Transport Infrastructure Development and Preference Functions : a case study of the journey-to-work in Sapporo

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(Received November 27, 1992)

Abstract

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 constuction). 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, there is a need to understood changes over time-the dynamic aspects of urban strucure and travel. Research in the Department of Transport Engineering, Univesity 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 17Km long Tozai (East-West) Line-was opened be-

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tween 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.

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 provides the essential background to Sapporo as a case study and indicates the data sources from the frist and second personal trip surveys. and The results of the empirical analyses of the 1972 and 1983 zonal preference functions are set out in Section 4. Major land-use and transport infrastructure developments in the Sapporo region are described in Section 5, and the impact of the Tozai Subway Line on jouney- 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 transpot 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 :

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

where,

P(dv) = probability of locating within the dv opportunities, **P(dv) = dP ;**

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

1–P(v) = probability of not having found a location within the v opportunities ;

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 :

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

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

$$Lv = -\ln(1-P) \qquad (3)$$

Hence

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

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 shallow gradients will imply a preference of those resident workers for shorter commuting, whereas, those with steep 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 Hitchcook transportation problem of operations research (Hichcock, 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 bounday 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 zonal trip attractions for zones 3, 4, and 5 are 550, 200, and 250, respectively.

(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).

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

(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 orgin 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 incredsing distance	400	600	700
(5) Cumulative proportion of zonal 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 row5, and the results plotted in Figure 1 as "distance minimisation". Similarly, "distance maximisation" leads to the other boundary condition illustrated in Figure 1.

(c) Gravity Model Calibration

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

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

where

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

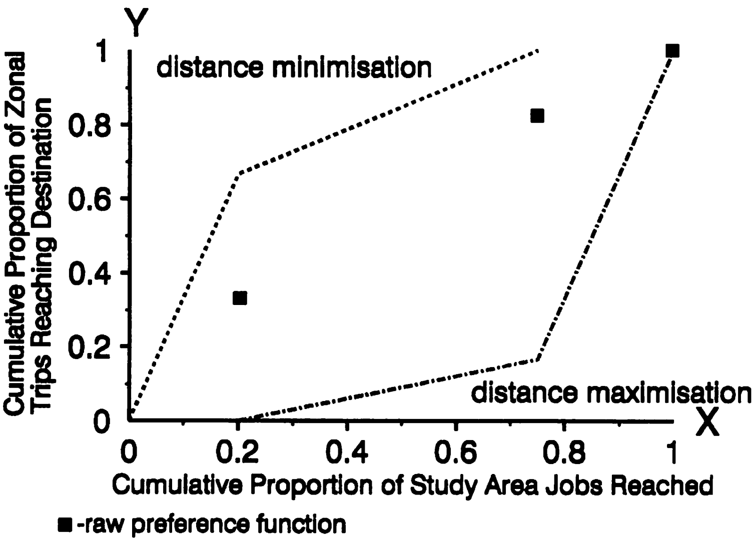

Figure 1 : Raw Preference Function for Zone 1 in a Hypothetical Example

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 distace 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 3.4km. Calibration is achieved by adjusting A until the correct value is found. Here, A equals approximately unity

(1) with the following set of balancing factors :

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

The gravity model yields m × n 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 from more commonly encountered in transport planning practice.

Lotus 123 spreadsheets have a number of built-in function 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 illustred 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

Sapporo is an unlikely choice for a study from among major Japanese cities. It is the only one to post-date the Meiji Restoration (1968). When the Hokkaido Colonisation Committee (Kaitakushi) founded its head-quarters there in 1869 its intention was to develop Sapporo as the future capital and base for further colonisa-tion of the region. They chose to import advisers and technology from the United States to conquer the sub-arctic conditions as the area is snowbound from December to February. Thus, Sapporo is the only Japanese city with a population in excess of one million without an historical core.

The distinctive feature of Sapporo is its gridiron street pattern in the central area. The Kaitakushi planned a green belt (now Odori promenade) to separate the northen government preinct from shopping and amusement quarters to the south; the Otomo-bori irrigation canal (now Sosei Canal) divided the western part of the city from the east (subsequently developed for industry). Apart from the creation of another north-south barrier with the addition of a railway line linking Sapporo to the port of Otaru in 1880–two years before the Kaitakushi was abolished-the basic features of the original plan have remained intact. Not surprisingly, Sapporo has the lowest population density of the major Japanese.cities (Table 2).

