extent by employment category (i.e., the primary and service employment sector breakdown). The issue is the familiar one of the trade-off between the increased accuracy and the value of disaggregated forecasts and the extra information, technical development, and financial cost that would be necessary for their derivation. The results of modeling exercises that have adopted a disaggregated approach to policy testing do not seem to justify the additional effort and investment required.

FURTHER RESEARCH

Several areas of research continue in regard to the UGSM and its application to the comprehensive regional planning process:

1. Policy design and evaluation;
2. Forecasting techniques for the development of regional control totals (i.e., population and employment) and the allocation of the primary employment activities are exogenous to the UGSM structure;
3. Sensitivity testing; and
4. Policy monitoring.

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Applications of Land Use Models to Strategic Transport Planning

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The nature of strategic land use and transportation planning in Ontario is discussed and the major phases of the typical study are outlined. The structure of a land use and transportation model that may be used in these strategic studies is described as well as two applications of the model. The first set of applications are described for a variety of regional planning problems in the Toronto-centered region of Ontario. These applications include the analysis of the probable impacts of various public sector investments on activity distributions and the analysis of the role of a new town. The second application is described for the Delhi region of India. A version of the model that is disaggregated by socioeconomic group is also outlined.

The metropolitan transportation planning process that emerged during the 1950s and early 1960s was directed primarily toward the formation of long-range capital investment programs for regional transportation facilities. Many cities throughout the world have abandoned transportation plans or critical elements of plans developed by this process. During the past decade two types of new transportation policy responses have been undertaken. Much of the recent effort in the United States has concentrated on programs for improving the efficiency of existing transportation facilities. The transportation system management program is geared to improving traffic flow, encouraging the use of high occupancy vehicles, and maintaining road and public transportation capacity.

In Canada, urban transportation policy responses also embraced the shorter run, but while also focusing on the longer run strategic planning of land use and transportation facilities. This longer run policy emphasis reflects the view that realistic and effective solutions to urban transportation problems may be achieved only through the formulation and implementation of good development plans. These development plans must embrace many of the public infrastructure sectors, including transportation.

PLANNING STUDIES IN ONTARIO

The emergence of strategic planning in Ontario may be traced to the creation of regional governments that have the power and finances to implement regional development plans. Strategic transportation planning studies have been performed in the major urban centers of the province. These studies vary in detail, but the typical study consists of five major steps:

1. To identify the major travel corridors that exist or are likely to develop during the time period for which the study is forecasting,
2. To establish the transportation capacities that are feasible in each of the corridors for selected screen lines,
3. To estimate the travel demands that are likely to occur by the end of the forecast period in each of these corridors as a result of trends in land development,
4. To compare travel demands to corridor capacities at critical screen lines and to isolate potentially congested corridors, and
5. To identify potential land use and transportation responses that are likely to lead to a balance between demand and supply in the congested corridors.

Most of these studies identified the land use responses subjectively and calculated the transportation demands by using simplified generation-distribution-assignment modeling procedures. This approach is generally unsatisfactory because it fails to identify the public policies necessary to yield the assumed land use configurations. Soberman described the nature of the strategic transportation planning process followed in the metropolitan Toronto studies (1). The required modeling capability allows the testing of the land use and transportation implications of a variety of public development policies.

AVAILABLE LAND USE AND TRANSPORTATION MODELS

A recent U.S. Department of Transportation report identified nine separate models that have been used for planning purposes in the United States (2). These models range from simple techniques designed to improve the reliability of the land use inputs to transportation models to optimization models designed to generate optimal development plans. Several of the models described are derivatives of the Lowry model. A great deal of work has also been conducted outside of the United States in the past decade, but most of the operational models are also derivatives of the Lowry model. Wilson (3), Hutchinson (4), and Batty (5) described many of these models.

The land use and transportation model work described in this paper is also a derivative of the Lowry model. A modeling capability has been developed that allows the household and employment sectors to be disaggregated by socioeconomic group and the population-serving employment to be stratified by employment sector.

