Canadian Studies in Population, Vol. 1, 1974, pp. 43-59.

AN APPLICATION OF NETWORK THEORY TO MIGRATION ANALYSIS*

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Résumé—Cette étude ébauche une manière théorique d'aborder la prévision des taux d'émigration pour des centres et leurs zones d'influence à l'intérieur des régions qui se caractérisent par des niveaux avancés de développement économique.

Abstract—This paper outlines a theoretical approach for forecasting migration rates for central places and their spheres of influence within regions characterized by advanced levels of economic development.

Introduction

The concern of this paper is to develop a methodology for examining the causes of migration and for projecting net migration figures among nodal regions. The first part of the paper reviews factors correlating significantly with net migration; the second part studies the transportation network, particularly the relationships among accessibility, economic growth, and net migration; the third part proposes a methodology, utilizing graph theory concepts, for projecting regional net migration figures by including topological accessibility as a separate factor. In part four, a simple pilot study of Ontario is examined to show the application of graph theory definitions of accessibility to migration study.

Factors in Migration

A basic premise of migration study has been that regions vary in their attractiveness to potential migrants. Three broad groups of causal variables have been identified as underlying areal decisions to migrate: socio-economic variables, demographic variables, and geographic variables.

Socio-economic variables have been examined in a series of "economic opportunity" models. For example, in an examination of urban in-migration ratios in Canada for the period 1956-61, Stone (1969) using cluster analysis, isolated six basic socio-economic clusters: tertiary activity specialization; social heterogeneity; income; modernity of income; manufacturing specialization; and intensity of trading activity. While he noted the dangers inherent in inferring causal mechanisms from correlations, Stone held that the technique had value when used judiciously. In his study he calculated a multiple correlation coefficient of 0.53, but pointed out that the level of multiple correlation would have been markedly increased if population potential, a demographic-geographic measure, had been included among the independent variables.

Population potential is one of a family of models commonly used by demographers and geographers in analyzing the attractive force of any particular location on the movement of goods or people. These models are termed gravity models since the basic formula is derived from Newtonian physics. Reilly (1929) expressed the concept by the formula:

$$M_{ij} = P_{ij}\,(d_{ij})^{-2}$$

* This paper was first presented at the Annual Meetings of the Population Association of America in Toronto, 1972.

In which M_{ij} is the interaction between two centres i and j, and P_{ij} is a measure of the combined mass of the two centres and d_{ij} is a measure of the distance separating them.

The problem with gravity models is that the parts of the expression are open to varying definitions. In practice, mass has conventionally been equated with population size, and distance with mileage or travel time. As far as the relationships among the parts are concerned, Stewart (1950) and Zipf (1949) modified the earlier gravity models by changing the exponent of the distance variable from -2 to -1. The formula thus restated, was considered to more nearly represent North American conditions.

The population potential concept referred to by Stone is an elaboration of this gravity model, the basic form of which was expressed by Anderson (1956) in the following formula:

$$H_i = \Sigma_j F_{ij}$$

where H_i is population potential, and

$$F_{ij} = \frac{KX_j}{d_{ij}}$$

where X_j is a characteristic of the jth area in the region to be considered, K is the coefficient of X which varies over time and d_{ij} is the distance between areas i and j. The model is, as stated, similar to the early gravity models, except that the total potential of an area is some combination of the contribution of each separate area. Anderson also suggested two interpretations of X: one, resources; the other, population. However, Stone (1969) implies that the latter interpretation—in terms of population numbers—should be the focus for potential studies, since growth appears to be centered on major metropolitan areas. He emphasizes that the population potential concept essentially refers to the degree of proximity of an urban complex to large agglomerations of population.

The numerous migration studies using such gravity model concepts reflect two major internal net migration trends during the century. One trend is the unprecedented swarming of the human race into urban centres. The second one is superimposed on the first, particularly in economically advanced societies, namely a movement from lower to higher order centres.[1] The net result of these two migratory trends has been increasing concentration of population into fewer but larger agglomerations. It is, therefore, extremely important for all facets of regional development and planning that these movements are analyzed in order to discover causal factors which can provide the basis for predicting future population distributions. Furthermore, it should be possible to utilize such factors as can be manipulated politically to guide migration into desired patterns. This paper proposes that one such factor, locational accessibility implicit in potential models, warrants further study. Furthermore, as the succeeding sections show, this factor through the use of network analysis and graph theory may be used to, refine existing potential models, assist in understanding the causes of migration, and improve existing methods of prediction.

Networks and Net Migration

The rationale for assuming the significance of networks in influencing migration patterns is based on a physical analogy. A network is a system involving flows. In physical phenomena, such as stream networks, flows are partly regulated by the discharge capacity of the individual branches of the stream network. Any change in a particular route of that network, occasioned, for example, by diverting or shortening any particular branch, will affect the rates of flow of the discharge elsewhere. Previous success in using physical phenomena as analogue models for human interactions suggests that a similar analogy may be drawn between the effects of changing stream networks on discharge flows, and the effects of changing communication networks on the direction and rate of commodity flows, capital flows and population flows.