Table 2: Area and Population Statistics of Major Japanese Cities, 1975

City	Administrative area (ha)	Urbanised area (ha)	Densely inhabited district (ha)	Population (thousands)	Population density*
Tokyo	58100	56531	57690	8647	148.83
Osaka	20811	20717	20620	2779	133.54
Yokohama	42146	31620	25890	2622	62.21
Nagoya	32618	30410	22590	2080	63.77
Kyoto	61061	14881	11560	1461	23.93
Kobe	53998	18770	9250	1361	25.20
Sapporo	111801	22010	12260	1241	11.10
Kita Kyushu	47477	17930	13080	1058	22.28
Sendai	13508	11954	10500	615	45.53
Fukuoka	33478	13960	10420	1002	29.93

*Population density is given by dividing the fifith column by the second column

Table 3: Urban Passenger Transport, Sapporo, 1977

Mode	Route network (km)	Number of daily operating units	Daily operating distance (10^3Km)	Daily passengers (thousands)
Subway	24.2	674	7.4	521.5
Tram	8.5	251	3.1	42.0
Bus	-	1105	115.5	559.1
Taxi	-	5026	1521.7	315.2

Sapporo also offers a complete range of public transport modes-tram, bus, subway, and taxi (Table 3). The tramway is an 8Km remnant of an earlier 25Km system which has been gradually replaced by municipal and private bus services. Linehaul city buses, in turn, have been largely integrated with trams and both provide feeder services to twenty-seven stations on the Sapporo subway though a transfer (transit) fare stucture introduced in 1973. Commenced in 1971, the subway system comprises a 14Km nouth-south line (Nanboku Line) and a 10Km east-west line(Tozai Line) offering services eighteen hours daily with four-minutes headways in the peak. The system has automatic traffic control, automatic train operation, automatic revenue machines, computerised public address systems, carriages that run on pneumatic-tired wheels using a guided rail, and snow shelters which offer protection to elevated sections.

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. The study area was divided into 53 zones illustrated in Figure 2. The matrix of inter-zonal distances were calculated from tte location of zone centroids and the configuration of the highway network.

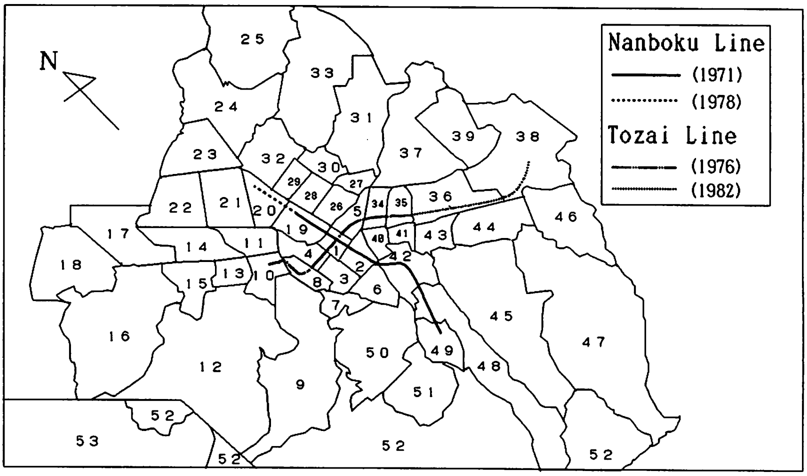

Figure 2 : Zone System Specified for the Analysis and Subway System of Sapporo

4. ANALYSIS

This section presents the results of a comprehensive investigation of the shapes of zonal preference functions. Sub-section 4.1 outlines all possible changes in shape of these functions over time. Changes from 1972 to 1983 are classified according to this schema. Sub-section 4.2 presents the results of the curve fitting exercises for the zonal preference functions.

4.1 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 4. 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.

Table 4 : Temporal Trend of Raw Preference Functions, Sapporo, 1772 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

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 to1983. 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) :

$dA < -0.01$ (18zones) ;

$-0.01 < dA < 0.01$ (15zones) ; and

$dA > -0.01$ (20zones) ;

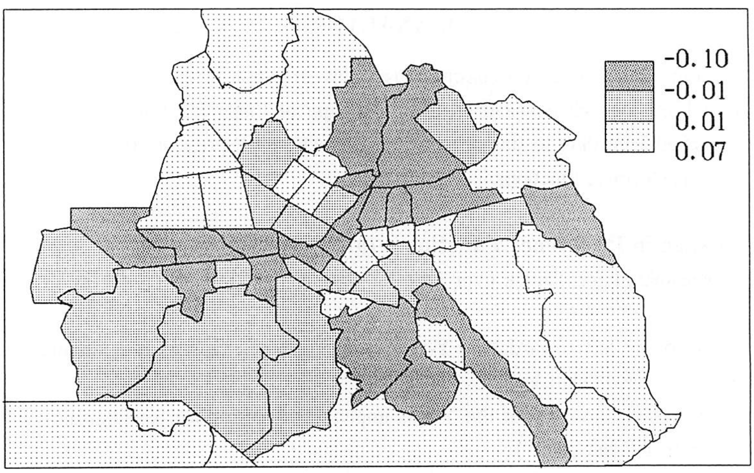

Figure 3 : Map Showing the Change in Area under the Zonal Raw Preference Function Curves, Sapporo, 1972 to 1983

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. The ten zones with the greatest difference in area between 1972 and 1983 are as follows. The five with the largest negative areas (shift right) are in the left column ; the five with the largest positive increase in area (shift left) are in the right hand column.

zone4	− 0.101	;	zone24	0.069
zone15	− 0.088	;	zone41	0.054
zone48	− 0.061	;	zone23	0.053
zone46	− 0.052	;	zone7	0.051
zone14	− 0.049	;	zone52	0.044

The location of these zones has already been given in Figure 2.