The basis of this land use and transportation model is a gravity allocation function of the following form:

$$\ell_{ij} = e_i \left[h_j \exp(-\alpha c_{ij}) \Big/ \sum_j h_j \exp(-\alpha c_{ij}) \right] \quad (1)$$

where

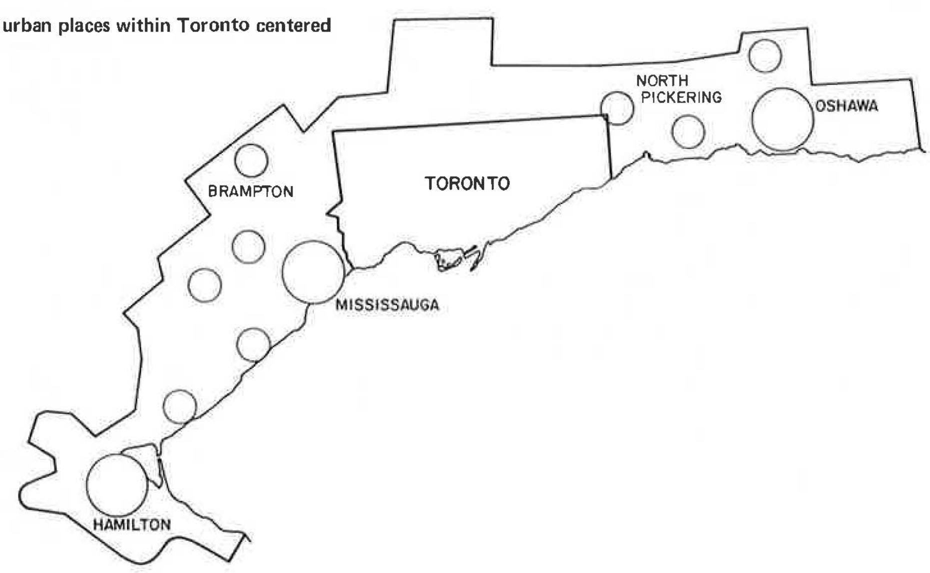
ℓ_{ij} = the amount of interaction between activities of type e in zone i and activities of type h in zone j,
e_i = the total amount of activity of type e in zone i,
h_j = the total amount of activity of type h in zone j,
c_{ij} = the generalized travel cost between zones i and j, and
α = a parameter that reflects the influence that travel costs have on destination decisions for the particular interactivity interaction being considered.

Gravity allocation functions of this type form the basis of the set of allocation models. Hutchinson (6) has described the detailed model structure elsewhere.

Use of Model in Regional Development Planning

In 1970 the government of Ontario adopted as general policy a plan for a large region centered around metropolitan Toronto. The urban part of this structure plan is illustrated in Figure 1. In 1973 the government of Ontario established a task force to refine the structure plan for the subregion illustrated in Figure 1, which was referred to as the Central Ontario Lakeshore Urban Complex (COLUC). The COLUC task force was an interministerial group composed of representatives from the Ontario government ministries of agriculture and food; natural resources; transportation and communications; environment; housing; and treasury, economics,

Figure 1. Distribution of urban places within Toronto centered regional concept.



and intergovernmental affairs. The primary responsibility of the COLUC task force was to refine the Toronto-centered regional concept so that it could be used as a common guideline by regional municipalities and various provincial government agencies in formulating development policies and programs (7).

A second initiative of the government of Ontario in implementing the Toronto-centered regional plan is the North Pickering Project, which is an undertaking of the Ontario Ministry of Housing. The aim of this project is to create a new community on a 100-km^2 (25 000-acre) site located to the northeast of metropolitan Toronto. This new community and the new Toronto International Airport were to represent the first major steps of the structure plan.

COLUC Regional Analyses

The COLUC task force identified a system of 23 urban places within the region. These urban places are grouped into four subregions, which center around Hamilton, Mississauga, Toronto, and Oshawa. Each subregion is intended to be diversified and self-sufficient for service employment, but dependent on Toronto for very specialized services. Each subregion will contain several functionally interdependent urban places of different sizes. Preferred population and employment targets were established for each of the urban places illustrated in Figure 1.

