TOPIC 1
TRANSPORT AND
LAND USE (SIG)

A MEPLAN LAND-USE / TRANSPORT / ENVIRONMENT MODEL OF EDMONTON

JOHN D. HUNT
Department of Civil Engineering
University of Calgary
2500 University Drive NW
Calgary, Alberta
CANADA T2N 1N4

J.D. PAUL MCMILLAN
Department of Civil Engineering
University of Calgary
2500 University Drive NW
Calgary, Alberta
CANADA T2N 1N4

Abstract

A MEPLAN model of Edmonton in Canada includes representation of interactions among land use, transport and the environment. Development of the model is a large undertaking involving a wide range of design and data requirement issues. The potential improvements for planning analysis justify the extensive time and effort required.

INTRODUCTION

A program of research is underway to investigate the applicability of land-use and transport modelling in the Edmonton Metropolitan Area in Canada. This program includes the development of a model based on the MEPLAN framework for land-use and transport interaction modelling, which arose from initial efforts at the Cambridge University Martin Centre and was further developed by the Cambridge-based consulting firm of Marcial Echenique and Partners (Echenique, 1994; Hunt and Simmonds, 1993).

The MEPLAN framework is a generalised system that includes four submodels and the interactions among these submodels in a pattern that simulates temporal dynamics as shown in Figure 1. The framework is very flexible, and the job of developing a model based on it includes both the selection of the specific structure for each submodel and the estimation of the relevant model parameters. This flexibility allows interactions involving land use and transport—and also the environment—to be included in a given model, with environmental quality possibly being a cause in some cases and an effect in others in one or more submodels.

This paper describes various aspects of the design and data requirements of the Edmonton model. It reviews issues considered in the development of the model structure, outlining the ways in which the structure is designed to address specific policy considerations in Edmonton together with the compromises that must be adopted in the light of data limitations. Environmental impacts are of major concern in Edmonton and the way in which the model structure is tailored to include representation of these impacts is given particular emphasis.

As a result, this paper provides an indication of the potential that a specific model based on the MEPLAN framework has to inform planning analysis, together with the sorts of data that can be used to calibrate such a model. The MEPLAN framework in general is described in the next section. Some specifics of the Edmonton model, including both the specific policy issues to be considered and the resulting model design, are outlined in the following section. The calibration process is described, the data requirements that arise as a result are presented and the sources identified for these data are indicated. Some conclusions are offered in the final section.

DESCRIPTION OF MEPLAN FRAMEWORK

The MEPLAN general framework uses an input-output (Leontief, 1941) type format to establish the demand for further production to satisfy consumption arising as part of the production activity within each zone in a system of zones covering the study area. Consumption in a given zone is determined as follows:

$$T_{cj}^{n}=D_{cj}^{n}+Q_{cj}^{n} \tag{1}$$

with

$$D_{cj}^{n}=\sum_{m} a_{j}^{mn}T_{gj}^{m} \tag{2}$$

where

j is an index representing land-use zones;

m is an index representing factors (categories of commodities, such as goods and services and labour);

n is another index representing factors in the same way as m;

a_j^{mn} is the volume of a factor n consumed in the production of a unit of factor m in zone j, called a 'technical coefficient';

