

RESIDENTIAL LOCATION-SPECIFIC TRAVEL PREFERENCES IN AN INTERVENING OPPORTUNITIES MODEL: TRANSPORT ASSESSMENT FOR URBAN RELEASE AREAS

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Abstract: The urban development of green-field areas requires an assessment against economic, social and environmental sustainability objectives of which vehicle-kilometers of travel (VKT) and journey to work patterns by automobile is one important criterion. Current practice in Australia on travel demand forecasting applies strategic land-use and spatial interaction models calibrated for the whole of the metropolitan area to the proposed urban release area to estimate future VKT, among other travel indicators. This will give misleading results for spatial patterns of traffic in these release areas as demonstrated by previous research. A case study of Canberra, the Australia's national capital, is being investigated to assess whether there is a case or not for a variation to the long-term metropolitan structure policy (linear development structure of the Y-Plan) using both the traditional gravity model and the intervening opportunities model with location-specific preference functions.

Key Words: Spatial interaction models, intervening opportunities models, journey to work, travel preferences

1. INTRODUCTION

Despite policies that encourage urban consolidation at higher densities there remain pressures at the metropolitan fringe for the urban development of green-field, predominantly rural lands. Major urban release areas are assessed against economic, social and environmental sustainability objectives of which vehicle-kilometers of travel (VKT) by automobile is one important criterion. Current practice in Australia on travel demand forecasting applies strategic land-use and spatial interaction models calibrated for the whole of the metropolitan area to the proposed urban release area to estimate future VKT, among other travel indicators. They will give misleading results for the spatial patterns of traffic in these release areas, as demonstrated by previous research (Cheung, et al, 2003).

The practical need to address this modeling problem is highly relevant in Sydney's south west sector and in Canberra – Australia's national capital – where an urban suitability study of the Molonglo Valley (Cox, 2005) has recommended a variation to the long-term metropolitan structure policy (linear development structure of the Y-Plan). Robust and credible travel estimates for this, and other potential urban release areas, are required. Clearly, a growth factor approach is inappropriate given zero development in the base case. Our aim is to test alternative synthetic model structures (gravity model and intervening opportunities model), and to compare their relative accuracies against Census Journey-to-Work (JTW) origin-destination (O-D) data.

The planning and policy context is described for Canberra and this forms the justification for this theoretical and applied research into spatial interaction models. We postulate mathematical functions to represent journey to work travel patterns. Two data sets are used to formulate the shape of these functions: the Census of Population and Employment, JTW tabulations for Sydney (1996) and for Canberra (2001), both supplemented by transport network characteristics (travel distance and travel time), provided by government transport planning agencies (NSW Department of Infrastructure Planning and Natural Resources and ACT Planning and Land Authority). These data form the basis of investigating the theoretical residential location-specific attributes of preference functions and the development of a new model structure suitable for modelling journey to work patterns from proposed urban release areas.

A statistical evaluation of spatially-stratified gravity and intervening opportunities models has already been completed with the Sydney JTW data. Commuting behaviour in the outer metropolitan regions is best represented by a linear-log preference function, the l-factor parameter in the model of intervening opportunities. A quadratic or power preference function best describes the commuting behaviour for inner and middle rings suburbs. A GIS representation of residuals demonstrates that a calibrated, two-tier zonal specific preference function in the intervening opportunities model eliminates significant spatial bias compared with the traditional gravity model approach. We use these findings, supported by analysis of the Canberra 2001 Census JTW data, to estimate the most likely calibrated preference function for Gungahlin (current policy) and for the alternative urban release area closer to the city centre (Molonglo Valley). A new model is developed to compare the trip length/VKT estimates of both release areas. Credible analysis of traffic that is sensitive to alternative land-use distributions contribute to a better understanding of trip length/VKT distribution from urban release areas, irrespective of their location in the region, and provide information to decision makers on one important evaluation criterion of alternative options for development.

2. CANBERRA PLANNING POLICY CONTEXT

The Australian Capital Territory (ACT) and surrounding NSW region includes the settlements of Canberra and its rural villages, the City of Queanbeyan, and a number of towns and villages including Yass, Murrumbateman, Bungendore, Sutton, Gunning, Gundaroo, Binalong and Bredbo. Currently, approximately 376,000 people live within this region, which makes it the largest inland growth region in Australia. At June 2002, the ACT's estimated resident population was 321,000 and neighbouring Queanbeyan's was 33,300. There were 114,800 occupied dwellings (an average of 2.6 persons per household) in the ACT and 15,500 in Queanbeyan, in August 2001. Population growth, demographic change and household change underpin the need to plan for growth and change in Canberra and surrounding NSW.

This was recognized in the Voorhees and Associates land-use and transport study of 1967 that produced a metropolitan structure plan for one million residents based on a collection of free-standing new towns spilling over into New South Wales. The Y-Plan, as it is commonly referred to, was adopted as a long-term development policy of government, and remains so to this day. However, for the interim population of 500 000 government is anxious to retain urban development within the boundaries of the ACT. The Canberra Spatial Plan, released by the ACT Government in March 2004, is the principal strategic planning document that guides the management of change and growth of Canberra to achieve the social, environmental and economic sustainability over the next 30 years and beyond.

The Plan seeks to achieve an urban renaissance city through a range of integrated initiatives as follows:

