Policy-Oriented Urban-Systems Model: Structure and Application

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An urban-systems model developed for the Toronto region of Canada is described. The model operates in five-year time increments that allocate exogenously estimated regional employment and dwelling-unit totals to zones in terms of the conditions that existed at the beginning of the time period and the major public-policy decisions taken during the time period. The state of the urban system at any point in time is described by (a) the spatial distributions of households stratified by household type; (b) the spatial distributions of basic, semibasic, and population serving employment, stratified by income group; (c) the spatial distributions of land use by five types; and (d) the transportation flows and generalized travel costs on each transportation link. Ten basic submodels are imbedded in the model and the structure of each of these submodels is discussed. The calibration of the model to a 1966-1971 data base is described along with some sensitivity tests on the model. Although the model captured the principal regional development patterns, significant deviations existed for some zones, which indicated inadequacies in particular submodels, and these deficiencies are discussed.

Several activity-systems models with dynamic or longitudinal frameworks were reviewed, including those by Batty (1,2), Putman (3,4), Ayeni (5,6), and Mackett (7,8). The capabilities of each of these modeling approaches were reviewed against the modeling requirements established for the Toronto region, and it was concluded that none of the models fully satisfied these requirements. The principal deficiency of the models proposed by Batty and Ayeni is their inadequate treatment of the transportation sector. The Mackett model provides good representation of the transportation sector but it has little chance of being made operational with its current degree of disaggregation. Estimates of transportation corridor flows were required along with the impacts that differential levels of transportation service in different corridors might have on the spatial distributions of activities. Although the PLUM and IPLUM derivatives developed by Putman treat the transportation sector more fully, they operate with rather aggregate activity information and their dynamic specifications are inadequate. Although existing model frameworks were rejected, there were a number of characteristics of existing models that have been incorporated into the model framework described in this paper.

MODEL FRAMEWORK

Figure 1 provides a more detailed illustration of the sequence of operations within the model, which is structured into 10 submodels. These models vary widely in their complexities and consist of the following:

1. Basic employment,
2. Semibasic employment,
3. Residential location,
4. Housing stock,
5. Housing-stock use,
6. Labor force,
7. Service employment,
8. Job supply,
9. Transportation, and
10. Land accounting.

Each of these submodels is described in detail later in this paper.

The state of the urban system at any particular time is defined in terms of the variables listed in the table below, along with the volumes and generalized travel costs on each transportation link:

Variable	Class
Housing	
Households	ℓ = 1 one person
	2 two or three persons
	3 four or five persons
	4 six or more persons
Housing stock	k = 1 single, semidetached
	2 town houses, semiattached
	3 apartment
Employment	
Basic	One class
Semibasic	g = 1 manufacturing
	2 construction
	3 transportation
	4 wholesale
Service	s = 1 retail
	2 small businesses, banks, medical services
Jobs/labor force	w = 1 low income
	2 medium income
	3 high income
Land use	m = 1 industrial
	2 residential
	3 commercial
	4 utilities, transportation
	5 institutional
	6 unusable, open land
	7 vacant, agricultural
	8 total

The model first calculates the spatial distribution of the expected growth in semibasic employment for each sector. The inputs to this submodel are designated vacant industrial land, the level of employment in each semibasic-employment sector at time t, and the regional total growth in Δt in each semibasic sector.

The spatial allocation of households by household type is then calculated by using as inputs the total employment in time t, the overseas migration rate, and the housing supply at time t and in time period Δt. In the first iteration of the residential-location submodel, a preliminary estimate of housing-stock supply is used that is estimated from the land available for each housing type during Δt and the relative accessibility of each land parcel to employment in time t.

The spatial allocation of housing stock is calculated by using as input the designated residential land, the supply of any public housing, and the output of the residential-location submodel. In general, there may be a spatial mismatch between the outputs of the residential-location and housing-stock submodels. In those zones with unacceptable differences between housing demand and supply in time period Δt, excess demand is reallocated to zones and available opportunities. This reallocation process is continued until a prespecified difference is no longer exceeded.

The output of the residential-location submodel that is obtained after the matching of demand and