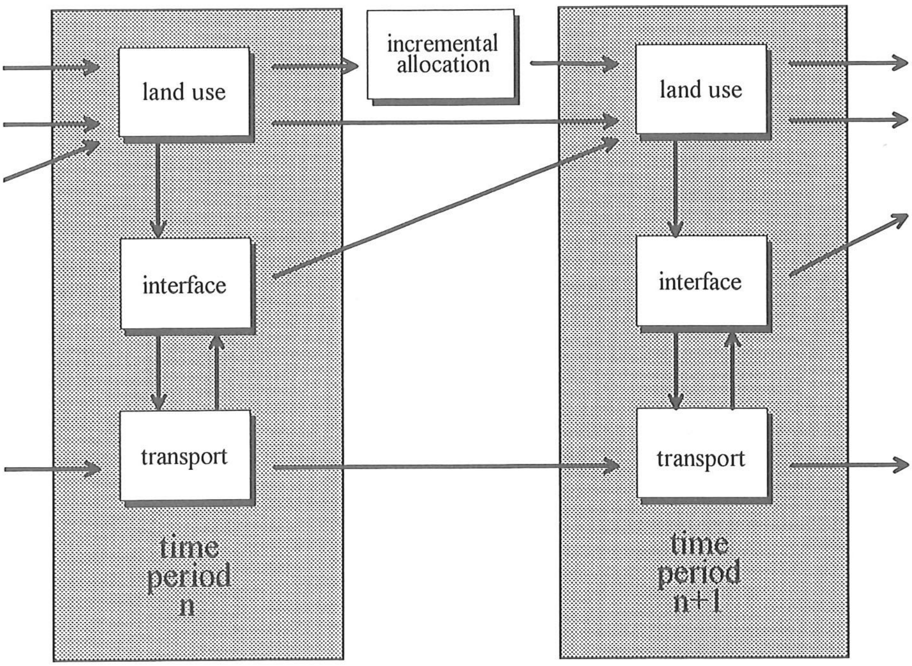

Figure 1 **MEPLAN Submodels and their interactions: Temporal dynamics are simulated by ordering the sequence of interactions among the program modules at adjacent points in time**

$T_{c_j^n}$ is the total volume of a factor n consumed in zone j;

$Q_{c_j^n}$ is the exogenous component of total volume of a factor n consumed in zone j, analogous to the Lowry (1964) basic component;

$D_{c_j^n}$ is the endogenous component of total volume of a factor n consumed in zone j;

$T_{g_j^m}$ is the total volume of a factor m produced in zone j.

A spatial element is introduced by allocating this production, $T_{g_j^m}$, among all zones according to the following formula:

$$t_{ij}^{n}=\frac{\exp[\lambda^{n}(T_{b_i^n}+d_{ij}^{n}+s_i^j+Q_{\varepsilon_i^n}+D_{\varepsilon_i^n})]}{\sum_i \exp[\lambda^{n}(T_{b_i^n}+d_{ij}^{n}+s_i^j+Q_{\varepsilon_i^n}+D_{\varepsilon_i^n})]} \qquad (3)$$

where

i is an index representing land-use zones;

t_{ij}^n is the volume of factor n produced in zone i and consumed in zone j;

d_{ij}^n is the disutility associated with transporting a unit of factor n from zone i to zone j; this for the person or agent making the production location decision;

s_i^j is a size term, which accounts for the a priori likelihood that a unit of factor n is produced in zone i;

$Q_{\varepsilon_i}^n$ is the exogenous component of zone-specific disutility associated with producing factor n in zone i;

$D_{\varepsilon_i}^n$ is the endogenous component of zone-specific disutility associated with producing factor n in zone i;

$T_{b_i}^n$ is the cost of producing a unit of factor n in zone i;

λ^n is a dispersion parameter associated with the distribution of production of factor n.

Transport demands (called 'flows') arise from the predicted transfers of output (called 'trade' matrices) between zones. These demands are loaded onto a representation of the transport network by means of nested logit (Williams, 1977) mode split and assignment models that take into account congestion effects. The resulting disutilities become the 'trade' disutilites that influence the allocation of production in the next time period.

The representation of the supply conditions for each mode available to a flow is built up from a collection of travel states which occur on links in the network. For example, the car mode could be made up of the 'walk to or from auto', 'auto ride' and 'park' states. A trip using the car mode is then made up of the links on which any one of these travel states occurs. Certain travel states can be limited to certain links and different categories of links can be used to specify money costs or other disutilities.

Space (both land and floorspace) is deemed to be 'nontransportable'; that is, the demand for space arising in a given zone must be satisfied by the supply of space in that zone. The demand for space is made elastic and price changes are used to bring the demand and supply back into equilibrium in each zone. The resulting prices for space feed back into the rest of the input-output structure to influence prices throughout the model. Space supply is changed in each zone when the model moves to the next time period.

As such, the framework is exceedingly general and flexible and can be used for a variety of situations and scales of analysis. For further descriptions of the framework see Hunt and Echenique (1993) and Hunt (1994).

EDMONTON MODEL SPECIFICS

The development of a specific model using the MEPLAN framework, which involves the design of the details of the model, requires the selection of the model structure, including the definitions of the various zones and categories for factors, transport demands, modes, and travel states.

