and the proportion of suburban jobs had risen by 1983. This was accompanied by relative dispersal of homes from the central area - zones 2, 3, 5 and 19 loosing over 6,000 resident workers.

Urban planning has undoubtedly influenced these locational trends. In 1965, a long-term plan for use zones and the road network was set up. This formed the basis for the present network of 1 ring road, 1 by-pass and 5 radials. The urbanisation promotion area was laid out in July, 1970, and, in March of the following year, the Sapporo Long-Term Comprehensive Development Plan was set up. In December, 1976, the New Long-Term Comprehensive Development Plan was completed with a target completion date of 1995. The expansion of urbanisation promotion areas required further alterations, and additional road plans have been designated (190 routes and 754 Km in total length) as of March 31, 1988. The urban rapid transit railway (subway) in now in operation and serves as a major means of mass transportation.

A 12.1 Km section of the Nanboku Line between Makomanai and Kita-Nijuyojo was completed in December, 1971. (The 2.2 Km extension from Kita-Nijuyojo to Asabu was completed in March, 1987.) The Tozai Line was also completed in two stages: from Kotoni to Shiroishi (9.9Km) was completed in June, 1976; and from Shiroishi to Shin-Sapporo (7.4Km) was completed in March, 1982. The 8.1 Km Toho Line between Sakae-Machi and Susukino was completed in 1988, and a 5 Km extension from Susukino to Fukuzumi is planned. The construction staging of the Sapporo subway system is illustrated in Figure 2.

This staging of the subway provides a convenient, if only partial, way of testing the hypothesis that transport infrastructure affects travel behaviour by inducing greater mobility. The Nanboku Line between Makomanai and Kita-Nijuyojo was opened before the 1972 person trip survey was carried out, whereas the Tozai Line was completed between the first and second person trip survey in 1983. We would expect the impact of the Nanboku Line on adjacent land-use still zones to be felt in the period 1972 to 1983, but we would expect the impact to be greater in those zones adjacent to the Tozai Line because there was no subway in 1972 but one in 1983. The Nanboku Line passes through zones 1,2,19,20,42,48 and 49; the Tozai Line passes through zones 1,3,4,5,8,10,34,35, 36 and 38.

Table 4 shows the difference in the area under the curve of the raw preference function by comparing the zone's area in 1972 and 1983. Positive areas indicate that the function is moving towards distance maximisation (see, Figure 1). The table lists zones adjacent to the Tozai Line on the left and zones adjacent to the Nanboku Line on the right. Both lines pass through zone 1 and so the change in area for this zone appears in both columns. When comparing the impacts on travel behaviour of both lines, zone 1 is eliminated, and the value that appears at the foot of each column is the zonal mean change in area from 1972 to 1983. Both values are negative, supporting the hypothesis that transport infrastructure extends the mobility of commuters. The mean zonal value associated with the Tozai Line is five times that of the zones associated with the Nanboku Line indicating a considerable "before" and "after" impact on travel.

Table 4 Change in Area of Zonal Raw Preference Functions Adjacent to Nanboku And Tozai Subway Lines. 1972 to 1983

Tozai Subway Zone No.	Tozai Subway Change in Area	Nanboku Subway Zone No.	Nanboku Subway Change in Area
1	-0.018	1	-0.018
3	+0.003	2	+0.013
4	-0.101	19	-0.005
5	-0.041	20	-0.003
8	-0.001	42	+0.002
10	-0.030	48	-0.061
34	-0.037	49	+0.026
35	-0.030		
36	-0.020		
38	+0.020		
Mean	-0.026	Mean	-0.005

5. CONCLUSIONS

A journey-to-work preference function has been defined as a curve of the relationship between the proportion of travellers from a designated origin zone who reach their workplace zone, given that they have passed a certain proportion of total metropolitan jobs. This is derived from the Stouffer hypothesis relating mobility to distance. Section 2 of the paper explained how to estimate raw preference functions from data provided by a simple, hypothetical, example. The theoretical relationships between the preference function approach (and its operational trip distribution model-intervening opportunities model), the fully constrained gravity model, and mathematical programming approaches were demonstrated. Curve fitting of the transformed preference function was also explained.

The methodology is a powerful tool to help examine whether there is a general preference for commuters to travel longer, rather than shorter, distances once changes in the relative location of homes and workplaces have been accounted for. The methodology allows the long-term dynamics of travel behaviour to be analysed. Its specific in this paper has been to study changes in journey-to-work preference functions in Sapporo using person trip survey data for 1972 and 1983. The influence of transport infrastructure on travel behaviour was examined by contrasting the findings for the Nanboku Subway Line that was opened before 1972, and the Tozai Subway Line that opened after the 1972 survey, but before the 1983 survey.

In Sapporo, analysis of 53 zones in the study area showed a trend for one half of the raw preference functions to shift over time to the right, implying a move towards distance maximisation. This shift was noticeable for those ten zones adjacent to the Tozai Subway Line, and was five times as greater in magnitude (as measured by the change in area under the raw preference function) as that recorded for zones adjacent to the Nanboku Subway Line. Comparative urban studies are especially useful to help unravel the trends between transport supply and travel behaviour, and this is a direction for further research. Comparable results for Shanghai in 1986 - a metropolitan region with some 13 million people where the predominant transport modes are walking, cycling and public transport - show that journey-to-work preference functions are skewed towards the left (distance minimisation) and this is especially noticeable in the outer areas where public transport provision is poor (Black, et. al, 1992).

Although the thrust of the research reported here is not building mathematical models of land-use and transport interaction, the findings do have implications for modelling. The gravity and intervening opportunities models of trip distribution both have one global calibration parameter for the whole of the study area, and this is assumed to remain the same over time. Research presented in this paper, and in our other work, demonstrates that travel behaviour varies considerably within a city at one point in time, and changes over time. There is clear evidence that the calibration parameter in the intervening opportunities model needs to be partitioned into long and short trips. Model builders need a better understanding of dynamics, and should have a clearer idea of the direction of zonal parameter changes rather than having to use ad hoc adjustment factors. The relationship between infrastructure development and travel behaviour is but one area requiring much further research.

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