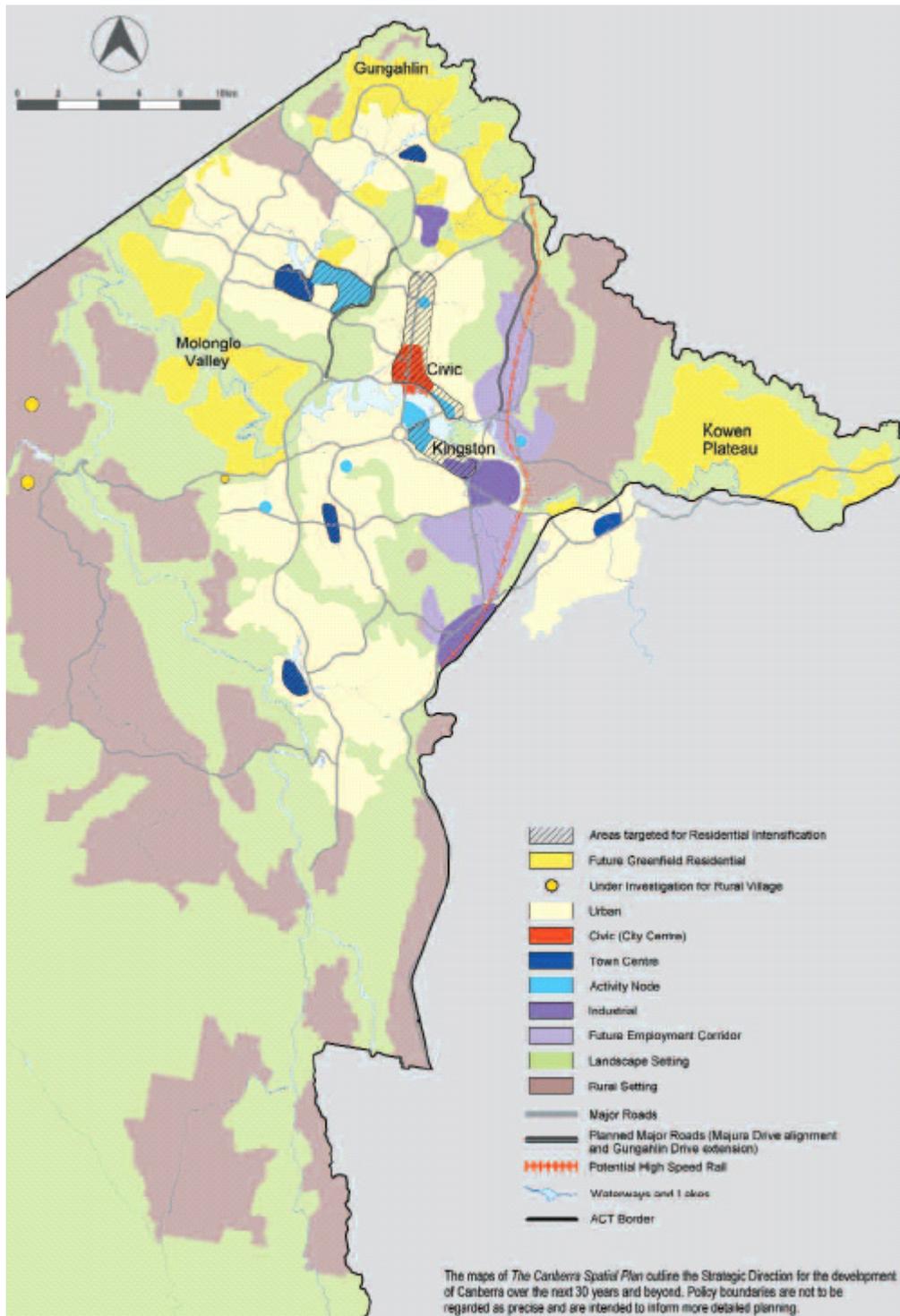
- It will strengthen Civic as the central business district (CBD).
- It will limit the continued dispersal of the urban form.
- It will achieve a more compact series of districts principally within the ACT and hence closer to the central employment areas, including the CBD.
- It will also achieve a more sustainable urban form by providing increased opportunities for higher density residential development in central locations thereby reducing travel distances and the consumption of land, water and energy.
- It recognizes changed employment patterns and locations and seeks to reinforce a central employment area supported by a series of centers that are connected by public transport and provide diverse employment opportunities.

If the population increased to 500,000, some 90,000 additional dwelling would be needed. Strategic directions have been identified in the Canberra Spatial Plan for future residential development to meet projected demand and to accommodate higher levels of development (Figure 1).

Molonglo Valley is identified as future greenfields residential development areas to meet the predicted demand for housing for low and medium density housing in addition to the completion of Gungahlin as a new town. If the city continues to grow in population beyond the capacity of these areas, further settlement will be accommodated on the Kowen Plateau.

The suitability of the Molonglo Valley for urban development was recently assessed by Cox (2005) who concluded development of the East Molonglo Valley warranted further investigation. Feasibility studies of the economic, social and environmental implications of alternative development options would be routinely undertaken to guide decision makers. Land-use and transport modeling would be part of a transport feasibility study and it is at this point that we emphasize the inherent weaknesses of current modeling capability in the ACT. Sound policy requires robust and credible analyses and this is the aim of our research with particular reference to spatial interaction models.

Whilst there is a window of opportunity in Canberra at the moment to select a new suite of models and a computer-based modeling platform, our research is directed towards the very specific requirement of a suitable spatial interaction model for the journey to work for urban release areas that are often on the metropolitan fringe, but not always as this case study of Canberra demonstrates. The research question is a general one: what is the best spatial interaction model to use; and what are the relative errors involved in not choosing the model that is best supported by the observed O-D data. The gravity model formulation is well known to academics and practitioners, but the intervening opportunity model less so. For this reason, the next section describes the concepts of preference functions in the latter model structure.



Source: ACT Planning and Land Authority, 2004

Figure 1. Potential Future Residential Areas

3. SPATIAL INTERACTION MODELS AND PREFERENCE FUNCTIONS

The gravity model of trip distribution forms the basis of modeling in urban transport planning practice. The model is the cornerstone of current computer packages, such as TransCAD, TRIPS and EMME/2. Interestingly, one of the first comprehensive land-use and transportation

studies of the 1950s (Chicago) applied the intervening opportunities model for trip distribution modeling and, despite comparative evaluations in the 1960s of both models that showed little difference in model accuracies; the gravity model appears to have been subsequently favored by practitioners on the grounds of computational ease (Easa, 1993). Our research, detailed below, suggests that there is merit in re-considering the intervening opportunities model with residential location-specific preference functions in software packages, which has been formulated based on a different concept to the gravity model.

Conceptually, the raw preference function that we refer to in this paper is simply the inverse of Stouffer's intervening opportunity theory that relates the proportion of migrants or travelers continuing given reaching various proportions of the opportunities reached, or, more technically correct, the l -factor parameter in the intervening opportunities model of trip distribution (Ruiter, 1969). In transport analysis, a preference function is an aggregate of the travel behavior response by a zonal grouping given a particular opportunity surface surrounding those travelers. A journey-to-work preference function is the relationship between the proportion of travelers from a designated origin zone who reach their workplace destination zones, given that they have passed a certain proportion of the total metropolitan jobs.

