TRANSPORT INFRASTRUCTURE PLANNING IN THE EEC

NOTES AND REFERENCES

1. Member States of the EEC(1983), Belgium, Denmark, The Federal Republic of Germany, Greece, France, Eire, Italy, Luxembourg, The Netherlands and the United Kingdom.

2. The ECSC was established in 1952 to create a free common market in coal and steel. Members were the Federal Republic of Germany, France, Italy and the Benelux.

3. The Ministry of Transport of the Federal Republic of Germany has a comprehensive manual covering projects in all modes of transport, while the United Kingdom has a system (COBA) for application to road schemes.

4. Commission Document
COM 81 (507)
Final 1981

5. Published with the Statistical Yearbook, Transport, Communications and Tourism
Office of the Official Publications of the EC
Luxembourg 1972

6. A Freight Simulation System for the European Community and Spain
Parts 1 and 2, Initial Forecast Results
NVI Rijswijk N.531/530 Dec 1978

7. The Future of European Passenger Transport
Final Report
OECD Paris 1977

8. A study to Link the Results of Project COST 33 and the Commission's Freight Forecasting Study for 1985 and 2000 on a Common Economic and Technical Base
NVI Rijswijk N.531/530 Dec 1979

9. Community Transport Infrastructure Needs Study
Vols. 1 and 2 plus 19 Appendices
NVI Rijswijk N.978/4101 Aug 1982

10. Since this work commenced Greece has joined the Community and, although at present Greece is not included in the system, a similar system has been developed by the Greek Ministry of Transport which allows a direct connection to be made between the two systems.

11. Ashworth S.A. and Weaver T.E.
"European Car Ownership - A Simplified Approach"
Traffic Engineering and Control May 1981

TRANSPORT AND THE RESIDENTIAL ENVIRONMENT : RELATIONSHIPS BETWEEN RESIDENTIAL DENSITY AND ACCESSIBILITY

by
Timothy A. Patton
Department of Civil Engineering
UNIVERSITY OF MELBOURNE
Parkville, Victoria 3052
Australia

1. INTRODUCTION

Although it is widely recognised that transport is an important influence on the pattern of residential development in an urban region, the nature and extent of this influence need to be appreciated in proper perspective. In some instances, such as in the evaluation of proposed transport projects and policies, the long-term effects of transport on the urban structure are often treated cursorily or are even ignored. In other circumstances, the effects may be overstated; for example, by pressure groups or lobbyists who claim that investment in public transport facilities (especially rail) will encourage higher densities of development, reduce the need for car travel (despite all other trends), and somehow revitalise the inner areas of our cities. These unbalanced attitudes arise as a result of inadequate knowledge of the inter-relation between transport and residential development, perhaps owing to insufficient quantitative evidence and the absence of a theoretical framework for interpreting empirical findings. In this paper, an attempt is made to address these deficiencies. The paper reports on a study of relationships between the spatial distributions of residential densities and patterns of accessibility in over a dozen urban regions of various sizes, mostly in Australia and Canada.

In most previous studies of residential densities, the urban region has been viewed as a monocentric system with densities declining in some regular manner with distance from the city centre (following Clark 1951). However, that model has become outdated in more affluent cities as widespread increases in car-ownership have led to massive decentralisation or suburbanisation of employment, retailing and other activities, and have considerably reduced people's dependence on radial public transport systems. Consequently, the attractive power of the central business district has declined in relative terms. It is more valid to measure the desirability for residential location of some place within the urban region as a function of the accessibility provided by the transport network from that place to all centres of attraction (following Hansen 1959). Empirical relationships between residential densities and accessibility indices have been established for some time (for example, Patton and Clark 1970). However, since the measurement of accessibility has, until recently, been a matter of arbitrary definition, the parameters of these kinds of relationships could not be interpreted meaningfully and the results could not easily be transferred to other situations.

In Section 2 of this paper, a theoretical rationale is described to explain the form of the relationship between residential density and accessibility in non-uniform cities with numerous centres of attraction. The theory enables the parameters of the density/accessibility relationship to be better understood, and provides a useful framework for introducing further refinements.

RESIDENTIAL DENSITY AND ACCESSIBILITY by: T.A. Patton

Two important measures of residential density are population density and housing value density; both gross and nett densities are considered. Relationships between these variables and accessibility are tested empirically with data collected for a number of cities (as described in Section 3),and the influence of other factors is examined using multiple regression analysis (in Section 4). The results are generally consistent in indicating the relative influences of accessibility, income, household size and quality of the environment on residential location patterns.

Other issues examined are the effect of city size on the parameters of the model, and the effect of zone size on the empirical results. The potential usefulness of the relationships for forecasting future development and for assessing the effects of transport plans or policies on patterns of land use and development is indicated.

2. THEORETICAL BACKGROUND

The economic equilibrium theory of the housing market for a monocentric city is now well established (Alonso 1964, Muth 1969, Evans 1973). On the demand side of the theory, each household is assumed to maximise the utility which it derives from its position within the urban area, its housing consumption, its consumption of other goods and services and its leisure time, subject to monetary and time budget constraints. Position within the urban area is measured as distance from the city centre; transport costs increase with increasing distance but unit housing prices decrease and so more housing space may be consumed. At the same time, on the supply side, developers at each location are assumed to construct housing to the optimum density so as to maximise their profits, while landowners are assumed to bid up their ground rents or land values to take away these profits. At equilibrium, no household can increase its total utility by moving to another location, and no property owner can increase his profit by producing more housing or trying to charge more rent.