In a study of sequential relationships among urban functions, functional regions and urban growth, Ray (1968) identified four main stages in the urbanization process. In the early phase, the economic foundations of urban growth are "low order central place" functions; the result is relatively high rates of growth in low order centres. In a later stage, urban growth accelerates in those centres where special functions, such as administration, mining and military, are acquired. In the third phase, improvements, primarily in transportation, reduce the friction of distance and permit the establishment of higher order central place functions and the creation of an hierarchy of market regions. Ultimately, higher order manufacturers with low distance decay enable some centres to capture national and subnational markets, thereby creating areal concentrations of punctiform agglomerations. Clearly, the significance of networks in accelerating differential economic and urban growth becomes increasingly important in the later stages.

Further evidence of the importance of networks in generating economic growth, and particularly of the relative accessibility of nodes in that network to one another, is implicit in the concepts of population potential and of market potential. Indeed, market potential and the allied concept of population potential are an extension of earlier theories on industrial location of Weber (1929) and Losch (1939). Harris (1954), defines this particular concept as:

$$P_i = \Sigma_j \left(\frac{M_j}{d_{ij}} \right)$$

where P_i is the market potential

M_j is a measure of each market

d_{ij} is an assigned constant-distance-decay exponent determined by an analysis of commodity flows, which in essence is an index of market accessibility.

In yet other studies Borts (1960) and Fuchs (1962) found that the locations of industry and regional population growth were strongly influenced by market accessibility. Duncan (1960) tied these ideas together with the finding that secondary manufacturing is highly correlated with population potential and that deviations of manufacturing from market accessibility are attributable to the locational pull of mineral deposits. As previously indicated, current potential models—whether measuring population potential or market potential—implicitly recognize the significance of accessibility on economic and population phenomena. Accessibility can also be stated in graph theoretic terms. In this context, networks are reduced to the level of graphs. The graph consists of a series of nodes which may be considered as polarization points. The routes connecting these points are limited to a single path representing the key link between any two nodes. However, accessibility in topological terms adds a new dimension to the concept since it involves the reduction of the elements of a network and the relations between them to their most elemental form. There is no concern with the length or the orientation of the lines, or with their curvature. It is, therefore, possible to redraw the graph in a series of alternative forms which still preserve the basic pattern of interconnections between nodes and links (see Figure 1). Accessibility in a topological sense is independent of distance and is concerned purely with the locational relationship of nodes, one with the other, within a given network. In this context then, accessibility can serve as a measure of intervening opportunity in both an economic and a demographic sense. It is in the mainstream of thought propounded by Ravenstein (1889) in laws of migration and more recently by Stouffer (1940).

A transportation network may be defined in the language of graph theory as a set of nodes (N) or geographic locations interconnected by a number of edges (E) or routes, along which flows take place. Graph theory, as a branch of combinatorial topology, can provide

FIGURE 1. GRAPH OF ONTARIO ROAD NETWORK CONNECTING ALL CENTRES OVER 25,000 POPULATION (1961)