The slope of these empirically determined preference functions tells us much about travel behavior as a pure response to land use opportunities, and not to transport impedance (distance, time or cost, depending on data availability) as in the gravity model. The residential location specific travel preference function is the propensity of travelers to take up nearer or further-away job opportunities compared to lower or upper bounds that can be uniquely specified. Zonal functions with steep gradients will imply a preference of those resident workers for shorter commuting (given the opportunities available), whereas those with shallow gradients will imply a preference for longer trips.

The estimation of the shape of the zonal 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, or generalized cost). Typically, such information may be extracted from the Census journey to work data.

The estimation of a raw preference function in a residential location specific nature is 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 is calculated at increasing distance from the origin zone, and these are expressed as a proportion of the metropolitan total.
3. From the O-D data, the number of jobs with destinations at increasing distance from the origin zone is set out.
4. The O-D flows are expressed as a proportion by destination of the total zonal trips productions.
5. Finally, the proportions are plotted as a graph.

These steps are repeated for all other zones in the system. For a system containing n zones there will be a vector of n raw preference functions and n lower bounds. It is easy to visualize the changes that the system might undergo. The number of zonal residential workers and jobs may change (spatial redistribution), the observed travel pattern may change (behavioral

response), and, if we had used travel time instead of distance, the relative ordering of zones may change (transport accessibility change). The typical shape of the raw preference function is shown in Figure 2.

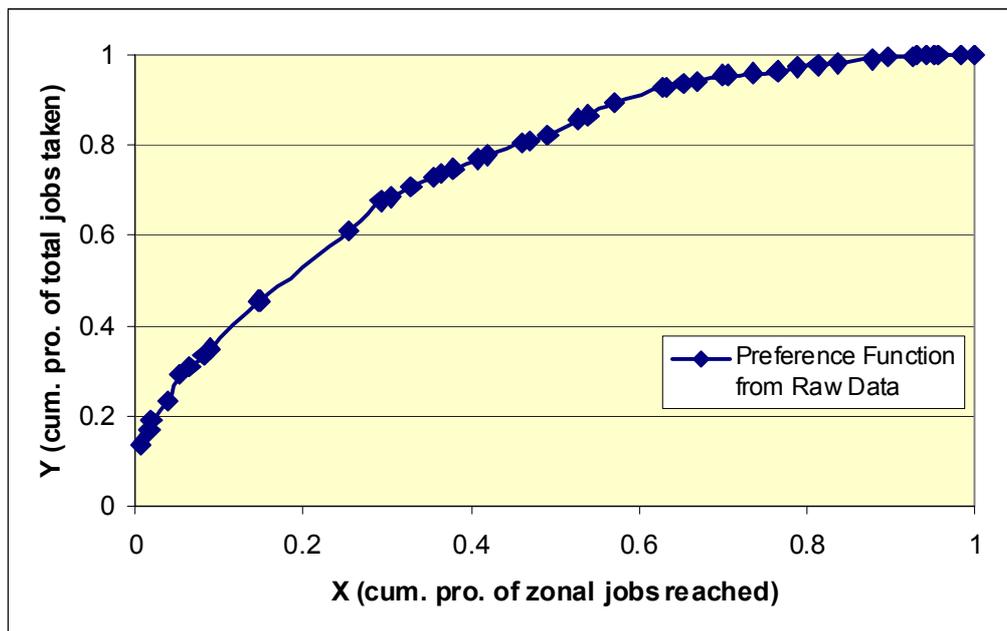


Figure 2. Raw Preference Function

To improve curve fitting, the shape of the observed preference function is first transformed as follows using a linear-natural logarithm function:

$$Y = a [-\ln(X)] + b \tag{1}$$

Where

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

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

a = regression coefficient; and

b = regression constant.

Unlike the raw preference function, the transformed preference function has a negative gradient, as in the above formula, where small (absolute) values of parameter, *a*, (hereafter the preference function) associate with a preference for shorter trips and large (absolute) values associate with a preference for longer trips, with everything else being equal.

Curve fitting is also improved by examining other functional forms.

A quadratic preference function is:

$$Y = aX^2 + bX + c \tag{2}$$

Where

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

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

a, b = regression coefficient; and
 c = regression constant.

And a power preference function is shown as follows:

$$Y = aX^b \quad (3)$$

Where

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

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

a = regression coefficient; and

b = power constant.

The spatial stability hypothesis of the preference functions implies that all zones have an identically shaped preference function. That is, once the different patterns of zonal job accessibilities are taken into account there is uniform travel behavior across the zonal system in terms of propensity to take up jobs. Previous research found that the slopes of the preference function are substantially different in different locations (zones) within a city and that this is clearly the case for metropolitan Sydney (Cheung, in preparation). However, until now, there has not been an attempt to investigate the commuting preference of a stratified residential location specific platform.

4. MODEL DEVELOPMENT AND EVALUATION FRAMEWORK

Previous research into the intervening opportunity model preference functions has suggested that there is a case to develop a model with residential zone specific preference functions. First, we present the case in favor of an intervening opportunity type spatial interaction model for the journey to work based on a standard statistical comparison. Secondly, we go one step further to examine and compare spatial residuals between model outputs and observed census data with the aid of GIS plots using the TransCAD traffic and transport modeling program.

The input data allows us to evaluate two broad classes of urban trip distribution model – the gravity model and the intervening opportunities model, together with their functional elements. The evaluation is based on statistical comparisons of the model output, and on the GIS mapping of spatial residuals. As a benchmark of conventional practice, doubly-constrained gravity models with various types of deterrence functions are used in the calibration process and their goodness-of-fit to the data are established. Intervening opportunities models are developed based on a residential location specific travel preference function. JTW O–D matrices of Canberra are calibrated for both the gravity and intervening opportunities models based on the mean trip length (MTL) criteria.