In the approach just outlined, transport can be regarded solely as a cost, an expenditure of time and money. There is no flexibility in the demand for travel, as it is implicitly assumed that all households generate similar numbers of trips to the one destination, the city centre, and that they all derive similar benefits from that interaction with the city centre (apart from the cost of travel), regardless of their locations within the urban region. Those assumptions are suitable for a monocentric urban system.

However, in a city with numerous possible destinations, each household's centre of attraction is not necessarily fixed and the household may vary its travel demands (particularly its destination choice or trip pattern) depending upon its residential location within the urban region. The travel demand function is no longer inelastic, and the transport benefits associated with alternative locations may be measured in terms of differences in the consumer's surplus between those locations. Neuburger (1971) has shown that when the travel demand function is negative exponential and production-constrained:

$$T_{ij} = \frac{g_i A_j e^{-\lambda t_{ij}}}{\Sigma_k A_k e^{-\lambda t_{ik}}} \tag{1}$$

then the consumer's surplus measure at a given location i is as follows:

$$\left[\frac{g_i V_t}{\lambda} \ln(\Sigma_k A_k e^{-\lambda t_{ik}}) + constant \right] \text{OR} \left[\frac{g_i V_t}{\lambda} \ln Z_i + constant \right] \quad (2)$$

where T_{ij} is the number of trips from origin i to destination j for a specific trip purpose (e.g. work)

g_i is the number of trips produced by households at origin i for that trip purpose,

A_j is the trip attraction variable for destination j (e.g. the amount of employment),

t_{ij} is the travel time or the generalised cost of travel from i to j,

λ is a travel impedance parameter,

V_t is the monetary value of a unit of t_{ij}, and

Z_i is commonly known as the accessibility at location i for the given trip purpose (e.g. accessibility to employment) and is equal to $\Sigma_k A_k e^{-\lambda t_{ik}}$

As before, for households seeking residential locations, the essential trade-off to be made is assumed to be that between these transport or accessibility benefits available at alternative locations and the benefits to be derived from the consumption of housing space. By concentrating on this primary trade-off and ignoring secondary inter-dependencies between the housing and transport demand functions, a model of the spatial distribution of residential densities in a polycentric city has been developed. Moreover, by assuming that the housing demand and housing supply functions have specific characteristics which correspond to those adopted by Muth (1969), a simple relationship between residential density and accessibility has been derived. The derivation is not presented here on account of its length, but details are available from the author (Patton 197B). The relationship is as follows:

$$D_i = W Z_i^{\omega} \quad (3)$$

where D_i is the residential density at location i, Z_i is the accessibility variable already defined, and W and ω are parameters.

The parameter ω is the one of most interest. In the theoretical derivation, it is defined to be equal to

$$\frac{gV_t}{\lambda C_Y R_L} \quad (4)$$

Each of the five symbols or subparameters in this expression has an identifiable significance and can be estimated independently. Two of these, C_Y and R_L, have yet to be defined. Firstly, C_Y is part of the housing demand function and, assuming unitary price elasticity of housing demand, is equal to average household expenditure on housing. It is obviously strongly related to income. The term R_L is part of the housing supply function and represents the ratio of land inputs to total housing outputs. Thus the product $C_Y R_L$ represents the average expenditure of households on land.

The remaining three symbols relate to transport, and the most portentous of these is the parameter λ in the destination choice or spatial interaction function. This is known to be an inverse function of the average travel time or generalised cost of travel $\bar{t}$ (as shown theoretically by Eastin and Shapiro 1973, for example), although the precise form of the function will vary between regions depending on the particular spatial distributions of origins and destinations. In an idealised city where the transport network facilitated travel at uniform speed in all directions (or at least in orthogonal directions), and where residences were distributed around workplaces solely in accordance with the form of the transport demand function (and without regard to the forms of the housing demand and housing supply functions), the average travel time or generalised cost $\bar{t}$ would be equal to $2/\lambda$ (Patton 1978). Obviously, under more realistic conditions of urban structure, the relationship between λ and $\bar{t}$ might take on a different form. However, it is apparent that the quantity $1/\lambda$ is an indicator of the average time or generalised cost of travel in the urban region.

Since the parameter g represents the trip production rate and V_t denotes the monetary value of travel time or generalised cost, then the expression gV_t/λ is an indicator of the average generalised expenditure on travel by households, though it may not be an exact measure for the reasons just described. Thus the significance of the parameter ω, as defined in equation (4), becomes clear. It is directly related to the ratio of average expenditures on transport to average expenditures on land.

An expected value of ω may be estimated by adopting suitable values for the subparameters g, V_t, $\bar{t}$ or λ, C_Y and R_L. The example given in Table 1 shows that the value of ω is likely to be approximately unity. This is a casual order-of-magnitude estimate. Different values would be expected for different urban regions as different assumptions are made about the appropriate values of the subparameters. More important than the actual estimate, however, is the capability to appreciate how the parameter will be affected through changes in its various components.