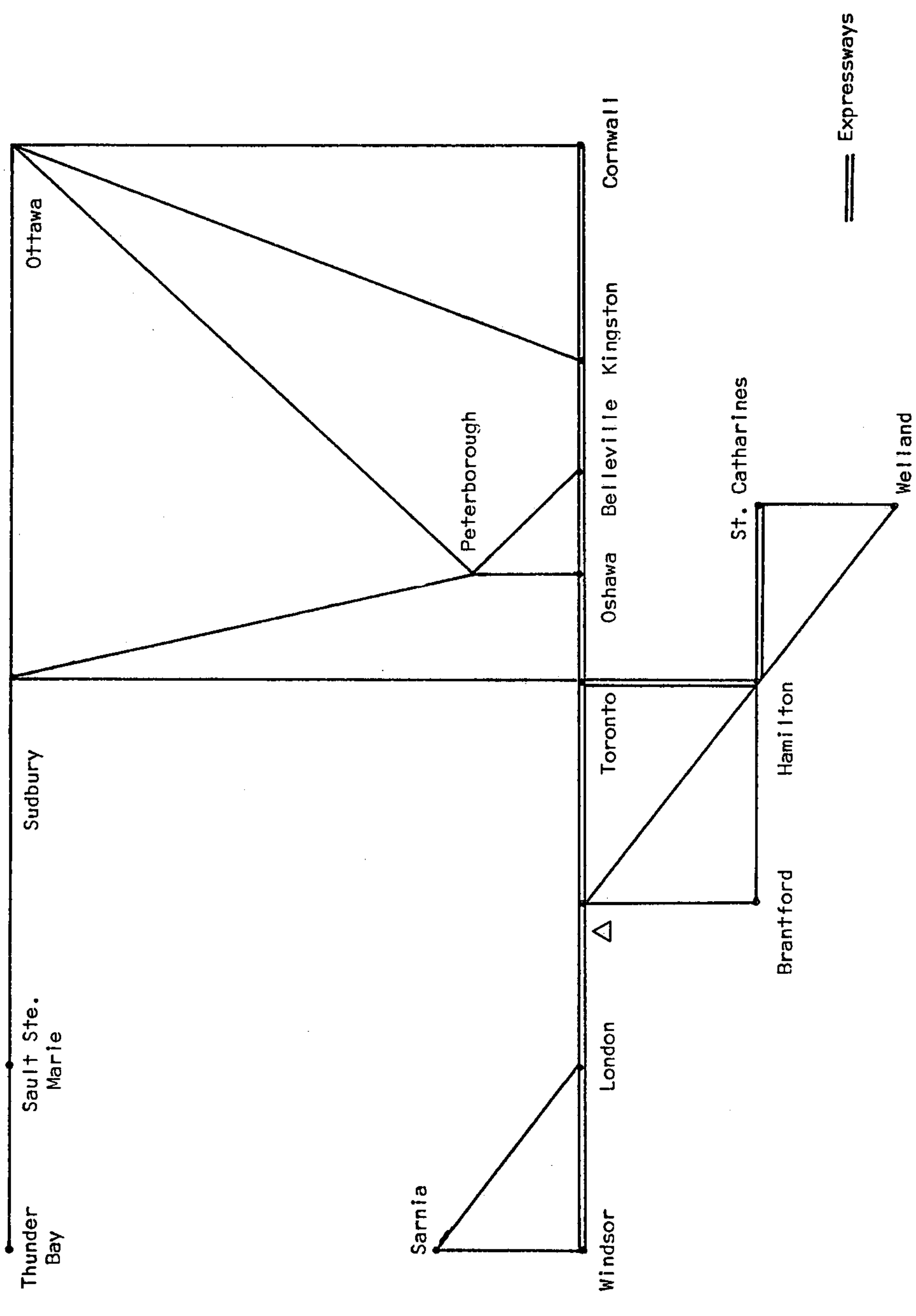

TABLE 1. RAW ACCESSIBILITY SCORE ON AN ALL ONTARIO ROAD NETWORK, FOR ALL VERTICES WITH A POPULATION OF 25,000 OR MORE (1966)

	Windsor	London	Sarnia	Golden Triangle	Brantford	Hamilton	St. Catharines	Welland	Toronto	Oshawa	Belleville	Kingston	Cornwall	Peterborough	Ottawa	Sudbury	Sault Ste. Marie	Thunder Bay	Raw Accessibility Score
Windsor	0	1	1	2	3	3	4	4	3	4	5	6	6	5	5	4	5	6	67
London	1	0	1	1	2	2	3	3	2	3	4	5	5	4	4	3	4	5	52
Sarnia	1	1	0	2	3	3	4	4	3	4	5	6	6	5	5	4	5	6	67
Golden Triangle	2	1	2	0	1	1	2	2	1	2	3	4	4	3	3	2	3	4	40
Brantford	3	2	3	1	0	1	2	2	2	3	4	5	5	4	4	3	4	5	53
Hamilton	3	2	3	1	1	0	1	1	1	2	3	4	4	3	3	2	3	4	41
St. Catharines	4	3	4	2	2	1	0	1	2	3	4	5	5	4	4	3	4	5	56
Welland	4	3	4	2	2	1	1	0	2	3	4	5	5	4	4	3	4	5	56
Toronto	3	2	3	1	2	1	2	2	0	1	2	3	3	2	2	1	2	3	35
Oshawa	4	3	4	2	3	2	3	3	1	0	1	2	3	1	2	2	3	4	43
Belleville	5	4	5	3	4	3	4	4	2	1	0	1	2	1	2	2	3	4	50
Kingston	6	5	6	4	5	4	5	5	3	2	1	0	1	2	1	2	3	4	58
Cornwall	6	5	6	4	5	4	5	5	3	3	2	1	0	2	1	2	3	4	61
Peterborough	5	4	5	3	4	3	4	4	2	1	1	2	2	0	1	1	2	3	47
Ottawa	5	4	5	3	4	3	4	4	2	2	2	1	1	1	0	1	2	3	47
Sudbury	4	3	4	2	3	2	3	3	1	2	2	2	2	1	1	0	1	2	38
Sault Ste. Marie	5	4	5	3	4	3	4	4	2	3	3	3	3	2	2	1	0	1	52
Thunder Bay	6	5	6	4	5	4	5	5	3	4	4	4	4	3	3	2	1	0	68
Raw Accessibility Score	67	52	67	40	53	41	56	56	35	43	50	58	61	47	47	38	52	68	931 $\sum_{i=1}^{n}\sum_{j=1}^{n}$

Source: Figure 1.

an appropriate language suitable for measurement and analysis of the structure of transportation networks.

Accessibility in this sense can be defined as the sum of the shortest number of edges connecting vertex i with every other vertex in the network, that is:

$$X_i = \sum_{j=1}^{n} d_{ij}$$

where X_i is topologic accessibility and d_{ij} is the topological distance from a vertex i to all other vertices in the network.