There is an array of suitable goodness-of-fit statistical measures, including the coefficient of determination (R^2); root mean square error (RMSE); intra-zonal trip proportions difference; coincidence ratio of the trip length frequency distribution (TLFD); and others. They are used to evaluate the accuracy of parameter estimates and the ability of the model to replicate O-D commuting flow patterns compared with the survey data. Traditional representations of the performance of the model are given by a trip-length frequency comparison.

The use of different goodness-of-fit statistical measures may lead to different conclusions

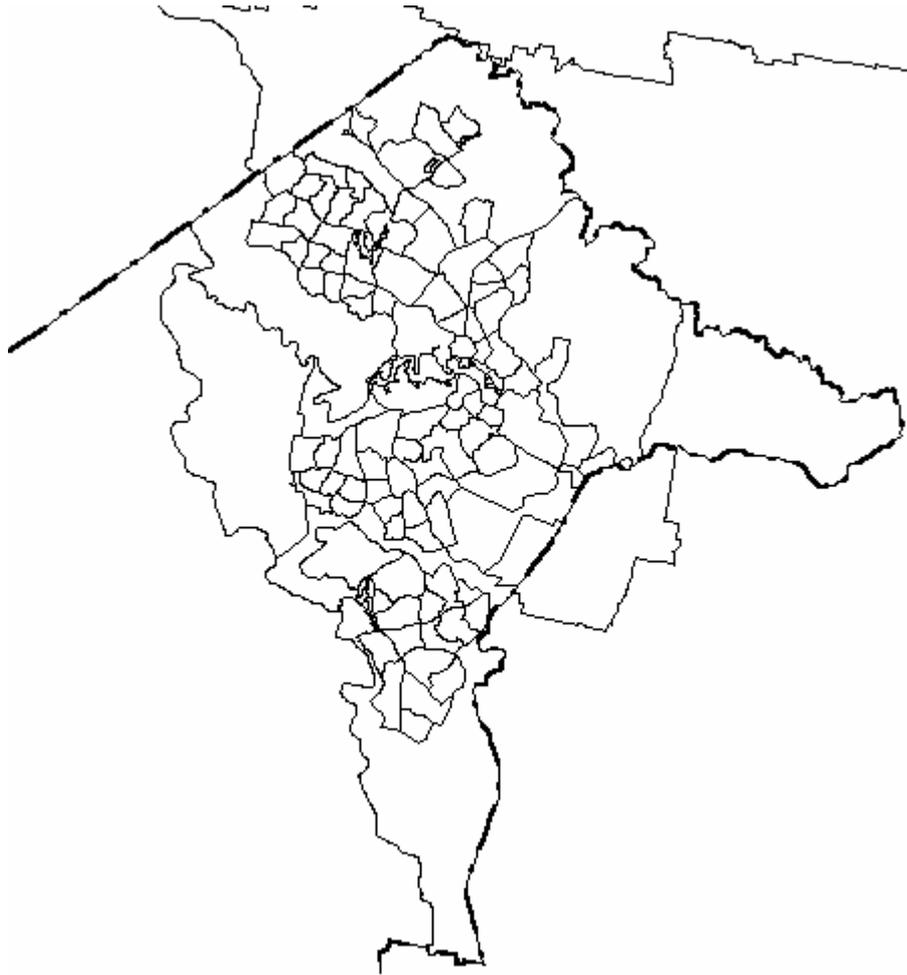
being reached on the model performance. Although a combination of two or three statistical measures can be used to determine the best model, these measures only provide indications on the overall global performance of the accuracy of interactions. More importantly, the global statistical measures are not assessing the actual prediction of spatial interaction, providing minimal spatial information for the appraisal of location specific developments.

The implications of these findings for transport policy development and infrastructure investment are articulated, and hence there is a need to investigate over- and under-estimation of O-D commuting flow patterns. The spatial residuals (derived from a cell-by-cell comparison of the survey matrix and the model matrix), obtained from the intervening opportunities model with residential location-specific travel preference functions, are compared with the benchmark (aggregate) model. Using the TransCAD traffic and transport modeling program, desire-line patterns of spatial residuals are plotted to represent the bias of inter-zonal (based on groups of Statistical Local Areas) O-D flows of journey-to-work commuters. The spatial residual errors plot illustrates where over-estimation and under-estimation of commuting flows are found, and pinpoint where recent infrastructure investment decisions may have been based on either over- or under-estimation of traffic flows from the conventional modeling approach.

4.1 2001 JTW Zoning System

The 2001 JTW O-D trip matrices for Canberra are the most recent sources of data available at the time of submission of this paper. The 2001 JTW data is derived by the ACT Planning and Land Authority from its 2001 Census of Population and Housing undertaken by the Australian Bureau of Statistics (ABS). The JTW data set provides information on the trip to work on Census day undertaken by all employed people aged 15 years and over who were enumerated in the JTW Study Area on Census night.

For the purpose of this research, an aggregate zone system of 27 zones (based on groups of Statistical Local Areas, or SLAs, shown in Figure 3) is used for the Canberra and Queanbeyan area in the development of zonal residential location specific travel preference functions.



Source: ACT Land Information Office, 2004

Figure 3. Canberra Zone System (Statistical Local Areas)