The parameter W in equation (3) can also be written as a function of several subparameters taken from the housing demand and housing supply functions, but the expression for W is more complex. Prediction of W from first principles is difficult because it requires the absolute level of utility derived by households from housing and transport to be specified. An easier method of estimating W is to use the constraint that the sum of the populations of all zones must equal the given total regional population:

$$P_T = \Sigma_i L_i D_i = W(\Sigma_i L_i Z_i^{\omega}) \qquad (5)$$

where L_i is the area available for residential development in zone i, and P_T is the total regional population. Using this constraint, equation (3) may be rewritten as follows:

$$D_i = P_T \frac{Z_i^{\omega}}{(\Sigma_i L_i Z_i^{\omega})} \qquad (6)$$

Hence the relationship between residential density and accessibility may be represented either as an unconstrained model with two parameters to be

TABLE 1

ESTIMATION OF THE EXPECTED VALUE OF THE PARAMETER ω

Subparameter	Definition	Typical Value for Medium-Large City
g	No. of trips between home and work per day.	2 trips per day
$\bar{t}$	Average travel time for work trips	20 mins
λ	Travel impedance parameter in spatial interaction function. Assume $\lambda = 2/\bar{t}$ as for theoretical situation described in text.	$2/20 = 0.10$ mins^{-1}
V_t	Monetary value of time. Estimates vary. Assume one-half of average wage rate.	$0.001\ Y_D$ \$ mins^{-1} where Y_D = daily wage.
C_Y	Expenditure on housing, strongly related to income.	$0.2\ Y_D$ \$ per day
R_L	Ratio of land value inputs to total housing value outputs (Muth 1969, Mills 1972)	0.1

Hence: $$\omega = \frac{gV_t}{\lambda C_Y R_L} \simeq \frac{(2)(0.001Y_D)}{(0.10)(0.2Y_D)(0.1)} = 1$$

estimated, as in equation (3), or as a constrained model with only the parameter ω to be estimated, as in equation (6). The latter would obviously require a non-linear estimation method. In this study, attention has been concentrated only on the unconstrained form.

3. SIMPLE EMPIRICAL ANALYSIS

The density-accessibility relationship described in the preceding section has been tested empirically with data collected from fourteen cities of various sizes (seven Australian, five Canadian, plus Merseyside and the San Francisco Bay Area). Table 2 shows the urban populations and the zone systems used, indicating the geographical levels of aggregation, and provides brief notes on the data used in the accessibility and density calculations. Before proceeding to the results of the empirical analyses, some further comments are required on how accessibility values and residential densities were actually measured. The explanations in the following paragraphs are necessarily brief; however, detailed descriptions of the data sources, the characteristics of the data and the computations are contained in Patton (1978).

Given the spatial distribution of employment and a matrix of zone-to-zone travel times for an urban region, the computation of accessibility to employment Z_i for each analysis zone is reasonably straightforward (see equation (2)) provided that an appropriate value of λ can be specified. For the reasons outlined earlier, λ was assumed to equal twice the reciprocal of the average home-to-work travel time (that is, $\lambda = 2/\bar{t}$). This provided some consistency in the travel impedance functions between regions, although it may not have provided the optimum travel impedance function for every

TABLE 2

SUMMARY OF LEVELS OF AGGREGATION OF DATA FOR VARIOUS CITIES

City		Level of Aggregation	Total Population	Total Employment	Notes on Data used in the Calculation of Densities and Accessibilities
San Francisco Bay Area	1965	290 Zones) 126 Districts)	4,013,600	1,620,900	1965 land use data and travel times (road only).
	1970	290 Zones) 126 Districts)	4,506,500	1,975,000	1970 land use data and 1965 travel times (road only)
Melbourne	1964	55 LGAs	2,230,800	935,300	1966 land use data. 1964 travel times (both modes).
Toronto	1964	301 Zones 100 Districts	1,774,600 1,980,100	711,730 761,800	1964 land use data and travel times (both modes).
	1971	400 Zones 100 Districts	2,093,500 2,471,000	897,200 1,025,900	1971 land use data and travel times (both modes).
Merseyside	1966	29 Superzones	1,430,700	637,500	1966 land use data and travel times (both modes).
Brisbane	1966	62 Stat. Areas	772,000	-	1966 population data) 1968 employment data and travel times (both modes)
	1968	238 Zones	801,700	296,100	1968 population data)
	1971	62 Stat. Areas	859,500	-	1971 population data)
Ottawa	1963	84 Zones	521,200	179,800	1963 land use data. 1963 road travel times, 1971 transit travel times.
	1971	84 Zones	617,700	236,200	1971 land use data and travel times (both modes)
Winnipeg	1962	124 Zones	471,400	149,800	1962 land use data and travel times (both modes).
Hamilton	1964	128 Zones	373,900	143,900	1964 land use data and travel times (both modes) extracted from Toronto-Centred Region (TARMS) data files
Calgary	1958	68 Zones	226,300	57,600	1958 land use data and travel times (road only).
	1964	68 Zones	304,100	105,900	1964 land use data and travel times (road only).
Canberra	1961	34 Suburbs	65,900	27,500	1961 land use data) 1971 travel times (road only)
	1966	34 Suburbs	105,800	38,000	1966 land use data)
	1971	105 Zones	148,300	65,800	1971 land use data)
	1976	135 Zones	239,500	101,800	1976 land use data (projected)) 1976 travel times (road only)
	1979	135 Zones	282,400	124,800	1979 land use data (projected))
Hobart	1970	89 Zones) 31 Districts)	130,700	52,500	1970 land use data. Road travel times from Harbeck (1972).
Townsville	1965	72 Zones	56,300	20,000	1965 land use data and travel times (road only).
Toowoomba	1964	52 Zones	49,100	18,000	1964 land use data and travel times (road only).
Rockhampton	1971	96 Zones	48,800	17,900	1971 land use data and travel times (road only).

individual region. For regions where both car and public transport travel time matrices were available, separate accessibility variables were first computed for each mode, and a composite accessibility measure was then devised to incorporate both influences.