Table 1 shows the matrix calculated from Figure 1. Ray's interpretation of the significance of stages of urban development in accessibility studies indicates that the selection of nodes and edges will vary with the stage of development. Thus in Canada, today, nodes could be based on the fourth and higher order centres described by Camu, Weekes, and Sametz (1964, p. 266) as:

> major industrial . . . with a labour force of 25,000 upwards of which sixty per cent are engaged in nonagricultural industries. Such a place is the centre of a . . . zone, and generally of a node region.

whereas at an earlier stage it would have been necessary to use lower order centres as nodes in addition to the higher order ones.

The rationale for the selection of paths is tied up with industrial location theory and the allied market potential concept. The agglomeration phenomenon already referred to, and the short distance cost advantages conferred upon truck vis-à-vis other forms of transportation have meant that major changes in the accessibility of nodes in industrialized economies are occurring as a result of changes in the road network. Hence, the major truck route between any two centres can be selected as the path connecting them on a graph net. Thus, for example, in Ontario, the Queen's Highway or the freeways provide the range of the domain from which the subset of paths is drawn.

The Concept of a Nodal Region in Migration Studies

There are two major problems in analyzing the contribution of migration in differential nodal growth. One is the change in urban boundaries from one time period to another which makes longitudinal comparisons difficult. A second problem involves the relations between growth of a node and growth of its immediate sphere of influence or "field." The concept of an urban field is important in migration studies in two ways. In the first place, differential rates apply to higher as against lower order central places in the urban hierarchy. Secondly, movements inside the urban field to the main node can obscure movements into the field from outside, and it is these latter movements which are the most significant in terms of regional growth. Hence nodes are not the best unit of analysis in examining regional migration. Indeed, the relationship between accessibility and net migration should be considered in terms of nodal regions rather than in terms of the nodes alone. However, nodes, as the nuclei of regions, provide practical terms of reference for calculating intervening opportunities in terms of topological distance.

Such considerations demonstrate the need to define the boundaries of urban fields. Various methods have been suggested. Christaller (1933), in his classic work on central places, laid the groundwork for a methodology in which he showed that, *ceteris paribus,* central places tended to develop spheres of influence approximating overlapping hexagons. Such a geometric shape maximizes the amount of packing of space into an area, consistent with minimizing movement and boundary costs. The work of Isard (1956) and Getis (1963) shows that regular hexagonal territories are not generally visible because they are related to population space and income space, rather than to geographical space, although according to Haggett (1965, p. 65) hexagons may:

> be thought to be latent in most human organization but only through appropriate transformations of geographical space is their form likely to be made visible.

Various methods have been employed to solve this problem of defining the boundaries of regions. Bogue's (1949, p. 17) Thiessen polygon procedure is most akin to the geometric form suggested by Christaller. Later approaches include those by Sebestyen (1962, pp. 69-71) who employed discriminant analysis, and Yeates (1963), who used distance minimization functions. Another entirely new perspective on the problem, however, was developed by Nysteun and Dacey, (1961), who pioneered the use of graph theory as a solution to the definition of regions.

The Basic Accessibility Approach

In this section two ways of using accessibility measure in migration studies will be considered. The first will be termed the basic accessibility approach and the second, the connectivity approach.

Accessibility in its basic topological form throws away a great deal of information, hence, the basic accessibility score for each node and its region must be weighted so that:

$$X_i = W_i \sum_{j=1}^{n} d_{ij}$$

where W_i is a weight. Population, commodity flows, and travel time are illustrations of weights that can be applied.

Since accessibility is concerned with flows, it is hypothesized that:

$$M = f\ (X_1)$$

where M is net migration (rate or absolute numbers), and
X_1 is a weighted accessibility measure.

Numerous studies, including those cited above, indicate that migration is a function of many factors other than accessibility, although some of them are related to network measures. Kansky (1963) isolated a technological scale index, using principal component analysis, a demographic scale reflecting birth and death rates, size and shape of territories, and relief. It is therefore proposed in this paper that:

$$M = f\ (X_1,\ X_2,\ X_3,\ X_4\ .\ .\ .\ X_n)$$

where M is net migration
X_1 is a measure of accessibility
X_2 is a population potential measure
X_3 is a measure of economic health
X_4 is a measure of attractiveness
X_n is any other measure indicated by the empirical evidence.

Although this paper is primarily concerned with the accessibility variable, a brief note concerning other variables is in order. The population potential and socio-economic health measures have already been discussed in connection with Stone's methodology. The attractiveness index introduces measures expressing climatic, relief and resource base differentials, some of the other variables suggested by Kansky (1963).

Since the proposed methodology in examining migration involves multiple regression analysis, and since this type of analysis seeks to discover and measure the relationship among variables, an equation is needed which weights the individual independent variables according to their respective effects upon the dependent variable. These weights are determined by empirical evidence. The final functional form of the equation is therefore:

$$M = f\ (a,\ b_1\ X_1,\ b_2\ X_2,\ b_3\ X_3,\ .\ .\ .\ b_n\ X_n)$$

where b_1, b_2 . . . b_n are the weights and a is the intercept.