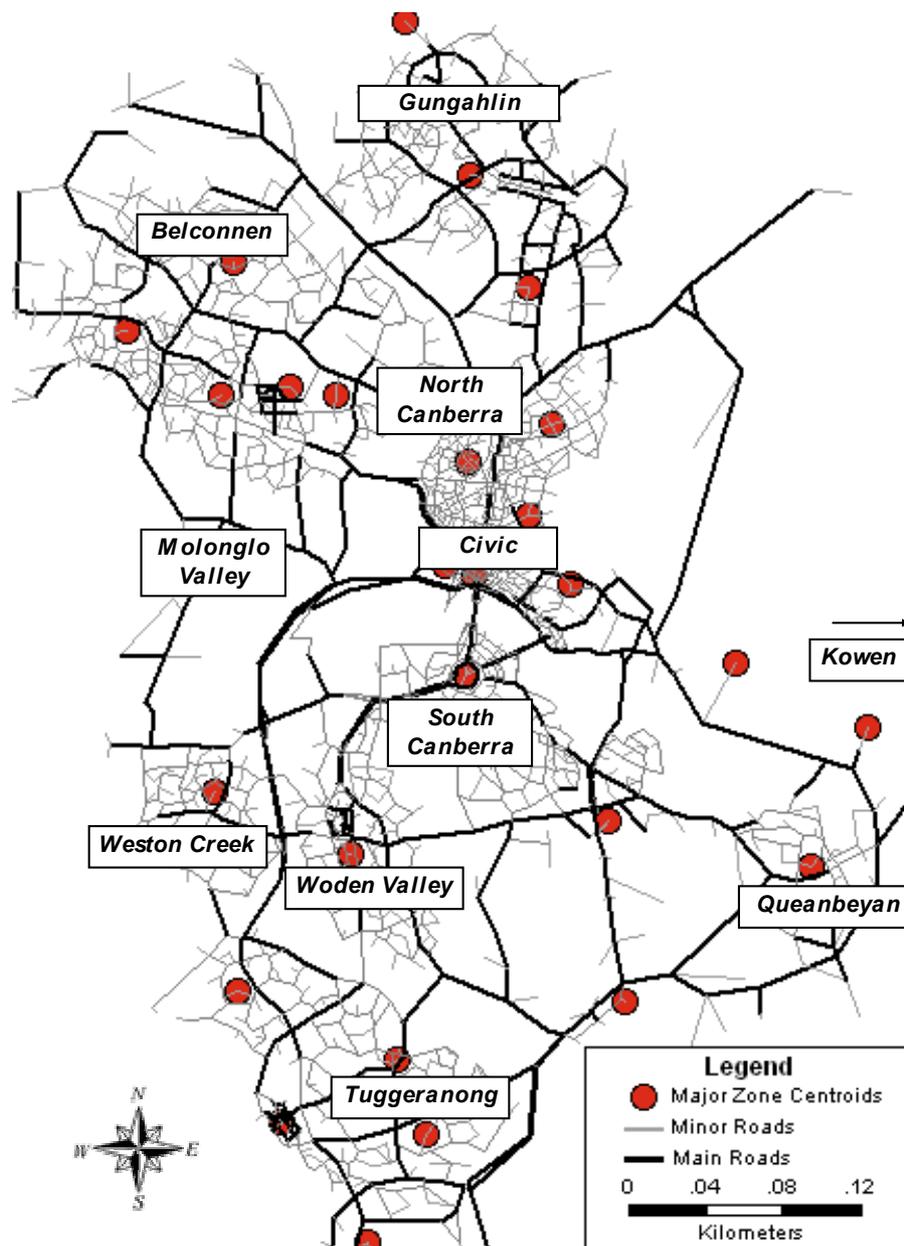
4.2 2001 JTW Origin-Destination Trip Matrices

Tabulation 1 of the 2001 Canberra JTW dataset provides the number of trips from an origin JTW travel zone to a destination SLA, stratified by mode of travel – bus, taxi, car driver, car passenger, motorbike/scooter, bicycle, walked only, work at home and others. For the purpose of this research, all modes of travel have been considered for the Canberra and Queanbeyan area in the development of zonal residential location specific travel preference functions. Further investigations could be undertaken using an O-D matrix based on other modes of travel.

4.3 Canberra Road and Transport Network

The road and transport network is essential in the modeling process to give measures of distance, time and cost of travel between pairs of zones. For the purpose of this research, the 2001 Canberra network was obtained from the ACT Planning and Land Authority. A travel impedance matrix is derived from the 2001 Canberra network with the aid of the TransCAD program. It records the average travel impedance, usually in the form of distance, time or cost, between each pair of origins and destinations. For the purpose of this analysis, distance

is used as a measure of travel impedance. Figure 4 illustrates the Canberra road and transport network based on a 27 zones system.



Source: ACT Planning and Land Authority, 2004

Figure 4. Plot of the Canberra Road and Transport Network

5. RESULTS - MODEL CALIBRATION AND EVALUATION

What follows in this section is a presentation of the model parameters, statistics on goodness of fit, and GIS plots of model residuals. Tables 1, 2 and 3 are standard model performance measures that show the model parameters and provide a statistical evaluation of both models.

Table 1. Calibration Parameters – Gravity Model and Intervening Opportunities Model

Trip Distribution Models	GM Deterrence Functions/ IOM Preference Functions	Parameters	Value
Gravity Model (also see Cheung, et al, 2003)	Exponential $f(d_{ij}) = \exp(-bd_{ij})$	Beta (b)	0.0012
	Power $f(d_{ij}) = d_{ij}^a$	Alpha (a)	1.1340
Intervening Opportunities Model	Linear-log $Y = a [-\ln(X)] + b$	Coefficient (a)	-0.269
		Constant (b)	0.959
	Quadratic $Y = aX^2 + bX + c$	Coefficient (a)	-0.652
		Coefficient (b)	1.498
		Constant (c)	0.150
	Power $Y = aX^b$	Coefficient (a)	1.031
Power Constant (b)		0.528	

Table 2. Statistical Evaluation of the Gravity Model

Statistical Measures	Exponential	Power
R ²	0.902	0.959
RMSE	9.55	6.15
Intrazonal Trip Difference (%)	-40.43%	-8.05%

Table 3. Statistical Evaluation of the Intervening Opportunities Model

Statistical Measures	Linear	Quadratic	Power	Zonal Type Functions¹
R ²	0.440	0.950	0.969	0.974
RMSE	32.50	6.87	5.51	4.95
Intrazonal Trip Difference (%)	-110.9%	14.93%	-5.98%	-1.21%

Note 1: The use of zonal specific function is based on the best functional form determined for each zone.

The results show the power function is the best fit for the gravity model and a zonal type preference function is best fitting for the intervening opportunities model. In global terms, the results obtained from this statistical evaluation do not support any conclusion that one model is any better than the other for location specific development appraisal.

Figures 5 and 6 illustrate the spatial residuals of the outer zones of the study area (derived from a cell-by-cell comparison of the observed and modeled trip O-D matrices and plotted as desired lines) of the gravity model (GM) and the intervening opportunities model (IOM) respectively. Both figures show positive and negative residuals – where the model over-estimates relative to the O-D data and under-estimates relative to the observed O-D data respectively. Outer zones have been selected because this paper concentrates on modeling for urban release areas, which are usually found on the urban fringe.