In the measurement of residential densities, the principal variable used was *population density*. In the derivation outlined in Section 2, households were assumed to be the basic residential units under consideration. However, one of the disadvantages of household density is that it tends to be almost the same as dwelling density, which can be a very slow-moving variable, particularly for established areas, owing to the durability of the housing stock. Population density is preferred as a variable since it may be slightly more responsive to pressures for growth or change, as families may move to areas more consistent with their family size, income level and so forth, as the characters of various suburbs change. Muth (1969) has shown that the decline of population density with distance from the city centre in a monocentric city may be attributed principally to the decline of housing output or housing value density with distance from the centre. Similarly in this study, any equilibrium relationship between population density and accessibility could be interpreted basically as a relationship between housing value density and accessibility. It is therefore appropriate to use *housing value density* as an alternative measure of residential density, and relationships involving this variable are examined in a later section.

Both gross densities and nett densities have been considered. Gross population densities were computed simply by adopting whatever zone system was available for a particular metropolitan area (this was usually a system of transportation study zones, planning districts or local government areas) and dividing the given zonal populations by the corresponding zonal areas. However, zones which were dominated by non-residential activity were excluded from the analysis. Inconsistent zone systems and levels of aggregation are probably the main factors causing variations in the density calculation and hence impairing comparisons between cities, and the extent of this effect was monitored by performing the analyses with alternative zone systems for some cities. Nett densities, on the other hand, were estimated by dividing zonal population by the area defined to be residential. Data on the nett residential areas of zones were obtained for seven of the cities; among these, however, there were some inconsistencies in the definition of "nett residential area".

The results of the regression analysis of the logarithm of gross population density against the logarithm of accessibility are presented in Table 3(a). The relationships are highly significant for all cities, excluding Canberra (where land use patterns and densities are determined not by free market forces but by the strict control exercised by the National Capital Development Commission). The coefficients of variance indicate that about 60% or more of the variance in gross population densities in the large and medium-sized cities may be explained in terms of varying accessibility values, whereas for the small Australian cities the percentage of variance is lower, being around 40-50%. Empirical estimates of the parameter ω are mostly in the range 0.5 - 1.5, in line with the coarse theoretical estimate produced in Table 1. The two extremes are for Hobart and San Francisco, and can be at least partly explained in terms of their irregular urban forms.

When nett population densities are analysed, a lower but still substantial percentage of the variance can be explained by the relationship with accessibility, except in the small Australian cities where the relationship

TABLE 3

SUMMARY OF RESULTS OF LOG-LOG REGRESSION ANALYSES OF POPULATION DENSITY AGAINST ACCESSIBILITY ($\ln D$ vs $\ln Z$)

City and Year	Analysis Units	No. of Units Incl.	Intercept $\ln W$ Estim. Mean	Intercept $\ln W$ Std. Error	Slope ω Estim. Mean	Slope ω Std. Error	Level of Signif.	R^2
(a) GROSS POPULATION DENSITIES								
San Francisco Bay Area 1965	Zones	181	-17.129	1.046	1.515	0.089	0.1%	0.62
	Districts	84	-18.417	1.841	1.591	0.157	0.1%	0.56
Melbourne 1966	LGAs	41	-11.245	0.727	0.759	0.047	0.1%	0.87
Toronto 1964	Zones	255	-14.303	0.833	1.268	0.066	0.1%	0.59
	Districts	79	-14.891	1.065	1.300	0.088	0.1%	0.74
Merseyside 1966	Super Zones	25	-11.177	2.117	0.771	0.129	0.1%	0.61
Brisbane 1966	Stat.Areas	50	-12.452	1.550	0.948	0.116	0.1%	0.58
1968	Zones	192	-10.557	0.966	0.806	0.074	0.1%	0.38
1971	Stat.Areas	50	-10.222	1.409	0.788	0.105	0.1%	0.54
Ottawa 1963	Zones	39	- 9.873	1.237	0.965	0.113	0.1%	0.66
Winnipeg 1962	Zones	79	-12.180	0.927	1.046	0.074	0.1%	0.72
Hamilton 1964	Zones	78	-13.781	2.076	1.380	0.199	0.1%	0.39
Calgary 1964	Zones	39	- 8.921	1.290	0.846	0.113	0.1%	0.60
Hobart 1970	Zones	55	- 4.416	0.814	0.497	0.093	0.1%	0.35
	Districts	20	- 4.774	0.974	0.552	0.110	0.1%	0.58
Townsville 1965	Zones	30	- 5.477	1.374	0.623	0.145	0.1%	0.40
Toowoomba 1964	Zones	29	-10.065	2.156	1.273	0.260	0.1%	0.47
Rockhampton 1971	Zones	54	- 6.169	1.174	0.861	0.152	0.1%	0.38
(b) NETT POPULATION DENSITIES								
San Francisco Bay Area 1965	Zones	181	- 8.517	0.934	0.874	0.079	0.1%	0.40
Melbourne 1966	LGAs	39	- 6.306	0.678	0.488	0.043	0.1%	0.77
Toronto 1964	Districts	64	- 8.236	1.178	0.829	0.095	0.1%	0.55
Winnipeg 1962	Zones	79	- 3.573	0.548	0.427	0.044	0.1%	0.55
Calgary 1964	Zones	39	- 1.811	0.823	0.326	0.072	0.1%	0.36
Townsville 1965	Zones	29	0.081	0.572	0.154	0.061	2.5%	0.19
Rockhampton 1971	Zones	54	-	-	-	-	N.S.	0.02

Note: Population density measured as thousands of personsper square kilometre. Accessibility Z based on negative exponential production-constrained spatial interaction formula.

is either very weak or not significant (see Table 3(b)). For the other cities, the values of the parameter ω are lower than those obtained with gross densities, and are in the general range 0.3 - 0.9.