Introducing the Time Element in the Basic Approach

Trends within X_2 . . .X_n can be calculated for each vertex and extrapolated. However, since X_1 is a variable subject to a single policy decision, and since it constitutes a significant component of the physical infrastructure of a region in which changes tend to be discrete rather than continuous, the calculations need to be done differently. In this case, proposed highway changes in the transportation network should provide the basis for drawing up new accessibility matrices and for calculating new accessibility ratings for each vertex. If such information is lacking, alternative methods of assessing likely route changes can be used applying Monte Carlo techniques and a comparative topologic approach.

Trends in the coefficients will reflect changes in weights of the independent variables once the methodology has been applied to a series of time periods, and as the bank of data grows. In the interim, if data are lacking, it may be necessary to assume constant weights.

The Connectivity Approach

In this approach, the graph is treated as a connectivity matrix C^1 in which links between vertices are shown by binary coding: one, if there is a direct link, and zero, if there is not. Table 2 shows a connectivity matrix based on Figure 2.

FIGURE 2. GRAPH OF A HYPOTHETICAL TRANSPORT NETWORK

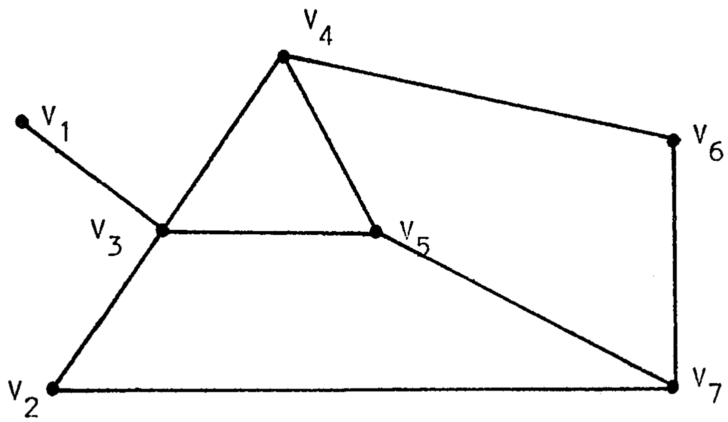

TABLE 2. CONNECTIVITY MATRIX FOR FIGURE 2

Vertices	1	2	3	4	5	6	7
1	0	0	1	0	0	0	0
2	0	0	1	0	0	0	1
3	1	1	0	1	1	0	0
4	0	0	1	0	1	1	0
5	0	0	1	1	0	0	1
6	0	0	0	1	0	0	1
7	0	1	0	0	1	1	0

The original binary matrix can be powered to give a series of matrices C^2, $C^3 \ldots C^n$. By continued powering of the matrix it is possible to eliminate all zero elements, at which point the solution time of the graph is reached (see Table 3).

TABLE 3. PART OF 39x39 MATRIX OF SETTLEMENTS IN MEDIEVAL RUSSIA SHOWING RESULTS OF SUCCESSIVE POWERINGS OF ORIGINAL BINARY MATRIX

$$C^1 = \begin{Bmatrix} 0 & 1 & 0 & 0 & . \\ 1 & 0 & 1 & 0 & . \\ 0 & 1 & 0 & 1 & . \\ 0 & 0 & 1 & 0 & . \\ . & . & . & . & . \end{Bmatrix} \qquad C^8 = \begin{Bmatrix} 110 & 15 & 143 & 16 & . \\ 15 & 155 & 21 & 167 & . \\ 143 & 21 & 580 & 32 & . \\ 16 & 167 & 32 & 257 & . \\ . & . & . & . & . \end{Bmatrix}$$

Source: Pitts, (1965).

It is hypothesized that in the original connectivity matrix C^1, each member of a pair of directly linked nodes represents an intervening opportunity to the other. The higher the figures (indicated by the larger numbers for later two, three and n step opportunities revealed by later powerings) the less the intervening opportunities and the greater the accessibility of a vertex. The powered matrices when summed can be expressed by the formula:

$$T^n = C^1 + C^2 \ldots + C^n = \sum_{i=1}^{n} C^i$$

If $t^n ij$ measures accessibility of node i to node j then:

$$\sum_{j=1}^{n} t^n$$

denotes the accessibility of node i to all the other nodes in the network.

Weighting methods have also been employed in this approach. Shimbel and Katz (1953) devised a weighted connectivity matrix using a scalar varying between 0 and 1 in their examination of the structural properties of networks. Migaji (1966) suggested that interesting results can be obtained by examining intermediate powers of the matrix. Indeed, Nysteun and Dacey (1961) used this technique in a linkage analysis of the interstate highway system of the Eastern United States. As a result of their study they were able to identify nodal regions, thereby providing a solution to the regional delimitation problem previously noted. The value of X_1 thus calculated enters into the basic multiple regression equation.

The connectivity approach seems to offer more flexibility in operation. The main difference in interpretation lay in the fact that in the basic accessibility approach the lower the score of a vertex the more accessible it is, whereas in the latter approach, the reverse holds true.