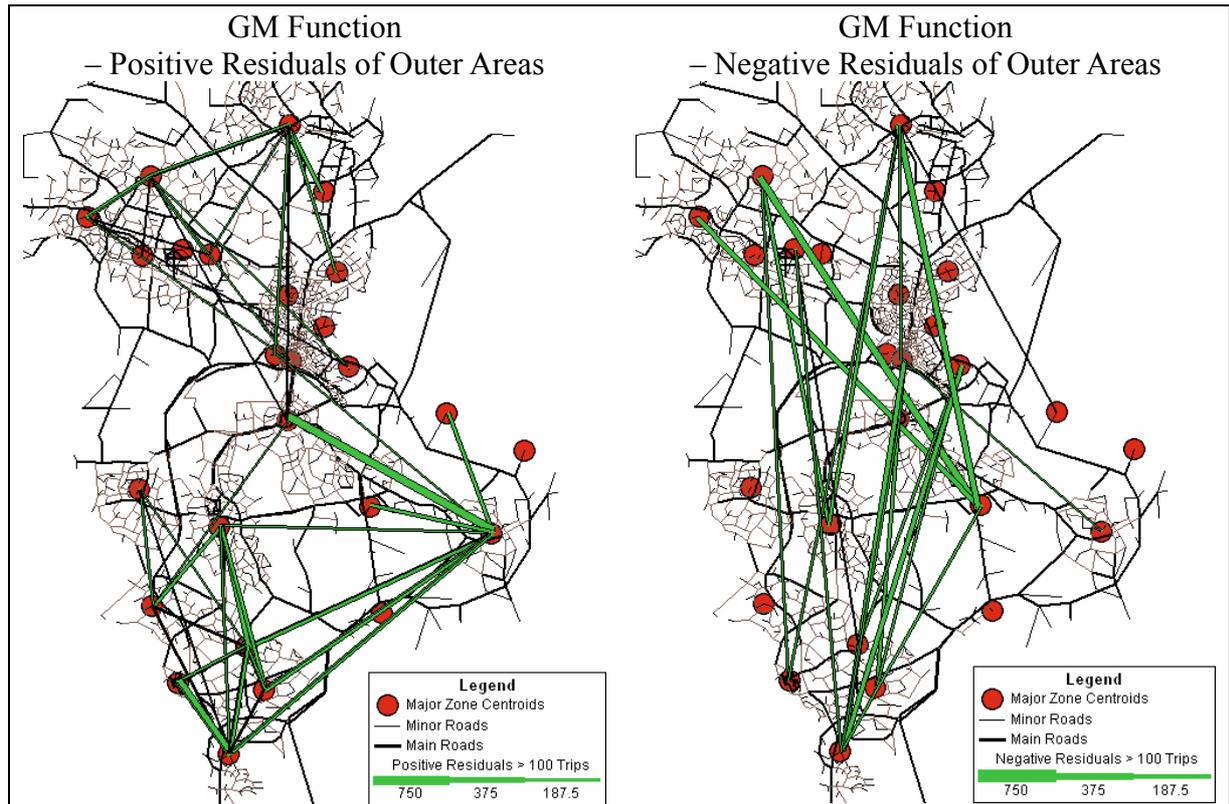


Figure 5 (a) & (b). Gravity Model – Spatial Distribution of Residual Errors, Canberra