4.2 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 5 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.

Table 5 : Frequency Distribution of the Gradients of the Transformed Preferen 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%

It may be noted that additional work on the transformed preference function 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 to1.0). 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 parition into X = 0 to X = 0.1, and X = 0.1 to X = 0.6, and use separate linear functions.

5. IMPACT OF TRANSPORT INFRASTRUTURE

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 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.

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 Nanboku Line which opened in 1972. First, however, changes in Sapporo′s urban spatial strucure are outlined.

From 1972 to 1983, growth was accompanied by internal restructuring of homes and workplaces (Table 6). 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 propotion 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 6,000resident 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 754Km 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 12.1Km section of the Nanboku Line between Makomanai and Kita-Nijuyojo was completed in December, 1971. (The 2.2Km extension from Kita-Nijuyojo to Asabu was completed in March, 1978.) The Tozai Line was also completed in two stages : from Kotoni to Siroishi (9.9Km) was completed in June, 1976 ; and from Shiroishi to Sin-Sapporo (7.4Km) was completed in March, 1982. The 8.1Km Toho Line between Sakae-Machi and Susukino was completed in 1988, and a 5Km 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 this 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 th 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 7 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

Table 6 : The Zonal Number of Resident Workers ans Jobs, Sapporo 1972 and 1983

	Workers Resident			Work Places		
Zone	1972	1983	(1972-1983)	1972	1983	(1972-1983)
1	1886	3750	1864	95432	111103	15671
2	8941	8403	-538	16495	22563	6068
3	10412	7851	-2561	8726	15571	6845
4	5191	8077	2886	20392	22704	2312
5	5323	3890	-1433	18793	20870	2077
6	10810	14105	3295	6117	10150	4033
7	3383	3470	87	982	1811	829
8	8432	9798	1366	6561	10352	3791
9	5595	6978	1383	2115	4265	2150
10	11659	15185	3526	9855	15160	5305
11	8127	11874	3747	4013	7199	3186
12	5874	14503	8629	1285	4166	2881
13	6836	7957	1121	3368	4479	1111
14	3856	7233	3377	4070	9229	5159
15	2939	6553	3614	3066	5502	2436
16	3251	5895	2644	1916	2887	971
17	2397	8180	5783	359	2060	1701
18	3087	7716	4629	1593	4253	2660
19	9663	7925	-1738	13962	17772	3810
20	14598	16844	2246	4339	9407	5068
21	10657	20692	10035	2689	7533	4844
22	1515	4048	2533	183	1469	1286
23	1466	5090	3624	200	1155	955
24	4468	10464	5996	1072	3597	2525
25	1048	1531	483	20	448	428
26	10065	10068	3	10210	11863	1653
27	4926	4968	42	3976	4802	826
28	10567	9944	-623	5749	6388	639
29	8049	9444	1395	3690	5651	1961
30	3854	6305	2451	1738	4029	2291
31	5407	12178	6771	2552	7839	5287
32	9386	16799	7413	3219	7936	4717
33	1962	3831	1869	1468	3885	2417
34	8601	6714	-1887	7423	9059	1636
35	7087	9317	2230	7952	11231	3279
36	16300	23646	7346	10407	17039	6632
37	8349	16264	7915	2155	6307	4152
38	10408	22706	12298	4596	16680	12084
39	396	3928	3532	190	1509	1319
40	6434	6951	517	5768	6180	412
41	6291	5947	-344	4574	4477	-97
42	15010	21166	6156	6414	11876	5462
43	11255	10633	-622	6214	7740	1526
44	4086	11690	7604	2748	6466	3718
45	3981	12385	8404	1833	4837	30004
46	1444	3924	2480	1444	2832	1388
47	2586	6406	3820	1405	4088	2683
48	6607	13019	6412	2956	5466	2510
49	7311	10606	3295	3008	3015	7
50	3213	4760	1547	1154	2171	1017
51	3432	6657	3225	1154	3427	2273
52	4468	7717	3249	1583	3929	2346
53	2329	2449	120	2035	2007	-28

Table 7 : Chage in Area of Zonal Raw Preference Functions Adjacent to Namboku and Tozai Subway Lines, 1972 to 1983

Tozai Subway Zone No.	Change in Area	Nanboku Subway Zone No.	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

values are negative, supporting the hypothesis that transport infrastrucure extends the mobility of commutes. 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.

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).

Althoug 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.

ACKNOWLEDGEMENT

This research was completed whilst Masuya was a Visiting Honorary Fellow in the School of Civil Engineering, University of New South Wales. Colleagues in the Department of Transport Engineering, Mr. T T Ton and Mr. Y Z Cheng, provided valuable advice on the broader research being undertaken. The authors thank Mr. K Yamaya, Chief of the Planning and Coordination Bureau, Sapporo Municipal Government, and Mr. Y Ono, Traffic Section Sapporo Municipal Government who provided data.

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