Application of Network Theory

A simplified study involving accessibility concepts was carried out by the principal author. In this study, a network was constructed for Ontario. Each vertex represented a settlement which in the 1961 Census had a population of 25,000 or more. The Kitchener-Waterloo, Galt, Guelph triangle and the Hamilton-Burlington complex were treated as one vertex since the separate entities can be considered a geographic, if not a political unity, because they are adjacent to each other in terms of metric distance.

Each edge of the network represented a major freeway, or Queen's Highway, connecting each vertex with other vertices. Wherever there was more than one edge connecting any particular vertex to another, the most probable truck route was chosen. Each edge was assigned a value of one, except for those vertices on major freeways. The greater efficiency in effecting movement between vertices of such divided highways as the Queen Elizabeth Way and the MacDonald Cartier freeway was taken into account by halving the value compared to other highways. Figure 1 illustrates the network thus defined.

Since the density of population varies so widely, an arbitrary weighting to account for this difference was assigned to the raw accessibility score. Thus those centres southwest of the Metropolitan Toronto orbit, incorporating the Oshawa-Oakville section of the Golden Horseshoe, were weighted by multiplying the raw scores by two, while the centres in Eastern and Northern Ontario were weighted by a score of two and a half. The weighted scores for each vertex are shown in Column B of Table 4. The centre with the lowest number is the centre where intervening opportunities have the least effect on migration; the centre with the largest number has the worst locational advantages in these terms.

In this study, only intermediate size centres—between 25,000 and 250,000—were analyzed in terms of the relation between accessibility and migration rates. However, the

TABLE 4. MATRIX OF ROUTES BETWEEN VERTICES IN ONTARIO

City (County)	Windsor	London	Sarnia	Golden	Brantford	Hamilton	St. Catharines	Welland	Toronto	Oshawa	Belleville	Kingston	Cornwall	Peterborough	Ottawa	Sudbury	Sault Ste. Marie	Thunder Bay	Access-ibility Score	Weighted Access-ibility Score	Net Migration 1961-1966 (County) in 000's	Net Migration 1961-1966 (County) % of 1961 Pop.
																			A	B	C	D
Windsor (Essex)	-	½	1	1	2	2	2½	3	1½	2	2½	3	3½	3	3½	2½	3½	4½	41½	83	4.6	1.8
London (Middlesex)	½	-	1	½	1½	1½	2	2½	1	1½	2	2½	3	2½	3	2	3	4	34	68	12.2	5.5
Sarnia (Lambton)	1	1	-	1½	2½	2½	3	3½	2	2½	3	3½	4	3½	4	3	4	5	49½	99	0.7	-0.7
Golden △ (Waterloo, Well.)	1	½	1½	-	1	1	1½	2	½	1	1½	2	2½	2	2½	1½	2½	3½	28	56	27.0	10.3
Brantford (Brant)	2	1½	2½	1	-	1	1½	2	1½	2	2½	3	3½	3	3½	2½	3½	4½	41	82	1.8	2.2
Hamilton (Wentworth)	2	1½	2½	1	1	-	½	1	½	1	1½	2	2½	2	2½	1½	2½	3½	29		excluded	
St. Catharines (Lincoln)	2½	2	3	1½	1½	½	-	1	1	1½	2	2½	3	2½	3	2	3	4	36½	73	10.4	8.3
Welland (Lincoln)	3	2½	3½	2	2	1	1	-	1½	2	2½	3	3½	3	3½	2½	3½	4½	44½	89	2.8	1.7
Toronto (York-Peel)	1½	1	2	½	1½	½	1	1½	-	½	1	1½	2	1½	2	1	2	3	24	24	excluded	
Oshawa (Ontario)	2	1½	2½	1	2	1	1½	2	½	-	½	1	1½	1	2	1½	2½	3½	27½	28	22.1	16.3
Belleville (Hastings)	2½	2	3	1½	2½	1½	2	2½	1	½	-	½	1	1	1½	2	3	4	32	80	-5.9	-6.3
Kingston (Frontenac)	3	2½	3½	2	3	2	2½	3	1½	1	½	-	½	1½	1	2	3	4	36½	91	3.1	3.5
Cornwall (Stormont)	3½	3	4	2½	3½	2½	3	3½	2	1½	1	½	-	2	1	2	3	4	42½	106	-2.5	-4.2
Peterborough (Peterborough)	3	2½	3½	2	3	2	2½	3	1½	1	1	1½	2	-	1	1	2	3	35½	89	1.2	1.5
Ottawa (Carleton)	3½	3	4	2½	3½	2½	3	3½	2	2	1½	1	1	1	-	1	2	3	40		excluded	
Sudbury (Sudbury)	2½	2	3	1½	2½	1½	2	2½	1	1½	2	2	2	1	1	-	1	2	31	78	-8.5	-5.1
Sault Ste. Marie (Algoma)	3½	3	4	2½	3½	2½	3	3½	2	2½	3	3	3	2	2	1	-	1	45	132	-9.3	-8.4
Thunder Bay (Thunder Bay)	4½	4	5	3½	4½	3½	4	4½	3	3½	4	4	4	3	3	2	1	-	61	152	-4.6	-8.3
	41¼	34	49½	28	41	29	36	44½	24	27½	32	36½	42½	35½	40	31	45	61				

Source: Migration data computed by the residual method from census data, after allowance for births and deaths during the period. Data prepared for the Ontario Population Study conducted at the Ontario Institute for Studies in Education.