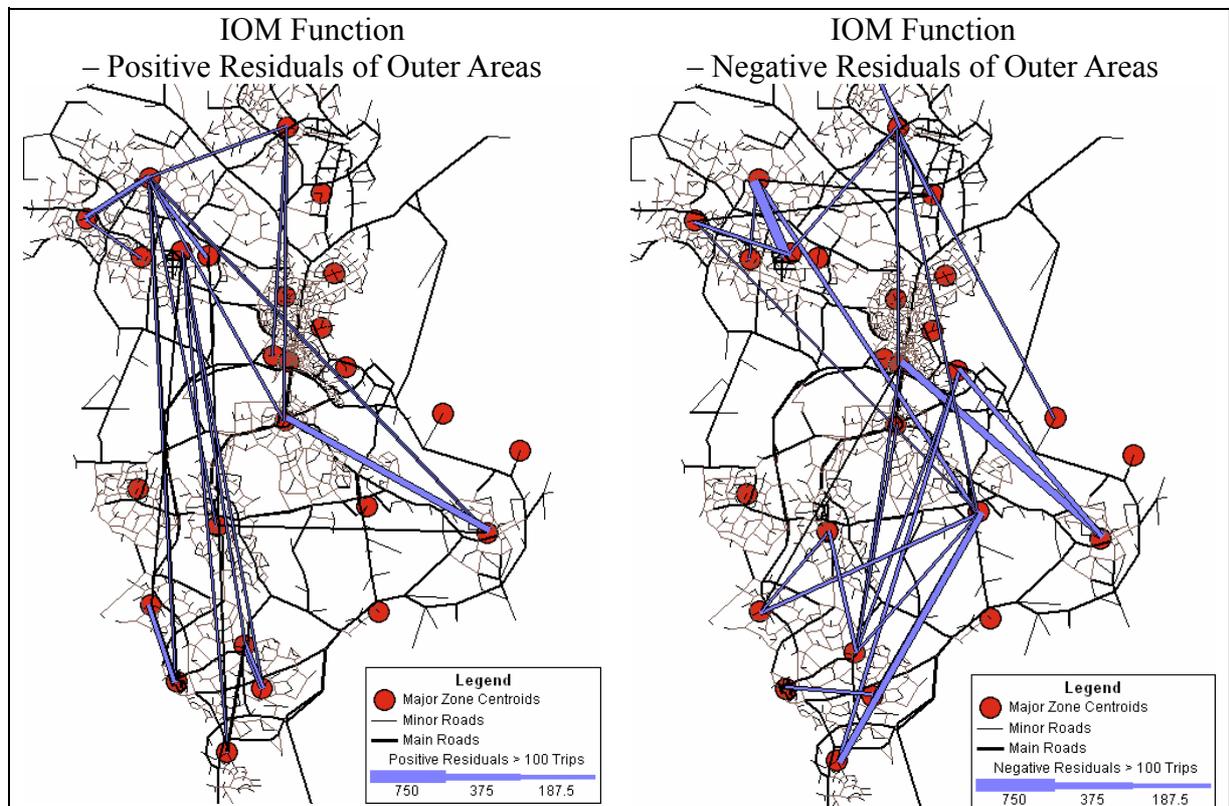


Figure 6 (a) & (b). IOM – Spatial Distribution of Residual Errors, Canberra

6. RESIDENTIAL LOCATION-SPECIFIC PREFERENCE FUNCTIONS

Previous research has shown the spatial differences in preference functions, and this research confirms this finding for Canberra. Figures 7, 8 and 9 illustrate the shapes of the preference functions (solid lines) for the inner (up to 8 km from the city centre at Civic), middle (8 to 13 km) and outer suburbs of Canberra (more than 13 km). Selective Sydney suburbs are included as a comparison (dotted lines). Travel behavior in Canberra is more maximizing than in Sydney.