Alternative programs were converted to input variables acceptable to the model. These inputs were used along with the appropriate model parameters to calculate population and employment allocations to each of the urban places and the associated travel demands assigned to a coarsely coded regional transportation network that reflects the principal transportation corridors. This analysis process will be helpful in understanding the probable impacts of the following policy elements on the preferred regional structure plan:

1. The distribution of basic (exogenously established) employment, particularly the location of airport employment;
2. Residential trunk servicing (population serving) policies and the residential densities of the urban places;
3. Urban population sizes and their influence on population-serving employment distributions (endogenously calculated employment distributions) and interurban and service demand orientations; and
4. Regional transportation policies.

The land use and transportation model was used to analyze the potential impacts of these alternative development policies. The model was calibrated for some 1971 transportation data. The behavioral parameters of the functions that impede travel were developed separately for eight subregions within the region to reflect differences in observed behavior between these subregions. The details of the calibration procedure were described in a previous report (8). The majority of the analyses were conducted for expected conditions in 1986, although some analyses were conducted for 2001.

Below are the characteristics of the public development policies analyzed. These policies included variations in the location of the new Toronto International Airport, alternative locations for the major trunk services extensions and alternative commuter rail networks.

1. COLUC base—1968 base condition reflecting some modifications to population and employment trends,
2. No new airport—proposed new Toronto International Airport abandoned and all air traffic uses existing airport,
3. Peel utilities network—a trunk services policy that would accelerate provision of serviced residential land on the western fringe of metropolitan Toronto,
4. York utilities network—a trunk services policy that would accelerate provision of serviced residential land to the northeast of metropolitan Toronto,
5. Oshawa utilities network—a trunk services policy that would accelerate provision of serviced residential land in the eastern end of the COLUC region,
6. All utilities network—simultaneous implementation of servicing policies 3, 4, and 5, and
7. Regional transportation—a variety of changes to the regional commuter rail network.

Changes in population from the COLUC base population allocations were calculated by the model for each of the five subregions for a number of the policy elements listed and transportation flows were assigned to a corridor level network. The concentration of all airport employment at the current airport site, Malton, had little impact on population distribution in the region. Shifting 15 000 employees would influence the residential location decisions of about 32 000 people. The principal residential zones affected are located on the fringes of metropolitan Toronto and within the Oshawa and Mississauga subregions, which are adjacent to the airport sites. The residential land servicing policies had the greatest influence on the distribution of population and employment within the COLUC region. The Peel network servicing policy had the greatest impact on the distribution of population and employment within the COLUC region. This could be expected because land use model analyses of the COLUC base concept showed that residential zones in the western areas of metropolitan Toronto and in the Mississauga subregion were likely to experience continued pressures for development; the provision of serviced land simply strengthened this demand. This servicing policy made Mississauga an important service employment center, which in turn increased the demand of service employees for residential location within the Mississauga subregion. Other servicing policies produced similar effects—residential demand and a certain amount of population-serving employment were encouraged to locate in the areas affected by the particular servicing policy.

The regional transportation policy alternatives tested all represented improvements in the public transportation system, except for the completion of one freeway link within the boundaries of metropolitan Toronto. These policies influenced the populations allocated to only the urban places whose access times to the Toronto central business districts were increased dramatically by the introduction of a high-speed commuter rail service. However, these effects were insignificant when viewed on the regional scale.

An interesting comparison of models is available from this study in that the EMPIRIC land use model was also used. Earlier studies for the regional government describe the EMPIRIC studies and provide some comparison between EMPIRIC and the Lowry model described in this paper (8, 9).

North Pickering Service Employment Analysis

A second series of analyses were performed on interurban place service employment allocations within the Oshawa subregion of the COLUC area. The particular interest of these analyses was the service employment allocations to the North Pickering new town under three development scenarios for the subregion. The characteristics of these three development scenarios are shown in Table 1. Scenarios A and B have the same population targets for the Oshawa subregion but differ from each other in terms of the activity rate and the proportions of basic (i.e., employment independent of where population lives) and population-serving (i.e., employment required to meet needs of the population) employment. Scenario C has a higher subregional target population and a higher activity rate. Table 2 summarizes the service employment demand rates for each service employment sector. The rates for scenarios A and C are based on 1971 census data; those for scenario B are forecasts developed by the COLUC task force.