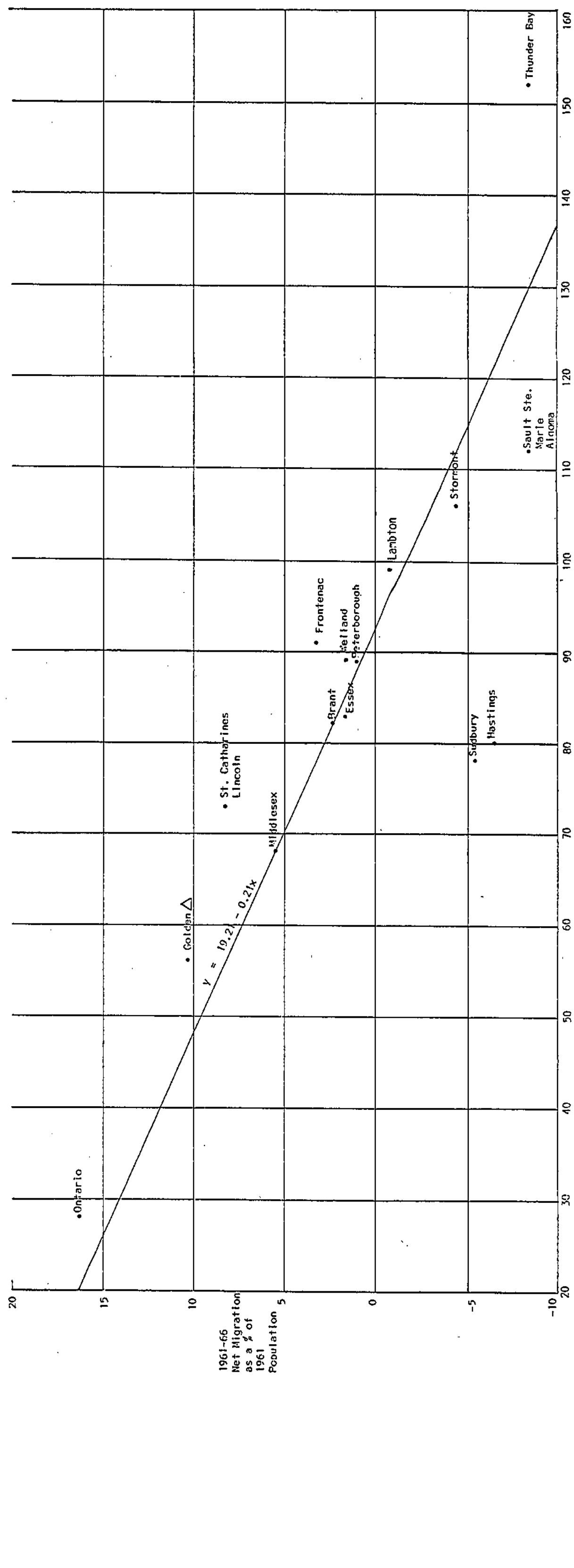

FIGURE 3. CORRELATION OF NET MIGRATION AND WEIGHTED ACCESSIBILITY FOR PERIOD 1961-1966

TABLE 5. MATRIX FOR 1956-61

	Windsor	London	Sarnia	Golden Triangle	Brant	Hamilton	St. Catharines	Welland	Toronto	Oshawa	Belleville	Kingston	Cornwall	Peterborough	Ottawa	Sudbury	Sault Ste. Marie	Thunder Bay	Associate Number A	Associate Number B	Net Migration 1956-61 % of 56 pop.	
Windsor	–	1	1	2	3	3	3½	4	2½	3	4	5	6	4	5	3½	4½	5½	60½	121	-4.8	
London	1	–	1	1	2	2	2½	3	1½	2	3	4	5	3	4	2½	3½	4½	45½	91	6.7	
Sarnia	1	1	–	2	3	3	3½	4	2½	3	4	5	6	4	5	3½	4½	5½	58½	117	3.0	
Golden Triangle	2	1	2	–	1	1	1½	2	½	1	2	3	4	2	3	1½	2½	3½	33½	67	6.2	
Brant	3	2	3	1	–	1	1½	2	1½	2	3	4	5	3	4	2½	3½	4½	46½	93	0.07	
Hamilton	3	2	3	1	1	–	½	1	½	1	2	3	4	2	3	1½	2½	3½	34½	69	4.0	Excl.
St. Catharines	3½	2½	3½	1½	1½	½	–	1	1	1½	2½	3½	4½	2½	3½	2	3	4	42	84	4.3	
Welland	4	3	4	2	2	1	1	–	1½	2	3	4	5	3	4	2½	3½	4½	52	104	0.74	
Toronto	2½	1½	2½	½	1½	½	1	1½	–	½	1½	2½	3½	1½	2½	1	2	3	29½	59	10.3	Excl.
Oshawa	3	2	3	1	2	1	1½	2	½	–	1	2	3	1	2	1½	2½	3½	32½	65	13.78	
Belleville	4	3	4	2	3	2	2½	3	1½	1	–	1	2	1	2	2	3	4	40	100	0.67	
Kingston	5	4	5	3	4	3	3½	4	2½	2	1	–	1	2	1	2	3	4	50	125	5.8	
Cornwall	6	5	6	4	5	4	4½	5	3½	3	2	1	–	3	1	2	3	4	62	155	-1.5	
Peterborough	4	3	4	2	3	2	2½	3	1½	1	1	2	3	–	1	1	2	3	39	97.5	3.6	
Ottawa	5	4	5	3	4	3	3½	4	2½	2	2	1	1	1	–	1	2	3	47	117.5	13.97	Excl.
Sudbury	3½	2½	3½	1½	2½	1½	2	2½	1	1½	2	2	2	1	1	–	1	2	33	82.5	2.2	
Sault Ste. Marie	4½	3½	4½	2½	3½	2½	3	3½	2	2½	3	3	3	2	2	1	–	1	47	117.5	18.5	
Thunder Bay	5½	4½	5½	3½	4½	3½	4	4½	3	3½	4	4	4	3	3	2	1	–	63	90.0	2.2	