4. THE INFLUENCE OF NON-TRANSPORT VARIABLES ON POPULATION DENSITIES

Clearly, there are several factors other than accessibility which influence spatial variations in residential densities and which need to be taken into account to ensure that the density-accessibility relationship is not distorted. The ideal method would be to define separate classes of households, according to household structure, income and other socio-economic characteristics, and to examine the location patterns of the various groups. However, this has not been possible owing to data limitations, and instead multiple regression analyses have been conducted using aggregate variables. Some brief comments on the variables examined are provided in the following paragraphs.

Family Income. With increasing income, households tend to consume more housing. Thus, given a constant level of accessibility and other factors, high income families are likely to live at lower densities than low income families. Aggregate data on average family incomes (*FAMINC*) by zones have been obtained for six cities. Although these average incomes tend to vary negatively with accessibility, the correlation ranges from very weak in the largest cities to not statistically significant in the smallest cities. It is therefore expected that the decline of density with decreasing accessibility could be attributed only marginally to variations in income patterns, and that the main effect of increasing family income would be a lowering of population density at any location. It should be recognised, however, that the slope of the density-accessibility relationship (ω) may be different for different income groups, as people's relative preferences for housing space and accessibility may change. A high income group will have higher values of C_Y and possibly R_L in the denominator of expression (4), countered to some extent by longer average trip lengths (hence a lower value of λ) and a higher value of travel time V_t, when compared to a low income group, but it has not been possible to examine these effects further in the present study.

Household Size. The overall effect of variations in household size on population density is not immediately obvious. On the one hand, if all other factors remained constant, then population density would increase as the average number of persons per household increased. On the other hand, since large families with children generally have high demands for space, increases in household size could be associated with decreasing density. The aggregate variable used is the average number of persons per household (*PPH*), which tends to increase as accessibility decreases, largely as a result of changing household structures, though the correlation is not strong in most cities. It would be desirable to determine whether variations in household size and structure cause households to adopt different positions along the one density-accessibility equilibrium spectrum, or whether household size or structure also represents a force for either consistently higher or consistently lower densities.

Physical Environment and Geographical Barriers. In Melbourne, Toronto and Brisbane, it was found that a few particular areas with pleasant physical environment (typically bayside, lakeside or mountain locations) were intrinsically attractive for residential development. A dummy variable *ENVRMT* was defined, with the value of 1 for zones judged to possess this quality, and with the value of zero for other zones. In Ottawa, Winnipeg and Calgary, dummy variables were also introduced to represent the possible effects of physical barriers (particularly rivers) on residential development patterns. For example, the Ottawa River is not only a geographical feature but also a socio-economic boundary, separating areas with different cultures, incomes and housing types. A dummy variable *QUEB* was therefore introduced, with the value of 1 for zones in the Province of Quebec.

Occupational Status. Since, in Melbourne and Brisbane, data were not available on average family incomes by analysis areas for the periods of interest, a measure of occupational status *(OCSTAT)* was used as a surrogate, for these two cities only. This was calculated as the percentage of the resident labour force employed in professional or administrative occupations.

Ethnic Background. Ethnicity is known to be an important component of the social structure of Melbourne, Toronto and many other large cities. A variable *ETHNIC,* defined as the percentage of residents born overseas, was therefore tested in the analyses of data for these two cities, and Brisbane. Unfortunately, data on ethnic background were not obtained for the San Francisco Bay Area or other cities.

The results of the multiple regression analyses are summarised in Table 4. Income is seen to be a significant negative influence on population density, either gross or nett, in most of the cities for which data were available. Occupational status (used as a surrogate for income in Melbourne and Brisbane) is statistically significant only in the relationship involving nett densities in Melbourne. Household size shows a negative influence on gross population densities in most cities indicating that large households have relatively large space demands, though the effect on nett densities is a little ambiguous. The physical environment dummy variable is highly significant in both Toronto and Brisbane (but not in Melbourne) when gross densities are considered, but has a far less important influence on nett densities. Ethnicity is confirmed as a significant factor in Toronto, even after income has been taken into account.

Notwithstanding these findings, accessibility is identified as the most consistently significant variable influencing population density patterns. In the stepwise analyses of gross densities, accessibility was freely selected as the most significant variable in seven of the eight cases, and in the analyses of nett densities, it was the most significant stable variable for the four largest cities. However, the elasticities of population density with respect to accessibility (that is, the estimates of the parameter ω) have decreased noticeably as other variables have been introduced to help explain residential density patterns. This is especially true for San Francisco and Toronto. For gross population densities, the empirical estimates of ω are now mostly within the range 0.7 - 1.1; for nett population densities, values are in the range 0.4 - 0.6 for the larger cities.