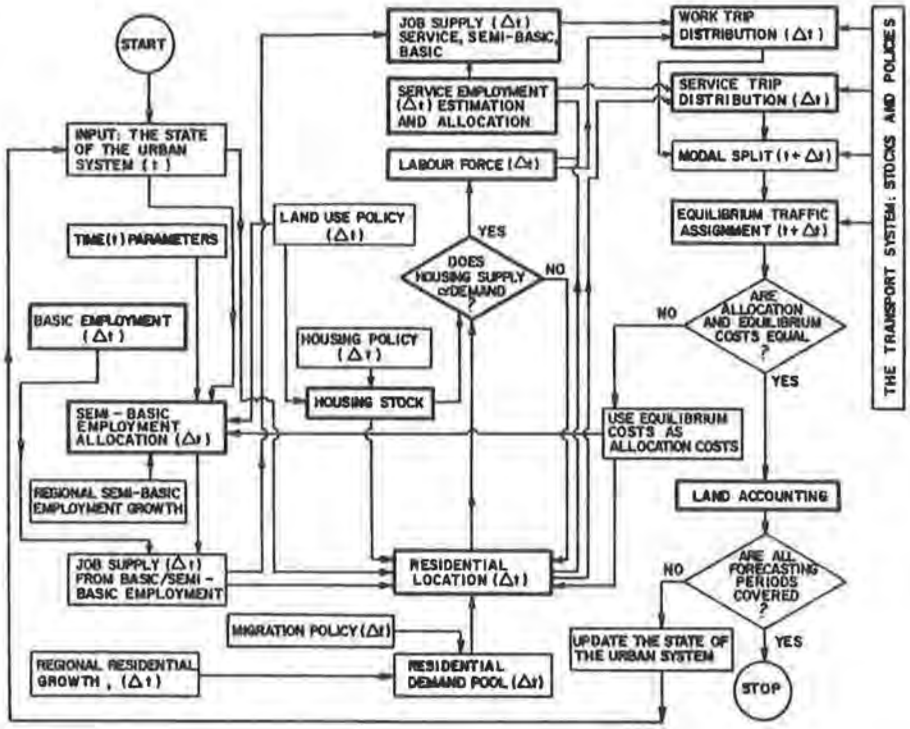

Figure 1. Structure of urban-systems model.

supply is used to estimate the labor force resident in each zone stratified by income group. This is achieved simply by multiplying the number of households in each household type by the average number of workers in each income group in each household structure.

The output of the residential-location submodel is used to estimate the new demand for service employment in time period Δt, and this demand is then allocated to service centers in the service-employment submodel. This allocation is a function of the attractiveness of the different zones to service trips and the travel times between residential zones and the service-employment zones.

The total supply of jobs in each zone in Δt is estimated from the sum of the exogenously specified basic employment, the semibasic-employment allocations, and the service-employment allocations calculated in the previous step. The distributions of jobs by income group are calculated from the employment composition in each zone.

A trip-distribution model is used to estimate the new pattern of work trips in Δt stratified by income group and uses as input the spatial distributions of jobs and labor force and the travel-time matrix. Trips to services are estimated in the service-employment submodel and the proportions of these two trip types that occur in the peak period are used to estimate peak vehicle trips.

An equilibrium traffic-assignment model due to Florian and Nguyen (9) is used to estimate link volumes and travel times on the coded network. Link travel times produced in the traffic-assignment model are then used in a minimum path program to produce a new estimate of travel times. The new and old travel-time matrices are compared and the model is rerun until the differences between the two matrices are acceptable.

Once convergence is achieved between the two travel-time sets, a land-accounting procedure is performed. The inputs to the land use accounting submodel include the land uses in time t, the changes in all activities in time period Δt, and a specification of the activities that consume each land use type. The outputs of the land use accounting submodel are the increments in land use consumption of the different types and total land use consumptions at time $t + \Delta t$. The consumption of land use in each zone is subject to capacity constraints on each land use type.

There are two levels of iteration in the model. The first level of iteration is carried out within several of the submodels, and these are the housing-use, traffic-assignment, and land-accounting submodels. The second level of iteration involves the entire model, where the purpose is to ensure consistency between the travel-time matrix estimated from the equilibrium link traffic flows and the ones used to allocate the different activities whose interactions yield the link flows.

At the end of each time period a check is made to see if all forecasting periods are covered. If all forecasting periods are not covered, the results for the end of the current time period are used as input for the next period and the allocation process begins again.

DATA BASE

The urban-systems model has been calibrated for the 1966-1971 period. The 1966 household information was obtained from the 1966 Census of Canada and aggregated to the zone system used in this study. Employment data were not available for 1966 but only for the years 1964 and 1971, so the employment by sector in each zone was interpolated. Land use data were assembled from various planning department sources, and both the land use and employment vectors assembled for 1966 required some significant assumptions that are described by Said (10). The 1971 data base was a little easier to assemble since the 1971 Census of Canada included place-of-work questions. Transportation data were assembled from the 1964 Metropolitan Toronto and Region Transportation Study, the 1971 Census, and the data files of the various municipal transportation planning departments in the region.

Table 1. Summary of semibasic-employment calibration.