Source: K. Hughes, "The Relation Between Net Migration and the Highway Network for Intermediate Size Centres in Ontario". Unpublished paper. The authors are indebted to Mr. Hughes for permission to reproduce this table and other material from his paper.

TABLE 6. MATRIX SHOWING THE EFFECT OF A NEW ROAD TO OWEN SOUND

	Windsor	London	Sarnia	Golden Triangle	Brant	Hamilton	St. Catharines	Welland	Toronto	Oshawa	Belleville	Kingston	Cornwall	Peterborough	Ottawa	Sudbury	Sault Ste. Marie	Thunder Bay	Owen Sound	Associate Number A	Associate Number B
Windsor	–	½	1	1	2	2	2½	3	1½	2	2½	3	3½	3	4	2½	3½	4½	1½	43½	87
London	½	–	1	½	1½	1½	2	2½	1	1½	2	2½	3	2½	3½	2	3	4	1	35½	71
Sarnia	1	1	–	1½	2½	2½	3	3½	2	2½	3	3½	4	3½	4½	3	4	5	1	51	102
Golden Triangle	1	½	1½	–	1	1	1½	2	½	1	1½	2	2½	2	3	1½	2½	3½	1	29½	59
Brant	2	1½	2½	1	–	1	1½	2	1½	2	2½	3	3½	3	4	2½	3½	4½	2	43½	87
Hamilton	2	1½	2½	1	1	–	½	1	½	1	1½	2	2½	2	3	1½	2½	3½	1	30½	61
St. Catharines	2½	2	3	1½	1½	½	–	1	1	1½	2	2½	3	2½	3½	2	3	4	1½	38½	77
Welland	3	2½	3½	2	2	1	1	–	1½	2	2½	3	3½	3	4	2½	3½	4½	2	47	94
Toronto	1½	1	2	½	1½	½	1	1½	–	½	1	1½	2	1½	2½	1	2	3	½	25	50
Oshawa	2	1½	2½	1	2	1	1½	2	½	–	½	1	1½	1	2	1½	2½	3½	1	28½	57
Belleville	2½	2	3	1½	2½	1½	2	2½	1	½	–	½	1	1	1½	2	3	4	1½	33½	83¾
Kingston	3	2½	3½	2	2½	2	2½	3	1½	1	½	–	½	1½	1	2	3	4	2	38	95
Cornwall	3½	3	4	2½	3½	2½	3	3½	2	1½	1	½	–	2	1	2	3	4	2½	45	112½
Peterborough	3	2½	3½	2	3	2	2½	3	1½	1	1	1½	2	–	1	1	2	3	2	43½	108¾
Ottawa	4	3½	4½	3	4	3	3½	4	2½	2	1½	1	1	1	–	1	2	3	3	47½	118¾
Sudbury	2½	2	3	1½	2½	1½	2	2½	1	1½	2	2	2	1	1	–	1	2	1½	32½	81¼
Sault Ste. Marie	3½	3	4	2½	3½	2½	3	3½	2	2½	3	3	3	2	2	1	–	1	2½	47½	118¾
Thunder Bay	4½	4	5	3½	4½	3½	4	4½	3	3½	4	4	4	3	3	2	1	–	3½	64½	161¼
Owen Sound	1½	1	1	1	2	1	1½	2	½	1	1½	2	2½	2	3	1½	2½	3½	–	31	62

Source: K. Hughes, *Ibid.*

Footnotes

[1] In central place theory the order of an urban centre, or central place, is determined by the number of functions it performs for its surrounding hinterland or field. The range of functions a central place performs reflects the areal extent of the hinterland and the number of the populations served. These observations bear out the contention that mass, as measured by population size, is a most suitable measure of attraction in potential models.

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Received June, 1974; Revised December, 1974.