5. HOUSING VALUE DENSITIES

As mentioned earlier, Muth (1969 Ch. 4) has attributed spatial variations in population densities principally to variations in the density of housing value. A study of the determinants of housing value density should therefore be informative. Housing value density was computed for each analysis zone by multiplying the density of dwellings by the average expenditure on housing rent in that zone. The analysis employed essentially the same set of independent variables as described in the previous section, and the results

TABLE 4

SUMMARY OF MULTIPLE REGRESSION ANALYSIS OF POPULATION DENSITIES

Regression Equation:

$$\ln D = k_o + k_1 \ln Z + k_2 \ln FAMINC + k_3 \ln PPH + k_4\ (ENVRMT \text{ or } Dummy) + k_5\ ETHNIC + k_6\ OCSTAT$$

City and Year		Estimates of Variable Coefficients						R^2
	k_o	$k_1(=\omega)$	k_2	k_3	k_4	k_5	k_6	
(a) GROSS DENSITIES								
San Francisco Bay Area	1965	-4.97	1.13	-0.66	-1.56	-	-	-	0.69

City and Year	k_o	$k_1(=\omega)$	k_2	k_3	k_4	k_5	k_6	R^2
(a) GROSS DENSITIES								
San Francisco Bay Area 1965	-4.97	1.13	-0.66	-1.56	-	-	-	0.69
Melbourne 1966	-8.99	0.71	-	-1.21	N.S.	N.S.	N.S.	0.89
Toronto 1964								
(Zones)	-1.70	0.97	-0.98	-0.57	0.36*ENVRMT*	0.0080	-	0.70
(Districts)	-6.11	1.08	-0.78	N.S.	0.57*ENVRMT*	0.0202	-	0.81
Brisbane 1971	-6.17	0.68	-	-1.90	0.36*ENVRMT*	-0.0371	N.S.	0.73
Ottawa 1963	12.18	0.78	-1.82	-2.95	N.S.	-	-	0.72
Winnipeg 1962	-9.83	0.96	N.S.	-0.97	N.S.	-	-	0.73
Calgary 1964	-8.45	0.81	N.S.	N.S.	-0.52*EAST*	-	-	0.71
Townsville 1965	-5.48	0.62	N.S.	N.S.	-	-	-	0.40
(b) NETT DENSITIES								
San Francisco Bay Area 1965	8.97	0.48	-1.30	-1.00	-	-	-	0.58
Melbourne 1966	-2.55	0.41	-	-1.62	N.S.	N.S.	-0.0292	0.88
Toronto 1964 (Districts)	8.30	0.61	-1.59	N.S.	0.19*ENVRMT*	0.0006	-	0.85
Winnipeg 1962	-2.33	0.51	-0.47	1.29	N.S.	-	-	0.69
Calgary 1964*	7.03	*omit*	-0.49	-0.73	N.S.	-	-	0.70
OR *	4.64	0.27	-0.67	*omit*	N.S.	-	-	0.57
Townsville 1965	1.69	0.08	N.S.	-0.70	-	-	-	0.36

Notes: Population density measured as thousands of persons per square kilometre.

N.S. Variable not significant at 10% level.

\- Data not available.

* Alternative equations as *Z* and *PPH* were highly correlated in Calgary.

are summarised in Table 5.

In almost all cases, accessibility was found to be a strong influence on housing value density patterns, both gross and nett, and to retain the significance which it had with population density as the dependent variable. Moreover, the estimated values of the coefficient ω in Table 5 are not substantially different from the corresponding values in Table 4 (with the exception of Brisbane, where correlation between *Z* and *PPH* confounded the coefficient estimates). The physical environment variable *ENVRMT* also had a significance approximating that identified previously.

However, a big change was evident in the significance of the household size variable. This was strongly negative, indicating that housing value density tends to be lower where the number of persons per household is higher. There are several plausible explanations for this, including differences in the types of dwellings occupied by households of different sizes, and possible differences in household expenditure patterns. A quite likely explanation is that large households generally need more space and tend to be attracted to outer areas where the housing value density is low. This line of reasoning is supported by two empirical observations : firstly that average household size was negatively correlated with accessibility, albeit mildly in most cities; and secondly that, in every case, the explanatory power of the accessibility variable (the magnitude of the coefficient of $\ln Z$) was reduced as the household size variable was introduced in the stepwise regression process.

The income or socio-economic status of an area does not appear to be especially related to the housing value density, although its effect on space consumption and hence population density was quite marked.

6. DISCUSSION

The multiple regression relationships described in the previous sections give reasonably good explanations of spatial variations in residential densities, in all but the smallest cities. The nexus between density and accessibility appears to have been firmly established, and empirical estimates of the parameter ω are generally of the expected order of magnitude. This is particularly true for mature cities. For smaller cities, with populations of a few hundred thousand persons, the density-accessibility relationship appears to be in a transition state, as the transport advantages associated with position in the urban area are not yet appreciable.