A number of development alternatives were postulated for the North Pickering community within each of these subregional scenarios:

1. North Pickering developed to a scale of 34 000 persons in 1986,
2. North Pickering developed to a scale of 80 000 persons in 1986,
3. New Toronto International Airport constructed and a total of 22 000 employed in 1986, and
4. New Toronto International Airport not constructed and all traffic using the existing airport.

The combination of subregional development scenarios and the North Pickering development alternatives and regional transportation policies were analyzed by the land use model using a disaggregated service employment submodel operated at the COLUC regional scale.

Figure 2 summarizes the population and service employment allocations to each of the urban places within the Oshawa subregion for four of the conditions analyzed. This diagram illustrates that under scenario A, when Oshawa provides only 180 000 residential opportunities, the population targets at North Pickering are exceeded for both scales of development of the new town. However, note that the service employment targets for North Pickering are not met. For a scale of development of 80 000 persons, 83 percent of the service employment target is met while only 59 percent of the target is achieved at the smaller scale of development. The service employment targets for Oshawa are just exceeded and Ajax, being the focus of the subregion, receives an overallocation of service employment.

Figure 2 illustrates that under scenario C, when Oshawa provides 300 000 residential opportunities, the population and service employment allocations to North Pickering are of a similar character to those just described for scenario A. Population targets are achieved, but the service employment targets are not achieved and the lakeshore communities of Ajax and Oshawa have been allocated too many service employees. These analyses provide a quantitative confirmation of the difficulties that might be experienced by the North Pickering development as a relatively self-contained service community.

Table 1. Oshawa subregion characteristics for three scenarios in 1986.

Variable	Scenario A	B	C
Employment			
Basic	57 660	55 300	70 900
Service	74 090	85 700	131 670
Total	131 750	141 000	202 570
Population	310 000	310 000	431 000
Service employment/population	0.239	0.276	0.305
Population/total employment	2.353	2.199	2.128

Table 2. Per capita service employment demand rates.

Service Employment Sector	Per Capita Service Employment Demand Scenario A	B	C
Retail	0.046	0.055	0.061
Finance and real estate	0.015	0.040	0.016
Education	0.028	—	0.030
Health and welfare	0.030	—	0.032
Business and personal services	0.100	0.160	0.105
Public administration	0.020	0.031	0.022
Transportation	—	0.025	—
Total	0.239	0.311	0.266

Applications to Delhi, India

Metropolitan transportation planning studies have been conducted in most of the large Indian cities. In Delhi, these studies produced recommendations for about 50

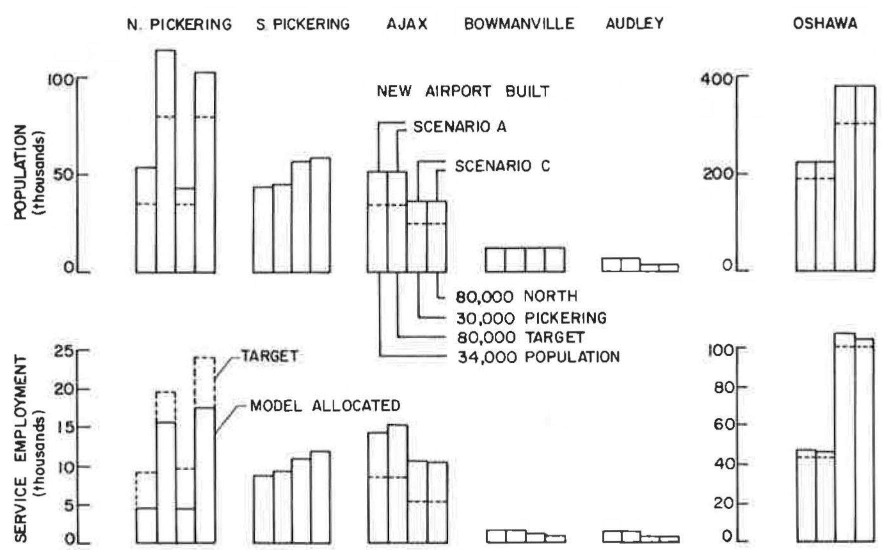


Figure 2. Population and service employment allocations to urban places within the Oshawa subregion for four strategies.

km of rapid transit facilities, which require large capital expenditures. The resources required for subway construction will probably not become available. Land use planning efforts are being directed to developing alternatives to minimize travel demand. Some of the land use development options under consideration include redistribution of the population throughout the area in order to achieve more desirable density patterns and the decentralization of employment.