Semibasic-Employment Type	Equation Form	R^2
Manufacturing	$E_i^3(1966\text{-}1971) = 147.3 + 0.6122 \cdot DIL_i(1966) + 0.058 \cdot E_i^3(1966)$ (12.2) (3.4)	0.87
Construction	$E_i^4(1966\text{-}1971) = 35.4 + 0.6097 \cdot DIL_i(1966) + 0.105 \cdot E_i^T(1966)$ (23.6) (7.6)	0.96
Transportation	$E_i^5(1966\text{-}1971) = 139.4 + 0.1100 \cdot DIL_i(1966) + 0.006 \cdot E_i^T(1966)$ (4.6) (9.1)	0.75
Wholesale	$E_i^6(1966\text{-}1971) = 38.3 + 0.2367 \cdot DIL_i(1966) + 0.251 \cdot E_i^6(1966)$ (13.3) (8.0)	0.93

URBAN-SYSTEMS MODEL

Semibasic-Employment Submodel

Table 1 summarizes the allocation equations developed for the four semibasic-employment zones. These equations have been developed only for those zones that exhibited growth in employment during the 1966-1971 period and the designated industrial land measure includes only that land area that was serviced during the period. It should be noted from Table 1 that all equations incorporate the amount of designated industrial land in a zone and the level of employment in the same sector, or total employment. The coefficients of determination are quite good for all of the equations except for the transportation sector. The Student's t-magnitudes for each partial regression coefficient are shown in parentheses in Table 1 and are all significant at the 1 percent level. The largest deviations for the allocation equations were for the manufacturing-employment sector where the very large areas of designated industrial land in some of the fringe area municipalities created overestimation in about six zones. These large tracts of designated residential land also created overestimations in the transportation employment allocated to a number of the peripheral zones.

Inspection of the allocation equations in Table 1 shows that the designated industrial land had the largest impacts on the growth in manufacturing and construction employment while the existence of employment in the same sector in the base year was an important factor in the growth of wholesale employment. A number of independent variables were explored in the development of these allocation equations, including accessibility to households, distance to nearest major highway, accessibility to the same type of employment, and accessibility to total employment.

Residential Submodel

In the residential-location submodel, four types of residential growth and change are possible. These are as follows:

1. Transitions in household structure $[HS_*^\ell(\Delta t)]$,
2. Households that are newly formed from the population already resident in the area $[HN_*^\ell(\Delta t)]$,
3. Households due to migration from overseas $[HO_*^\ell(\Delta t)]$, and
4. Households due to migration from within Canada $[HC_*^\ell(\Delta t)]$.

The transitions in household structure and the newly formed households are calculated in the following way:

$$HS_*^\ell(\Delta t) = H_*^\ell(t)\,[SHF^{\ell'|\ell} - I] \quad (1)$$

and

$$HN_*^\ell(\Delta t) = \sum_\ell a^{\ell'|\ell} \times HS_i^\ell(t + \Delta t) \quad (2)$$

where

$H_*^\ell(t)$ = total number of households of type ℓ in the region at time t,
$SHF^{\ell'|\ell}$ = transition matrix that shows the probability that households of type ℓ will shift to households of type ℓ' during time period Δt,
$HS_*^\ell(\Delta t)$ = total number of shifted households of type ℓ in the region in time period Δt, and,
$a^{\ell'|\ell}$ = rate of household formation of type ℓ' households out of type ℓ households.

The regional total number of households of each type due to overseas migration is specified exogenously to the model, and the total number of households due to migration from within Canada is calculated from the following:

$$H_*^\ell(\Delta t) = HO_*^\ell(\Delta t) + HN_*^\ell(\Delta t) + HS_*^\ell(\Delta t) + HC_*^\ell(\Delta t) \quad (3)$$

The spatial allocation of households that migrate from overseas is calculated by using the following gravity-type allocation function:

$$HO_i^\ell(\Delta t) = HO_*(\Delta t) \cdot \left(\left\{ H_i^*(t) \cdot [F_i^\ell(t)]^{\gamma^\ell} \cdot f(c_{ic}) \right\} \div \left\{ \sum_i H_i^*(t) \cdot [F_i^\ell(t)]^{\gamma^\ell} \cdot f(c_{ic}) \right\} \right) \quad (4)$$

where

F_i^ℓ = proportion of households of structure ℓ in zone i at time t,
$H_i^*(t)$ = total number of households in zone i at time t, and
$f(c_{ic})$ = some function of the travel time between residential zone i and the center of the region.

The calibration approach matched the observed and estimated mean travel times between all zones and the center of the region. Because of the small numbers of overseas households of structure $\ell = 1$ and $\ell = 4$, the four household groups were grouped together with group 1 consisting of $\ell = 1$ and $\ell = 2$ and group 2 consisting of $\ell = 3$ and $\ell = 4$.

The table below summarizes the calibration results obtained for the two groups:

Household Group	α	γ	Mean Travel Time (min) $\bar{c}$	$\hat{\bar{c}}$	R^2
1	0.0192	0.2	27.15	27.25	0.80
2	0.0164	1.0	28.32	28.45	0.83

The travel time to the center of the region has a relatively small influence on the location of households of overseas migrants. The proportions of households of a similar type have the most important influence, particularly for the larger-sized households.