Design occurs with the selection of the model structure and with the further modification of the structure as development progresses. In order to address policy concerns, the model must contain certain functional aspects and categorisations. In addition, the model must also appropriately represent the relevant behavioural mechanisms and associated causal-behavioural links. All these functional aspects, categorisations and representations are identified as much as possible at the start of the model development in an 'initial design'. They may be (and usually are) modified as model development progresses in response to various practical data limitations and problems with model fit.

Policies considered

Some of the most significant issues to be considered with the Edmonton model—and the corresponding influences on the initial design—are:

- *LRT development*: The impacts of expanding the light rail transit (LRT) system and associated park+ride facilities are to be examined. In response, a separate series of nodes and links is used to represent the LRT system and a finer zoning system is used along the potential future right-of-ways.

- *Ring road expansion*: The impacts of expanding the existing partial ring-road are to be considered. Thus, as with LRT, a finer zoning system is used in the vicinity of the portions of the ring road to be completed.

- *Central area employment*: The effectiveness of various schemes for managing downtown employment levels—either upwards or downwards—are to be examined. Employment in each category in the central area zones is forecast directly by the model and the relevant totals can be determined as required.

- *Increased tendency to work at work at home*: The effects of the potential increase in the popularity of working at home are to be considered. In response, the private service employment factor is split into 'regular' and 'at home' service employment categories. The 'regular' service employment factor generated in a zone stays in that zone consuming office floorspace produced in that zone and labour produced by households in various zones whereas the 'at home' employment generated in a zone is distributed among zones in proportion to residential volumes without taking into account travel disutility or floorspace costs.

- *Alternative uses of municipal airport lands*: The potential redevelopment of the central downtown airport in Edmonton is to be explored. Represented by a single zone, the airport lands can be designated by alternative 'land-use' designations and associated maximum volumes and densities.

- *Development and role of suburban activity centres*: The formation of suburban activity centres is to be investigated. Their representation is similar to that of the airport: land-use designations and maximum densities are specified and the resulting activity and traffic volumes predicted.

- *Improving transit effectiveness using land use measures*: The effects of using land-use measures such as high density development within walking distance of LRT stations to improve transit effectiveness are to be investigated. Although the zoning system is too coarse to analyse the area immediately around an LRT station, pockets of increased density around stations are modelled by reducing the walking distance to the station and/or increasing the total volume of development in the zone by releasing more space for development.

- *Electricity demand*: The amount of electricity demanded is to be predicted by the model. In response, electricity is a factor that has been included in the model as something consumed by all employment and all household factors according to industrial and residential consumption rates. This will allow the model to determine the volume of demand for electricity by activity in each zone for different scenarios. Totals for groups of activities and zones, right up to a single aggregate value for the entire region, can then be determined. The rate at which each employment and household factor consumes electricity must be known. It can be expressed per employee or per unit floorspace or land for employment; and it can be expressed per household or per unit floorspace for households.

- *Air quality aspects*: The treatment and resulting representation of air quality impacts are similar to those described above for the consideration of electricity demand. 'Air pollution' has been included in the model as a factor that is 'consumed' by all employment and all household factor categories. This allows the model to determine the volume of emissions generated (to satisfy the 'demand') by both industrial and residential activity in each zone for different scenarios. Aggregate transport emission volumes are calculated according to the average speed, vehicle mix and volume on each link as calculated in the transport model. These values are added to the values generated by activities in zones in order to establish total emission volumes for point and mobile sources together. A different factor is defined for each separate type of emission to be considered. In addition, it is possible to include the influence of air quality on the allocation of production among zones by including an air quality effect on the zone specific disutility associated with producing a factor.

- *Impacts of municipal taxes*: Taxes can be applied to each factor and zone to test resulting changes of urban form. This is accomplished by adding a tax to the costs of location for an activity using the space in a particular zone.

- *Inner city redevelopment:* Potential plans for the redevelopment of the inner city are to be investigated. The incremental allocation models include separate models of demolition and construction of each floorspace category and use the zonal price for the relevant space determined in the previous time period to allocate a total demolition and then a total construction to individual zones as appropriate.