There is a tremendous range in the characteristics of the socioeconomic groups who live in Indian cities. The spatial distribution of employment and housing opportunities, as well as the transportation services that are compatible with each of these socioeconomic groups, vary widely. An adequate estimate of the activity patterns and associated travel demands that might result from a particular set of public development policies must be conducted in terms of a number of separate socioeconomic groups.

Table 3 shows the distribution of household incomes observed in Delhi in 1969, average family size, motor vehicle ownership, work trip generation rates, and modal transportation choice for the journey to work. The information in Table 3 is based on data collected in 1969 by interviews conducted in homes by the Central Road Research Institute.

This table indicates that about 70 percent of the households in Delhi had monthly incomes of less than Rs (rupees) 500/month ($66.75/month). The information also indicates that motor vehicle ownership is quite low, except in households that have incomes greater than Rs 1000/month. Another feature illustrated by Table 3 is the high proportion of walking trips made by the lower income groups. The modal choice characteristics illustrate that the use of motor vehicles increases systematically with income. Mass transit usage increases with increasing household income and begins to decrease when household incomes are greater than about Rs 1000/month.

Another interesting feature was the proportions of various types of trips made by households in the various income groups. About 52 percent of all trips made were to work; educational and social or recreational trips formed the next most important type of trip. For households whose incomes were less than Rs 500/month, work trips represented more than 60 percent of the total trips made by these households; but when monthly incomes were greater than Rs 1500/month, this proportion dropped to less than 40 percent. The proportion of educational trips varied from a low of about 4 percent for households whose incomes were less than Rs 100/month to a high of about 22 percent for the upper income households.

A version of the land use and transportation model disaggregated by socioeconomic group was selected for calibration because of the need to understand the impacts of alternative development policies on the separate socioeconomic groups. The parameters of this version of the model have been estimated from the data collected in the 1969 Delhi home interview study. Because the Delhi home interview study was based on a simple random sample of households, some of the household income groups are not well represented in the sample and their behavioral characteristics had to be estimated subjectively. The criteria used for model calibration were agreement between observed and model-calculated trip length frequency distributions and observed and model-allocated activity vectors. In addition, model-calculated travel demands, which had been assigned to a system of travel corridors, were also used as a check on the validity of the model calibrations.

Table 4 summarizes the parameter magnitudes estimated from the Delhi home interview data. The table shows the behavioral parameter magnitudes of the residential and service submodels respectively, the work and service trip generation rates, and the modal split probabilities for work and service trips. Note that differences among the behavioral parameter magnitudes of the three income groups are not significant. The home interview study revealed that the trip length frequency distributions of motorists, transit riders, and bicyclists were very similar. However, the spatial distributions of activities compatible with each of the socioeconomic groups are quite different and the disaggregated model is required. Table 4 reveals large changes in the trip generation rates as incomes change. The lower income groups generate a much higher proportion of pedestrian trips, which is reflected in the lower trip rate in Table 4. The modal split probabilities also reveal interesting differences among income groups as well as differences in modal choice within an income group but between trip types. The lower income group households make few service trips, but the majority of these trips are by mass transit rather than bicycle, which is used for the majority of work trips. More detailed analyses of modal choice behavior were conducted, but the coarsely drawn regional transportation network used for the 1969 study prevented transportation system responsive modal choice models from being developed. The calibration of this model is described fully by Sarna (10).

The calibrated land use and transportation model has been used to explore the transportation implications of a number of changes to the 1981 master development plan for Delhi. These concepts varied as to the location of basic employment, housing opportunities, and transportation system properties (10).