Despite the coarse macroscopic approach adopted, several useful generalisations about urban structure can be drawn from the empirical findings. Firstly, although income differences within the population affect the densities at which people live, they appear not to affect markedly the spatial distribution of housing output (that is, housing value densities), as groups with different incomes seem to fit within a single equilibrium model of the housing market. In effect, the poor, as a group, are not outbid by the rich, since they live at a higher density such that their housing value density is roughly the same as that of the rich. There are of course exceptions to this general model, which is illustrated in Figure 1. In the diagram on the left, the housing value density profiles of various income groups are seen to coincide, while in the right-hand diagram the population density profiles for the various groups separate out, as the

TABLE 5

SUMMARY OF MULTIPLE REGRESSION ANALYSES OF HOUSING VALUE DENSITIES

Regression Equation:

$$ln\ HVD = k_o + k_1 lnZ + k_2 ln\ FAMINC + k_3 lnPPH + k_4 (ENVRMT\ or\ Dummy) + k_5\ ETHNIC + k_6\ OCSTAT$$

City and Year	Estimates of Variable Coefficients k_o	$k_1(=\omega)$	k_2	k_3	k_4	k_5	k_6	R^2
(a) GROSS DENSITIES								
San Francisco Bay Area 1965	-1.47	1.09	N.S.	-2.46	-	-	-	0.71
Melbourne 1966	-3.53	0.81	-	-2.06	N.S.	-0.0190	N.S.	0.91
Toronto 1964								
(Zones)	-5.51	1.12	N.S.	-1.14	0.39*ENVRMT*	0.0107	-	0.66
(Districts)	-5.29	1.10	N.S.	-1.73	0.53*ENVRMT*	0.0286	-	0.83
Brisbane 1971*	-8.30	1.04	-	*omit*	0.74*ENVRMT*	N.S.	N.S.	0.30
OR*	11.05	*omit*	-	-4.26	N.S.	N.S.	N.S.	0.29
Ottawa 1963	2.20	0.84	N.S.	-3.63	N.S.	-	-	0.74
Winnipeg 1962	-13.82	1.05	1.03	-1.30	N.S.	-	-	0.65
Calgary 1964	-1.95	0.83	N.S.	-0.77	-0.79*EAST*	-	-	0.82
Townsville 1965	1.05	0.73	N.S.	N.S.	-	-	-	0.43
(b) NETT DENSITIES								
San Francisco Bay Area 1965	5.98	0.51	N.S.	-2.09	-	-	-	0.58
Melbourne 1966	3.74	0.43	-	-2.50	N.S.	N.S.	-0.0180	0.91
Toronto 1964 (District)	12.30	0.66	-1.23	-1.48	N.S.	N.S.	-	0.83
Winnipeg 1962	3.88	0.37	N.S.	-0.83	-0.23*EAST*	-	-	0.65
Calgary 1964*	9.49	*omit*	N.S.	-1.60	N.S.	-	-	0.82
OR*	11.90	0.41	-1.01	*omit*	-0.42*EAST* -0.23*NORTH*	-	-	0.69
Townsville 1965	10.01	0.10	N.S.	-1.47	-	-	-	0.65

Notes: Units of housing value density vary among cities.

N.S. Variable not significant at 10% level.

\- Data not available.

* Alternative equations as Z and PPH were highly correlated in Calgary and moderately correlated in Brisbane.

RESIDENTIAL DENSITY AND ACCESSIBILITY

by : T.A. Patton

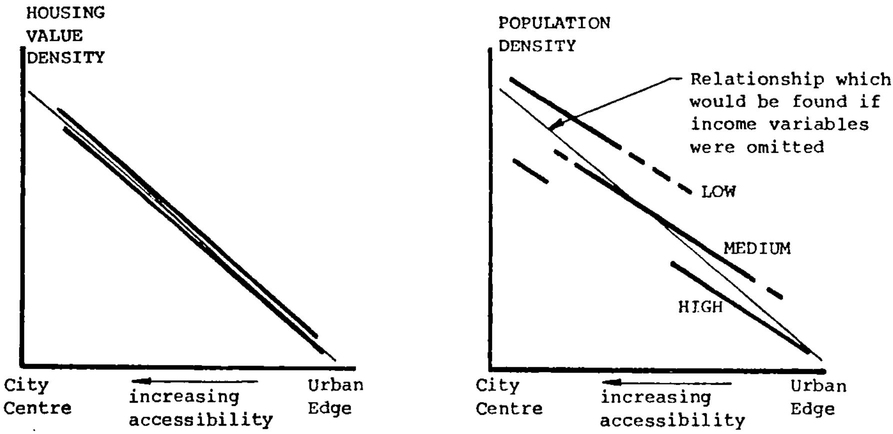

FIGURE 1 ILLUSTRATION OF THE EFFECT OF INCOME ON THE RESIDENTIAL DENSITY/ACCESSIBILITY RELATIONSHIP

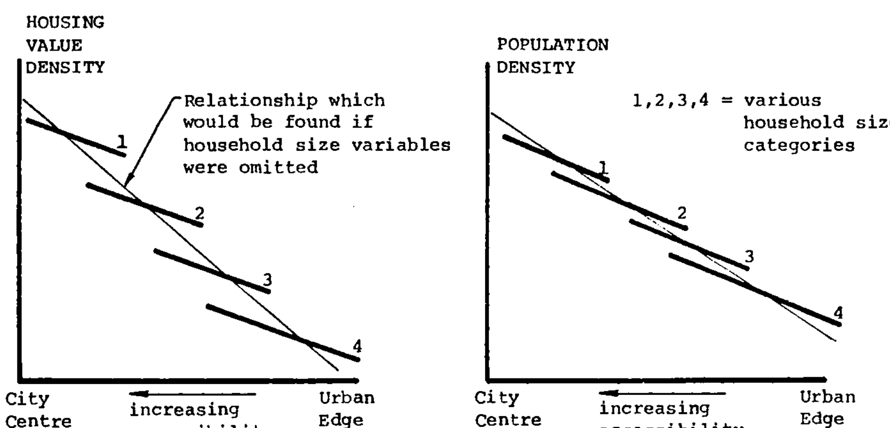

FIGURE 2 ILLUSTRATION OF THE EFFECT OF HOUSEHOLD SIZE/STRUCTURE ON THE RESIDENTIAL DENSITY/ACCESSIBILITY RELATIONSHIP

people in each group form their own neighbourhoods according to their socio-economic and space consumption characteristics. The sketch also illustrates a very weak tendency for high-income neighbourhoods to be located towards outer areas, consistent with observations reported earlier.