Net migration from within Canada is also allocated by using a gravity-type allocation function of the following form:

$$HC_i^{\ell}(\Delta t) = HC_*^{\ell}(\Delta t) \cdot \left(\left\{ \left[\sum_k a^{\ell|k} \cdot DUO_i^k(\Delta t) \right]^{\gamma^{\ell}} \cdot ACCE_i(t) \right\} \div \left\{ \sum_i \left[\sum_k a^{\ell|k} \cdot DUO_i(\Delta t) \right]^{\gamma^{\ell}} \cdot ACCE_i(t) \right\} \right) \quad (5)$$

where

$a^{\ell|k}$ = probability that a dwelling unit of type k will be occupied by a household of structure ℓ,

$DUO_i^k(\Delta t)$ = number of dwelling-unit opportunities of type k in zone i in time period Δt, and

$ACCE_i(t)$ = accessibility of the households in zone i to the surrounding employment.

The accessibility of households is defined as follows:

$$ACCE_i(t) = \sum_j E_j(t) \exp(-\alpha^{\ell} c_{ij}) \quad (6)$$

where c_{ij} is the travel time between zones i and j, and α^{ℓ} is the parameter that reflects the sensitivity of travel time of type ℓ households in selecting residential locations. The calibration proceeded by identifying the set of parameters that maximized the magnitude of the simple correlation coefficient between the observed and estimated household vectors. The four household groups were aggregated into two groups for calibration purposes in the same way as the overseas migrant households.

The table below summarizes the results of the calibration process:

Household Group	α	γ	λ	R^2
1	0	0.8	1.6	0.81
2	0	1.2	1.0	0.83

It shows that the estimated α magnitude is 0 for both household groups, which indicates that accessibility to jobs as defined in Equation 6 had no influence on the locations of households migrating from within Canada. This is probably because the dwelling-unit opportunities term already reflects the accessibility of zones to jobs. The magnitude of γ for the two groups indicates that the availability of opportunities is of much greater importance to the larger household sizes, which indicates that larger household groups tend to locate in the newly developing areas. The λ-magnitudes illustrate that the existence of households of a similar structure in the base year have a much greater influence on the location decisions of the smaller-sized households.

The following regression equation has been developed for estimating potential nonmovers:

$$HNM_i^* = -32.1 + \underset{(23.4)}{0.604 X_1^*(1966)} + \underset{(14.9)}{0.437 X_2^*(1966)} \quad (7)$$

where $R^2 = 0.93$. The allocation function used for movers is as follows:

$$M_{ij}^*(1966\text{-}1971) = HMG_j^*(1966\text{-}1971) \cdot \left\{ [DUO_i^*(1966\text{-}1971) \cdot \exp(-\alpha^m c_{ij})] \div \left[\sum_i DUO_i^*(1966\text{-}1971) \cdot \exp(-\alpha^m c_{ij}) \right] \right\} \quad (8)$$

$$HMA_i^{\ell}(\Delta t) = \sum_j M_{ij}^* \quad (9)$$

where $DUO_i^*(1966\text{-}1971)$ includes the new dwelling units constructed during the period and the dwelling units vacated by movers. The term $HMG_i^*(1966\text{-}1971)$ represents the number of movers generated by zone j who are going to locate in the same region, and analyses of the 1971 census data showed that 85 percent of the movers in the Toronto region located within the region and 15 percent moved outside of the region. Calibration of α^m proceeded by matching the observed and estimated trip length frequency distributions of movers, where the observed distribution had been developed by Simmons (11).

The total change in residential growth in each zone may be estimated from the sum of the four growth components and the relocating households:

$$H_i^{\ell}(\Delta t) = HS_i^{\ell}(\Delta t) + HO_i^{\ell}(\Delta t) + HN_i^{\ell}(\Delta t) + HC_i^{\ell}(\Delta t) + HMA_i^{\ell}(\Delta t) - HMG_i^{\ell}(\Delta t) \quad (10)$$

Housing-Stock Submodel

The housing-stock submodel is calibrated as follows:

$$DUO_i^k(\Delta t) = DUO_*^k(\Delta t) \cdot \left(\left\{ ACCE_i^k(t) \cdot [DRL_i(t) \cdot DUO_i^k(t) \div L_i^{rk}(t)]^{\gamma^k} \right\} \div \left\{ \sum_i ACCE_i^k(t) \cdot [DRL_i(t) \cdot DUO_i^k(t) \div L_i^{rk}(t)]^{\gamma^k} \right\} \right) \quad (11)$$

where

$DUO_i^k(\Delta t)$ = number of dwelling units of type k allocated to zone i in time Δt,

$DUO_*^k(\Delta t)$ = regional total number of dwelling units of type k available in Δt,

$DRL_i(t)$ = amount of designated serviced residential land in zone i at the beginning of the time period, and

L_i^{rk} = amount of land available for type k dwelling units.

In the calibration, single detached units have been treated separately while attached units and apartments have been grouped together. The accessibility term is defined by the following:

$$ACCE_i^k = \sum_j E_j(t) \cdot \exp(-\alpha^k c_{ij}) \quad (12)$$

The table below summarizes the calibration results for that calibration run that maximized the correlation coefficient between the observed and estimated dwelling-unit vectors:

Dwelling-Unit Type	αk	γ	R^2
Single unit, k = 1	0.06	1.0	0.79
Attached units plus apartments, k = 2 + 3	0.09	1.0	0.81

The greater sensitivity of apartments and attached units to employment accessibility is illustrated.