CONCLUSIONS

This paper describes several applications of a land use

Table 3. Characteristics of households in Delhi, 1969.

Monthly Income Range		Average Size (persons)	Motor Vehicles[b]	Work Trips		Modal Transport Choice[c] (%)		
Rs[a]	%			Non-Walking	Including Walking	Motor Vehicle	Mass	Bicycle
Less than 100	3.7	2.7	—	0.14	0.49	7.5	31.4	59.6
100 to 149	8.7	4.2	—	0.28	0.71	0.3	26.3	68.4
150 to 249	25.3	4.8	—	0.47	0.98	0.6	24.0	70.7
250 to 499	30.1	5.6	0.051	0.69	1.20	4.1	36.5	53.3
500 to 749	12.1	6.1	0.189	0.99	1.41	13.7	48.4	32.3
750 to 999	4.1	6.4	0.303	1.20	1.64	18.1	51.1	24.6
1000 to 1499	4.6	6.0	0.500	1.33	1.63	33.0	47.2	11.5
1500 to 2000	2.0	6.1	0.909	1.27	1.51	50.2	31.1	4.1
2000 to 2500	1.5	6.0	0.909	1.45	1.60	53.3	28.1	3.2
More than 2500	1.3	6.3	1.429	1.65	1.75	78.9	9.1	1.2
Unknown	6.6	4.2	0.083	0.20	0.29	25.0	38.7	28.6

[a] In 1969, Rs7.49 = $1.00.
[b] Includes motorcycles, motor scooters, and automobiles.
[c] Percentages are for nonwalking trips only.

Table 4. Parameter magnitudes for socioeconomically disaggregated version of model.

Variable	Income Group[a] Low (less than Rs 500)	Middle (Rs 500 to 1499)	High (more than Rs 1500)
Behavioral parameters			
α	0.112	0.105	0.120
β	0.120	0.140	0.120
Trip generation rates			
Work to home/employee	0.33	0.62	0.84
Home to service/household	0.29	1.02	2.31
Modal split probabilities[b]			
Work			
Motor vehicle	0.03	0.21	0.69
Mass transit	0.33	0.52	0.27
Bicycle	0.64	0.27	0.04
Service			
Motor vehicle	0.04	0.23	0.71
Mass transit	0.61	0.64	0.21
Bicycle	0.35	0.13	0.08

[a] In 1969, Rs7.49 = $1.00. [b] Entries do not include pedestrian trips.

and transportation model to issues encountered in regional strategic development planning. Analysis models used for this type of planning must have modest data requirements, be adaptable to a variety of issues, and have quick computer turn-around time.

The first application of the model was to aid in the formulation of a consistent and desirable set of public development policies. In this application, the behavioral parameters of the model were disaggregated spatially, but the residential submodel was aggregated over all socioeconomic groups and the service submodel was aggregated over all service sectors.

The second application involved detailed analyses of the distribution of service employment by sector within one subregion. In this application the service employment submodel was disaggregated into a number of service employment sectors.

The final application involved the development of a version of the model disaggregated by socioeconomic group for Delhi, India. A disaggregated version is required because of the tremendous range of socioeconomic groups in Indian cities and the very different spatial distributions of employment and housing opportunities available to these groups. This version of the model has been used to explore the impacts of alternative land development policies on the corridor level volumes of road and public transportation trips.

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Impact of Transportation on Urban Density Functions

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A method is proposed for analyzing the variable impact of transportation on urban structure. The varying coefficient model, which uses the negative exponential density function as a theoretical base, provides a means for systematically incorporating hypothesized effects of current and past levels of transportation while holding constant population, income, and other factors identified with current urban spatial structure. The aspects discussed include the following: the theoretical basis for the hypothesized effects of the conditioning variables to be investigated, the development of the model in relation to changing density functions, the estimation of model parameters by use of available cross-sectional data, the application of the model to the generalized problem of the urban density function, and simulated forecasts and analyses of transportation-related changes in urban structure for selected cities.

The relation between density and distance—or, more generally, the density gradient—has been used in recent years to explain urban spatial structure. The standard