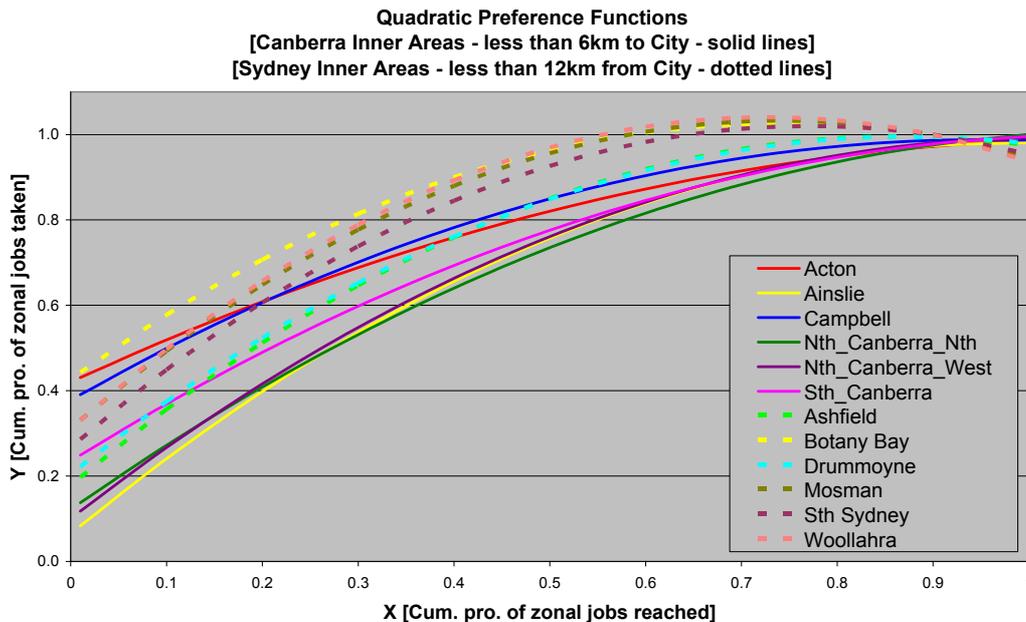


Figure 7. Plot of Preference Functions for Inner Areas, Canberra and Sydney

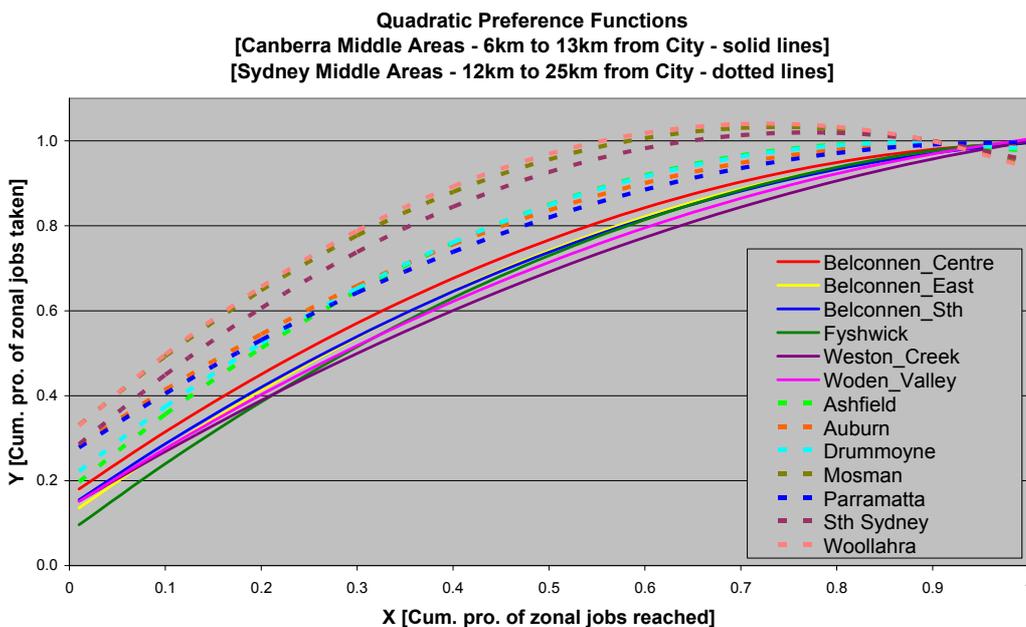


Figure 8. Plot of Preference Functions for Middle Areas, Canberra and Sydney

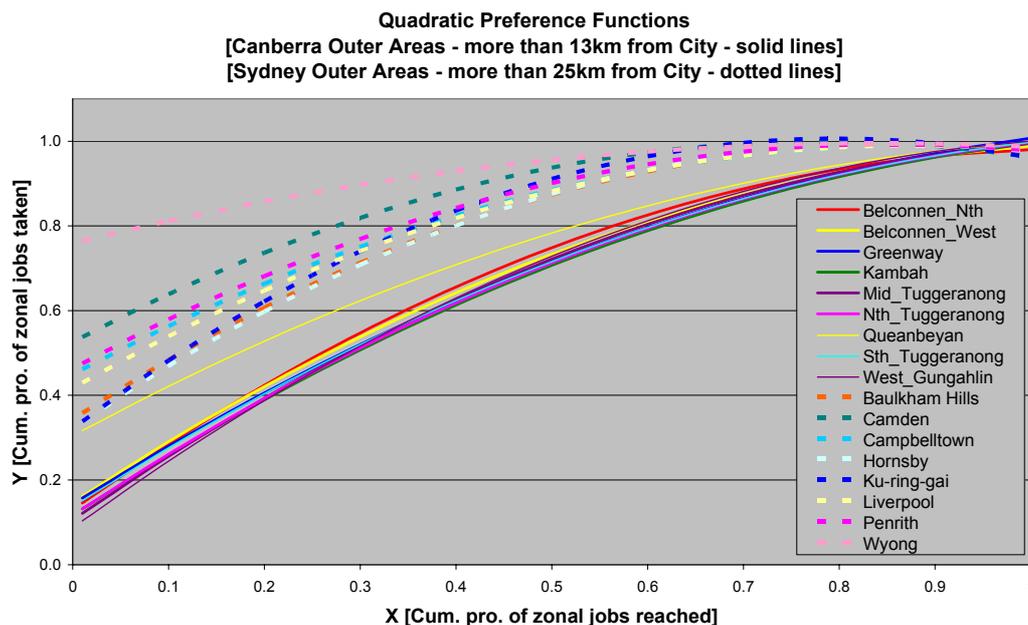


Figure 9. Plot of Preference Functions for Outer Areas, Canberra and Sydney

The point where the colored lines touch the Y-axis in Figures 7, 8 and 9 represents the amount (proportion) of intra-zonal journey-to-work trips. For example, in Figure 9, the free-standing town of Wyong on the Central Coast of the Greater Sydney Metropolitan Region has the highest proportion of intra-zonal travel. The preference functions for the Canberra suburbs are to the right of those for Sydney suburbs indicating that when we control for the opportunity surface as a proportion of metropolitan jobs, Canberra commuters exhibit more of a travel distance-maximization behavior than those commuters in the outer suburbs of Sydney (see, also, the text with Figure 2). Similar conclusions may be drawn for the middle suburbs (Figure 8). In Figure 7, the preference functions for the Canberra suburbs of Acton and Ainslie are similar to those inner city suburbs of Sydney, but the remaining suburbs in inner Canberra show the same travel distance-maximization behavior as the middle and outer suburbs of Canberra. To summarize, the results of the analysis show that the good road network design in Canberra does not act as a constraint to travel greater distance. On the other hand, congested roads in Sydney probably contribute to the relative travel distance-minimization behavior, which is more apparent in the outer areas suburbs.

Given the differences in the shapes of the preference functions in different parts of Canberra there is a case for building a residential location specific intervening opportunity model. In the case of the Molonglo Valley Study (inner area), its future journey to work patterns should be synthesized by a residential location specific preference function, and the results compared with an assumption that such urban development takes place not in the Molonglo Valley but elsewhere in the region (in the outer areas). Once alternative options are proposed, their journey to work travel patterns should be synthesized with the same model but with an appropriate (outer area) residential location specific preference function.

7. FUTURE LAND USE SCENARIOS AND TRIP DISTRIBUTION FORECASTING

The section shows a selection of a suitable preference function for any urban development site at the eastern end of the Molonglo Valley and contrasts this with a far distant site, Kowen or North Gungahlin, (also with a suitable location specific preference function) within the Y-Plan structure for Canberra at a 500,000 population level. Journey to work travel patterns will be synthesized from the intervening opportunities model by assuming the residents and employment distribution for Canberra at 500,000 in the Voorhees' land use and transport study with an assumption of a 50 percent participation rate. Results are compared with the use of the conventional gravity model, and the implications that arise from the differences in O-D flows are discussed from the perspective of modeling accuracies and future model development.

Table 4 illustrates the modeled mean trip lengths for the three future development scenarios, with each of those assuming a future population of 30,000 and a centralized employment base.

Table 4. Model Results for the Three Scenarios

Future Land Use Scenarios	Population	Work Trip Generation	GM - MTL	IOM - MTL
East Molonglo	30,000	15,000	9.92km	9.89km
Kowen	30,000	15,000	10.88km	10.67km
North of Gungahlin	30,000	15,000	11.43km	11.08km

Note: Existing JTW mean trip length (for 2001) is 10.52km.

The results presented in Table 4 show a clear difference of predicted MTL between the gravity model and the intervening opportunities model. The gravity model is yielding a greater MTL value in all scenarios. These findings are in line with the observations from Figures 5 and 6, which shows that the gravity model is more likely to over-estimate trip interactions between the new urban release areas, especially in the fringe areas, and the city centre and hence may give misleading results for spatial distribution of traffic.

8. CONCLUSION

There are a number of points that arise from this analysis that warrant further discussion in the context of strategic land use and transportation model development. First, commercial land-use and transport packages, such as TransCAD, TRIPS, and EMME 2, support a gravity-type model for the spatial (origin – destination) pattern of traffic, but the intervening opportunity model is better supported by the Census journey to work data from a zonal specific spatial distribution viewpoint.

Secondly, in Sydney, as in Canberra, the Census data shows there is not a constant behavioral travel response to the opportunity surface of jobs. The shapes of the preference functions vary across both cities (see Figures 7, 8 and 9). One parameter of spatial impedance, as in the gravity model, is unlikely to model accurately trip distribution data and hence generates significant spatial bias. When the intervening opportunity model was applied in transport planning practice in the Chicago Area Transportation Study of the late 1950s it too had one

global, average “preference function” (called “1-factor”).

Thirdly, the development of an intervening opportunity model specifically for Canberra (its TRANSTEP package, which is currently being replaced, in concept used a similar modeling device) would require residential location specific parameters to be developed with an average value for inner, middle and outer suburbs being a sensible compromise between model complexity and practical requirements in long-term strategic planning. Further investigations should be undertaken using the intervening opportunities approach with location specific parameters from the employment based viewpoint, and it is also advisable that the analysis can be done at a more disaggregate zonal level.

ACKNOWLEDGEMENTS

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