Housing-Use Submodel

In the housing-use submodel, $H_i^{\ell}(\Delta t)$ is altered (if necessary) to achieve acceptable agreement between the spatial distributions of both the demand and supply for housing. Excess demand for houses is reallocated to zones with excess housing supply. This process is conducted iteratively and terminates when either a satisfactory matching has been achieved between demand and supply or the maximum number of iterations has been reached.

This iterative process begins by estimating the difference between supply and demand in Δt and $ERR_i^k(\Delta t)$. Zones are classified into three sets, where Z_1 contains zones with differences within the acceptable limit, Z_2 contains zones with excess demand, and Z_3 contains zones with excess housing supply. Excess demand in zones $j \epsilon Z_2$ is allocated to excess supply in zones $i \epsilon Z_3$ by using the following:

$$H_i^{\ell,m}(\Delta t) = \Sigma\, a^{\ell|k} \left[\sum_{j \epsilon Z_2^k} ERR_j(\Delta t)\right] \cdot \left\{[ERR_i^k(\Delta t) \cdot f(c_{ij})] \div \left[\sum_i ERR_i^k(\Delta t) \cdot f(c_{ij})\right]\right\} \quad \text{all } i \epsilon Z_3^k \tag{13}$$

where $H_i^{\ell,m}(\Delta t)$ is the number of type ℓ households that are relocated to zone i in time period Δt in the mth iteration of the housing-use submodel, and Z_2^k and Z_3^k are, respectively, the sets of zones with excess demand and with excess supply partitioned into k housing types. Equation 12 allocates the excess demand to zones as a function of their excess supply and their spatial separations from the zone of excess demand.

Service-Employment Submodel

The service-employment-allocation submodel has the following form:

$$T_{ij}^{Ss}(\Delta t) = \left[\sum_{\ell} H_i^{\ell}(\Delta t) \cdot r^{Ss|\ell}\right] \cdot \left(\left\{[(FL_j^*/FL_*^s) + (E_j^*/E_*^*)]\gamma^s \cdot \exp(-\alpha^s c_{ij})\right\} \div \left\{\sum_j [(FL_j^s/FL_*^s) + (E_j^*/E_*^*)]\gamma^s \cdot \exp(-\alpha^s c_{ij})\right\}\right) \tag{14}$$

Three calibration subregions have been isolated, and these consist of the three census areas within the region. The parameters of Equation 13 have been estimated by matching the observed and estimated trip length frequency distributions. The calibration could only be undertaken for type 1 service employment, since appropriate trip length frequency information was not available for type 2 employment (banks, small businesses, etc.). The results of the calibration process are summarized in the table below for subregions 1 and 2. The parameters for subregion 3 are estimated subjectively, since this subregion consists of only three zones:

Calibration Subregion	α	γ	Mean Trip Length Observed	Mean Trip Length Estimated	Sum of Absolute Errors (%)
Toronto	0.20	0.52	11.38	11.13	18.6
Hamilton	0.23	0.39	9.37	9.12	16.2

There is only a marginal difference in the deterrence parameter magnitudes between the two subregions while γ decreased significantly for the Hamilton subregion. This is due to the use of only 9 zones in the Hamilton subregion, which resulted in almost 70 percent of the area retail activities being concentrated in two zones, and the lower γ magnitude decreases the influence of these zones. A similar effect may be noted for the Toronto calibration subregion since $\gamma \ll 1$, but the retail activities are more widely distributed.

Labor-Force and Jobs Submodels

The labor-force submodel calculates the growth in the spatial distribution of the labor force from the estimated growth in households $[H_i^{\ell}(\Delta t)]$ in the following way:

$$LF_i^w(\Delta t) = \Sigma\, a^{w|\ell} \cdot H^{\ell}(\Delta t) \tag{15}$$

where $LF_i^w(\Delta t)$ is the growth in the labor force in income group w in zone i in time period Δt, and $a^{w|\ell}$ is the probability of having a worker of income group w in household type ℓ.

The jobs submodel simply sums the employment growth estimated by each of the submodels and the exogenously specified basic employment:

$$J_i^w(\Delta t) = e^{w|b} \cdot E_i^b(\Delta t) + e^{w|sb} \cdot E_i^{sb}(\Delta t) + e^{w|s} \cdot E_i^s(\Delta t) \tag{16}$$

where E_i^b, E_i^{sb}, and E_i^s are basic, semibasic, and service employment, respectively, and $e^{w|b}$, $e^{w|sb}$, and $e^{w|s}$ are the probabilities of having workers in income group w who are employed in basic, semibasic, or service employment, respectively.