By contrast, average household size is not so consistently related to population density but is strongly and negatively related to housing value density. The sketches in Figure 2 show the general effect of household size and structure on the density-accessibility relationship. The correlation between average household size and accessibility, although weak in most cities, is more pronounced than that between income and accessibility. The left-hand diagram in Figure 2 suggests that large households (which tend to have greater demands for space and possibly smaller proportions of their incomes available for housing) cannot outbid small households and have to locate more towards outer areas. Their larger household size, however, has a counterbalancing effect on population density patterns, such that population densities do not vary so markedly between small-household neighbourhoods and large-household neighbourhoods at comparable levels of accessibility. Thus, the right-hand diagram in Figure 2 shows how households with varying sizes and structures may tend to occupy certain ranges of the population density-accessibility continuum.

The effect of alternative zone systems or levels of spatial aggregation may be gauged from the results for Toronto in Tables 4 and 5 (and, to a lesser extent, from the results for four cities in Table 3). It appears that the main general conclusions, and the estimates of the parameter ω in particular, are not sensitive to the choice of zone system. However, the estimates of the coefficients for some variables other than accessibility are significantly different between the alternative systems. A more important consideration is the choice between gross and nett densities as the dependent variable. With gross densities, the mean estimates of ω are in the range 0.7 - 1.1, while with nett densities the estimates are in the range 0.4 - 0.7 (excluding the smaller cities). The narrowness of each range is remarkable; so too is the difference between them.

The insights into transport and urban structure gained from these analyses may be useful to planners in various ways. For example, a measurement can be made of the premium which is attached to accessibility within urban regions. In the planning of Albury-Wodonga, an urban growth centre in south-eastern Australia, it was desired to know how property values throughout the region would appreciate as the planned growth occurred, since this might affect property investment and the viability of certain projects. The problem may be tackled by considering the region as it approaches a future population of, say, 100,000 persons. By examining accessibility patterns in other cities, it was reckoned that the measure of accessibility described in this paper would have a value of approximately 1,500 units at the outer edge of an urban area of this size, and a value of approximately 9,000 units around the city centre. Moreover, values of ω were assumed to be in the range 0.15 - 0.20, based on the results reported in Table 5(b). A simple calculation according to equation (3) shows that nett housing value densities near the city centre would then be approximately 30-40% higher than those at the urban fringe. This provides a good indication of the extent to which site values within the region might appreciate differentially as the development of Albury-Wodonga proceeds.

In the planning of Canberra, the national capital, which now has a population of about 230,000 persons, an approximately uniform distribution of residential densities has been achieved. In the future, as the city becomes large, pressures for changes in densities would be expected if free market conditions prevailed. Housing value densities are likely to become increasingly related to accessibility patterns, but, given uniform population densities, different income groups are likely to take up different positions along the accessibility spectrum. The high-income groups would tend to occupy the most central parts of the city, while the low-income groups would tend to occupy the least accessible suburbs, since by doing so they would both be closest to their market equilibrium positions as illustrated in Figure 1. The social consequences of this type of spatial distribution of the population would need to be evaluated according to a wide range of criteria. However, one possibly undesirable feature, from the point of view of transport planning, would be that the potential demands for public transport would probably be greater in the more remote locations, where the incomes and car ownership levels tended to be lower.

The relationships described in this paper have obvious applicability in the field of impact analysis; a study is currently being conducted in Melbourne to examine the development implications of alternative levels of road and public transport investment designed to improve access to the central city area. Moreover, the relationships and empirical findings should provide a basis for further model development at a more disaggregate level. A need exists for a similar comparative study of the location characteristics of separate classes of households, defined according to household structure, income and ethnic or other socio-economic characteristics.

7. ACKNOWLEDGEMENTS

The author is grateful to a large number of persons and agencies in various cities, for providing data for the analyses described, and for their support of this research project. Regrettably they are too numerous to acknowledge individually.

B. REFERENCES

Alonso, W. (1964). *Location and Land Use.* Harvard University Press.

Clark, C. (1951). Urban Population Densities. *Journal of the Royal Statistical Society, CXIV,* 4.

Eastin, R.V. and Shapiro, P. (1973). The Design of a Location Experiment. *Transportation Research, 7* pp. 17-29.

Evans, A.W. (1973). *The Economics of Residential Location.* Macmillan.

Hansen, W.G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners, 25,* 2, pp. 52-75.

Mills, E.S. (1972). *Studies in the Structure of the Urban Economy.* Resources for the Future Inc. John Hopkins Press, Baltimore.

Muth, R.F. (1969). *Cities and Housing.* University of Chicago Press.

Neuburger, H. (1971). User Benefit in the Evaluation of Transport and Land Use Plans. *Journal of Transport Economics and Policy,* 5, 1.

Patton, T.A. (1978). *Transport and Residential Location in Western Cities.* Ph.D. thesis, University of Melbourne.

Patton, T.A. and Clark N.F. (1970). Towards an Accessibility Model for Residential Development, in Clark N.F. (ed) *Analysis of Urban Development.* Procs Tewksbury Symposium, Department of Civil Engineering, University of Melbourne.