Transportation Submodel

Service trips are calculated in the service submodel and work trips are estimated by using the following doubly constrained model, which is calculated on the basis of location behavior within the incremental development period:

$$T_{ij}^w(\Delta t) = LF_i^w(\Delta t) \cdot \left\{[J_j^w(\Delta t) \cdot \exp(-\alpha^w c_{ij})] \div \left[\sum_j J_j^w(\Delta t) \cdot \exp(-\alpha^w c_{ij})\right]\right\} \tag{17}$$

where c_{ij} is the travel times between zones, and a^W is the sensitivity of workers in income group w to travel time in their joint selection of residential and work place locations. Because Equation 16 is a production-constrained form of the gravity model, an attraction trip-end balancing procedure is used to ensure the following:

$$\sum_i T_{ij}^w(\Delta t) = J_j^w(\Delta t) \tag{18}$$

Trips at the end of time period $t + \Delta t$ are estimated from the following:

$$T_{ij}^w(t + \Delta t) = \hat{T}_{ij}^w(t) + T_{ij}^w(\Delta t) \tag{19}$$

where $\hat{T}_{ij}(\Delta t)$ is an adjusted work-trip matrix at time t for workers in income group w to account for workers who change their place of residence during Δt.

$$\hat{T}_{ij}(t) = T_{ij}^w(t) - \left[\sum_{\ell} HMG_i^{\ell}(\Delta t) \cdot a^{w|\ell}/H_i^{\ell}(t)\right] T_{ij}^w(t) \tag{20}$$

Equation 19 adjusts the time t trip matrix by removing trips from the rows in proportion to the number of household movers from the residential zone represented by the row. Employment turnover is assumed not to influence the trip matrix.

The peak-hour car-trip matrix at $t + \Delta t$ is estimated by the following equation:

$$T_{ij}(t + \Delta t) = \sum_w T_{ij}^w(t + \Delta t) \cdot SP^w/OC^w + \sum_i T_{ij}^{Ss}(t + \Delta t) \cdot SP^s \cdot PK^s/OC^s \tag{21}$$

where

- SP^W, SP^S = proportion of trip makers who use private automobiles for work and service trips, respectively;
- OC^W, OC^S = average number of persons per car for

Table 2. Calibration results for work-trip transportation submodel.

Calibration Subregion	Deterrence Function Parameter α^w					
	Low, w = 1		Medium, w = 2		High, w = 3	
	Result	Percent[a]	Result	Percent[a]	Result	Percent[a]
Toronto	0.122	30.2	0.115	30.0	0.111	30.0
Hamilton	0.125	21.3	0.114	18.1	0.195	18.3

[a]Absolute percentage error of differences between the observed and estimated trip length frequency distributions.

work and service trips, respectively; and

PK^s = proportion of service trips that occur in the peak hour.

The calibration criterion used was the minimization of the absolute differences between the observed and estimated work-trip-length frequency distributions for each income class. Two calibration subregions were used for the work-trip model and these are the Toronto plus Oshawa census areas and the Hamilton census area. The results of the calibration process are summarized in Table 2. Within the Toronto calibration area the sensitivity to travel time decreases with increasing income while in the Hamilton area the sensitivity of the high-income group to travel time is the largest. The reason for this higher parameter magnitude appears to be the concentration of the higher-income groups in the Hamilton area in just two zones.

The traffic-assignment part of the transportation model uses an equilibrium assignment procedure developed by Florian and Nguyen (9). Transportation flows are assigned to the alternative paths between origin and destination pairs so that the travel times are equal for all paths that are used. The supply characteristics of transportation network links are represented through their travel-time and volume-capacity functions.

Land-Accounting Submodel

The land-accounting submodel simply updates the land use data at the end of each time period. The model distinguishes between the physical land use categories and the human activities that occupy the land. Following the ideas of both Seidman (12) and Wilson (13), incremental changes in land uses are estimated from the following:

$$L_i^u(\Delta t) = \eta_i^u(\Delta t) \cdot L_i^u(t) \cdot \left\{ \left[\sum_{Q \in u} AC_i^Q(\Delta t) \right] / \left[\sum_{Q \in u} AC_i^Q(t) \right] \right\} \qquad (22)$$

where

$L_i^u(\Delta t)$ = change in land use type u in period Δt,

$AC_i^Q(\Delta t)$ = increase in activities in zone i that consume land use type u in time Δt, and

$\eta_i^u(\Delta t)$ = index between 0 and 1 that reflects the constraints on land use in zone i.

Equation 21 indicates that, when no constraints exist on land capacity and $\eta_i^u = 1$, the increase in land consumption is proportional to the ratio between land consumption and activities that existed in a zone at time t.

CAPABILITIES OF COMPLETE MODEL

Although most of the calibrations of the individual submodels have been shown to be quite reasonable, one important test of the integrity of the model is its performance when all submodels operate together. The entire model was run with the 1966 data as input and used to estimate 1971 conditions. Because all of the data required by the model were not immediately available for all parts of the regions, some assumptions had to be made and are detailed in Said (10).

A comparison of the observed and estimated semibasic-employment magnitudes for the four sectors demonstrated generally good agreement, but there were significant deviations for selected zones. Significant overestimations of manufacturing employment occurred in three very large industrial zones located on the fringe of the developing area. These zones contained very large tracts of designated industrial land but contained little employment at the beginning of the forecast period. Underestimations occurred for those zones with available industrial land that were well-established manufacturing employment zones at the beginning of the time increment. Although the manufacturing-employment allocation function captured the average effects of manufacturing-employment growth, the deviations between estimated and observed growths would suggest that a logistic-type allocation function would be more appropriate.

Similar deviations were detected for the other semibasic-employment sectors. There were some unusual deviations for the transportation sector, as several of the zones contained large concentrations of transportation employment, such as the zones containing the head offices of the Toronto Transit Commission and the railway freight yards. The other concentrations of transportation employment were largely in the peripheral zones where many trucking companies locate.

Although some of the residuals of the type highlighted in the previous paragraphs might be reduced by modifications of the allocation functions, it is clear that some of the residuals, particularly in the transportation sector, can only be removed by the exogenous allocation of employment growth. This approach is justified, since the locations of much of the transportation employment are not sensitive to changes in public policy of the type incorporated in the allocation functions.

The capabilities of the model in allocating retail employment could not be assessed properly, since reliable observations of retail-employment distributions were not available for the fringe-area municipalities adjacent to the boundaries of metropolitan Toronto. The limited evaluations of the predictive capabilities of the household and housing submodels showed that they had generally satisfactory capabilities but that some deviations could be detected that were related in part to the misallocation errors in the employment submodels.

Comparisons of the observed and model-estimated traffic volumes showed excellent agreement. This is not surprising, however, given that an equilibrium traffic-assignment procedure was used.

SENSITIVITY ANALYSES

Because the calibration approach that was adopted estimated the parameters of each submodel separately, the model was subjected to a sensitivity analysis to examine the extent to which relatively large changes in the parameters of particular submodels had impacts on the behavior of the other submodels. Table 3 summarizes the changes in calibration parameter magnitudes for the four model runs conducted where all of these changes are in the

Table 3. Changes in parameter magnitudes used in sensitivity analysis.

Run No.	Submodel	Parameter	Change of the Parameter Value (%)	Old Value	New Value
1	Transportation	α^w	+20	$\alpha^1 = 0.122$ $\alpha^2 = 0.115$ $\alpha^3 = 0.111$	$\alpha^1 = 0.146$ $\alpha^2 = 0.133$ $\alpha^3 = 0.133$
2	Housing stock	α^k	+20	$\alpha^1 = 0.060$ $\alpha^2 = 0.090$ $\alpha^3 = 0.090$	$\alpha^1 = 0.072$ $\alpha^2 = 0.108$ $\alpha^3 = 0.108$
3	Residential location (allocation of movers)	β^m	-20	$\beta^m = 0.245$[a]	$\beta^m = 0.195$[a]
4	Service employment	α^s γ^s	-20 +20	$\alpha^s = 0.210$ $\alpha^s = 0.490$	$\alpha^s = 0.175$ $\alpha^s = 0.590$

[a]All k.

Table 4. Effects on model performance of parameter changes.

	Parameters Changed (%)			
Submodel	α^w	α^k	β^m	α^s and γ^s
Semibasic employment	NC	NC	NC	NC
Residential location				
Overseas migration	±3	NC	NC	±2
From Canada migration	±3	±10	±1	±2
New households	±3	±5	±1	±2
Allocation of movers	±8	±5	±25	±2
Total	±5	±5	±15	±2
Housing	±10	±22	±3	±4
Service employment				
Zone attractiveness	NC	NC	NC	±50
Demand for service employment (origin)	±5	±15	±15	±4
Demand for service trips (origin)	±5	±15	±15	±4
Allocation of service employment	±15	±12	±15	±30
Service trips	±15	±15	±15	±30
Jobs	±7	±10	±5	±10
Labor force	±15	±20	±5	±5
Transportation: trip distribution				
Mean trip length				
w = 1	−15.2	−0.44	NC	+0.4
w = 2	−14.8	−0.40	NC	+0.05
w = 3	−14.2	−0.56	NC	+0.15
Traffic assignment objective function[a]	−31	−4.7	−7	NC
Objective function[b]	−35	−6.5	−4	−4.2
Vehicle hours	−27	−4.5	−1.9	−2.7
Vehicle kilometers	−18	−0.2	−1.3	+1.05
Avg speed	+12	+4.5	+0.6	+3.9
Overall convergence[c]				
Percentage of travel time difference[d]				
1 iteration				
Base run	38	38	38	38
New run	25.4	39.6	39.8	41.7
2 iterations				
Base run	12.6	12.6	12.6	12.6
New run	7.4	12.9	11.3	11.1

Note: NC = no change.

[a]All or nothing assignment.
[b]After 5 iterations.
[c]Number of iterations for both the base and new runs was 2.
[d]Percentage travel time difference is the aggregate absolute difference between allocation travel time matrix and equilibrium travel time matrix.

parameters of the deterrence functions imbedded in various allocation functions. These parameters were selected because of their impacts on the spatial allocations calculated by the model.

Table 4 summarizes the impacts of these parameter changes on the outputs of various submodels compared with the basic run. Inspection of Table 4 illustrates that most of the significant changes in submodel output are confined to the submodel in which the parameter change occurred. For example, the increases in the α^w parameters of the transportation submodel reduced the mean trip lengths by some 15 percent and through this increased the average speed of travel on the network. However, the impacts of these changes outside of the transportation model were quite small. A 20 percent increase in α^k of the housing-stock submodel had significant impacts on the allocation of housing stock and, because of this, had impacts on the distribution of households and service employment. It should be recalled that α^k is the deterrence function parameter of the accessibility to employment term of the housing-stock submodel.

The decrease in the mover-allocation parameter β^w had a strong impact on the spatial distribution of movers, as indicated in Table 4, which in turn had an impact on the spatial distribution of total households. These changes had impacts on the service-employment submodel as indicated in the table. The changes in the parameters of the service-employment submodel had very significant impacts on the output of the submodel, but the impacts on the other submodels were small, except of course for the jobs submodel.

These sensitivity tests illustrate that the calibration strategy adopted of independent calibration of each submodel is acceptable. These tests also suggested that the goodness of fit of the model might be improved by some additional adjustment to the parameter magnitudes. The parameters of the trip-distribution part of the transportation submodel are the most sensitive parameters, since they have important influences within the transportation submodel itself and, when the changes are large, on the results of the housing, service-employment, and labor-force submodels as well.

CONCLUSIONS

The allocation functions calibrated for the four semibasic-employment sectors showed that the spatial distribution of growth in semibasic employment was influenced mainly by the availability of serviced industrial land and the existence of employment in the district at the beginning of the period. Although the calibrated allocation functions have been shown to explain observed growth quite well, they had a tendency to overallocate growth to the large peripheral zones. This tendency might be corrected by using a logistic function for the allocation procedure.

The spatial distributions of the various components of household growth were influenced primarily by the availability of new dwelling-unit opportunities and the existence at the beginning of the period of housing stock with similar household characteristics. The spatial distributions of the growth in households of overseas origin were influenced primarily by the existence of households with a similar structure at the beginning of the period while households moving from within Canada tended to locate in newly developing residential areas. Accessibility to employment was not isolated as a significant factor in the household-allocation functions, although this effect is reflected in the allocation of the spatial distribution of dwelling-unit opportunities input to the household-allocation model. These dwelling-unit allocation functions showed that the locations of apartments were more sensitive to employment accessibility than those of the detached dwelling units. The household-allocation submodel also has a tendency to overallocate household growth to the peripheral locations, which is also a zone size effect.

The spatial distribution of the growth in service employment is influenced by the size of the retail shopping area and travel deterrence, the factors incorporated in most allocation functions.

The model described in this paper may be used to support strategic planning studies at the regional scale. It seems to be capable of capturing the major influences on development in growing areas. The allocation functions have plausible structures, and the response of the model to changes in parameter magnitudes suggests that the initial calibration strategy and internal structure of the model were satisfactory. The major deficiency of the model, as in all models of this type, is that it relies heavily on the exogenous input of many of the supply-related variables.

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Urban Transportation in Korea: Lesson for the World or a Passing Phase?

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Research into Korean urban transportation prospects conducted in 1979 and 1980 is summarized. This paper identifies unusually low automobile ownership during a period of rapid growth as the distinctive feature of Korean cities and traces the fiscal, financial, and utilitarian reasons for this phenomenon. It is argued that the low number of automobiles has benefited both existing automobile owners and users of public transportation. The public transportation system is described and evaluated. Future plans for Korean cities are based on the assumption that rapid motorization will occur. It is argued that the plans contain contradictory policies about decentralization and fail to consider viable alternatives. These consist of increasing the efficiency of the existing transportation system while retaining the full set of policies for constraining the growth of automobile ownership and use. It is suggested that this strategy would maintain the efficiency and equitability of the existing city while minimizing investment. If this alternative strategy is adopted, then Korean cities will become the scene for important experiments in urban transportation, comparable to the Singapore area licensing scheme. In this case, Korea might become a lesson to the world. However, if existing constraints on automobile ownership are relaxed, then the present system will prove only a passing phase and Korea will experience the problems of adjustment to the motorcar faced by European and Japanese cities in the past. Irrespective of which strategy is adopted, the achievements in holding down the growth of private cars is a lesson that might be considered in other developing countries.

Automobile ownership in South Korea has remained at an unusually low level during a period of rapid economic growth that spans more than 20 years. This paper presents a summary of research conducted in 1979 and 1980 into the results of restricting such an important variable in the urban transportation system and the prospects for the future (1-4). It is argued that the effect has been beneficial to the majority of urban Koreans, but that a combination of forces is now working to reverse past policies and accelerate the growth of automobile ownership. The short- and medium-term consequences of this growth will be to destroy the existing system. Alternatives exist that would allow sufficient time to experiment to preserve many of the beneficial fea-