Category specification

The definitions for employment factors, space (floorspace and land) factors, mode categories, travel states and zoning systems in the initial design are discussed below.

Employment and space factors

The definitions for employment and space factors are closely linked. Definitions of employment based on combinations of economic sector and type of occupation are allocated to types of space as indicated in Table 1. For example, employment in the industry sector is split into (1) 'industry/office', which includes all non-blue-collar occupations in the industry sector and occupies office space, and (2) 'industry/industrial', which includes all blue-collar occupations in the industry sector and occupies industrial space.

Economic sector classifications are based on Canadian Standard Industrial Classification (SIC) Codes (Statistics Canada, 1986) and occupation classifications are based on Canadian Standard Industrial Classification (SOC) Codes (Statistics Canada, 1981). They are employed in various databases, allowing for a certain consistency in definitions across different components of the data used. The input/output table used to develop the technical coefficients is for the Province of Alberta in 1984 (Alberta Bureau of Statistics, 1991). This table is expressed in terms of SIC codes, which necessitates the use of both SIC and SOC codes in the definition of employment factors as shown in Table 1. The use of an input/output table for all Alberta for 1984 represents an compromise: a table for a point in time closer to 1991 and/or for the Edmonton Metropolitan Region by itself is not available.

Table 1 Floorspace consumption categories by economic sector and occupation classification

	Agriculture	Industry	Wholesale	Retail	Private services	Government	Education
White collar	office	office	office	office	office	gov't	gov't
Blue collar	agricultural	industrial	wholesale	retail	industrial	gov't	gov't
Sales	office	office		retail	office	gov't	gov't
Service	office	office	office	retail	commercial	gov't	gov't
PS teaching	office	office	office	office	office	gov't	PS institute
ES teaching	office	office	office	office	office	gov't	schools

Ideally, the allocation of SIC categories to space categories would be based on observed data. Such observations are not available and the use of SOC codes is a compromise based on assumptions about the types of space used by employment in each SOC code consistent with available indications from land use information collected by the City of Edmonton.

Selection of travel modes and states

Modes were chosen to allow a reasonable analysis of policy and to provide an appropriate level of detail concerning mode split. For the Edmonton model, 'metabolic' (non-motorised) was specified along with 'car', 'public transit', 'park + ride' and 'truck' modes.

The states that make up each mode are chosen to represent the different activities that are involved with the use of the mode. Walking states specific to different modes are used in order to facilitate various constraints on the use of specific network links as part of the simulation of the transport network. Ride states specific to different modes are used in order to allow different values of time to be specified.

Zoning system

The zoning system is developed based aggregations of the zones used in the existing Edmonton transport model and Canada census divisions. Finer levels of detail are provided in geographic areas of greater concern to policy-makers. This allows the model to provide a more specific indication of the results of potential policy options in areas of interest.

Overall structure of Edmonton model

A depiction of the specific structure of the Edmonton model resulting from the various considerations indicated above is provided in Figure 2. The way the diagram works is described in detail below, with the single-letter symbols used in the diagram indicated inside parenthesis. A summary of these symbol definitions is provided in Table 2.

Table 2 Summary of symbols and abbreviations used in Figure 2

Incremental			
d	changes coded directly		
p	changes proportional to previous distribution		
r	changes influenced by prices		
Land use			
f	fixed demand coefficient		
e	price elastic demand coefficient		
v	variable household consumption demand coefficient		
Interface			
c	fixed factor flow conversion coefficient		
g	disutility elastic factor flow conversion coefficient		
Transport			
m	modes available to flows		
s	travel states comprising modes		
a	link types available to states, with capacity constraints		
w	link types available to states, without capacity constraints		
Abbreviations			
AGRI	agriculture	COMM	commercial
IND	industry	EDU	education
WHOL	wholesale	HH	household
PRI	private	ELEC	electricity
SERV	services	PS	post secondary
OGS	other goods and services		
FLSP	floorspace	PUB	public

The large matrix in the middle of the diagram indicates the pattem of consumption and production for each factor considered in the land-use submodel. A given row in this matrix relates to the consumption behaviour of the production process for one of the factors, indicating those factors whose output is consumed.

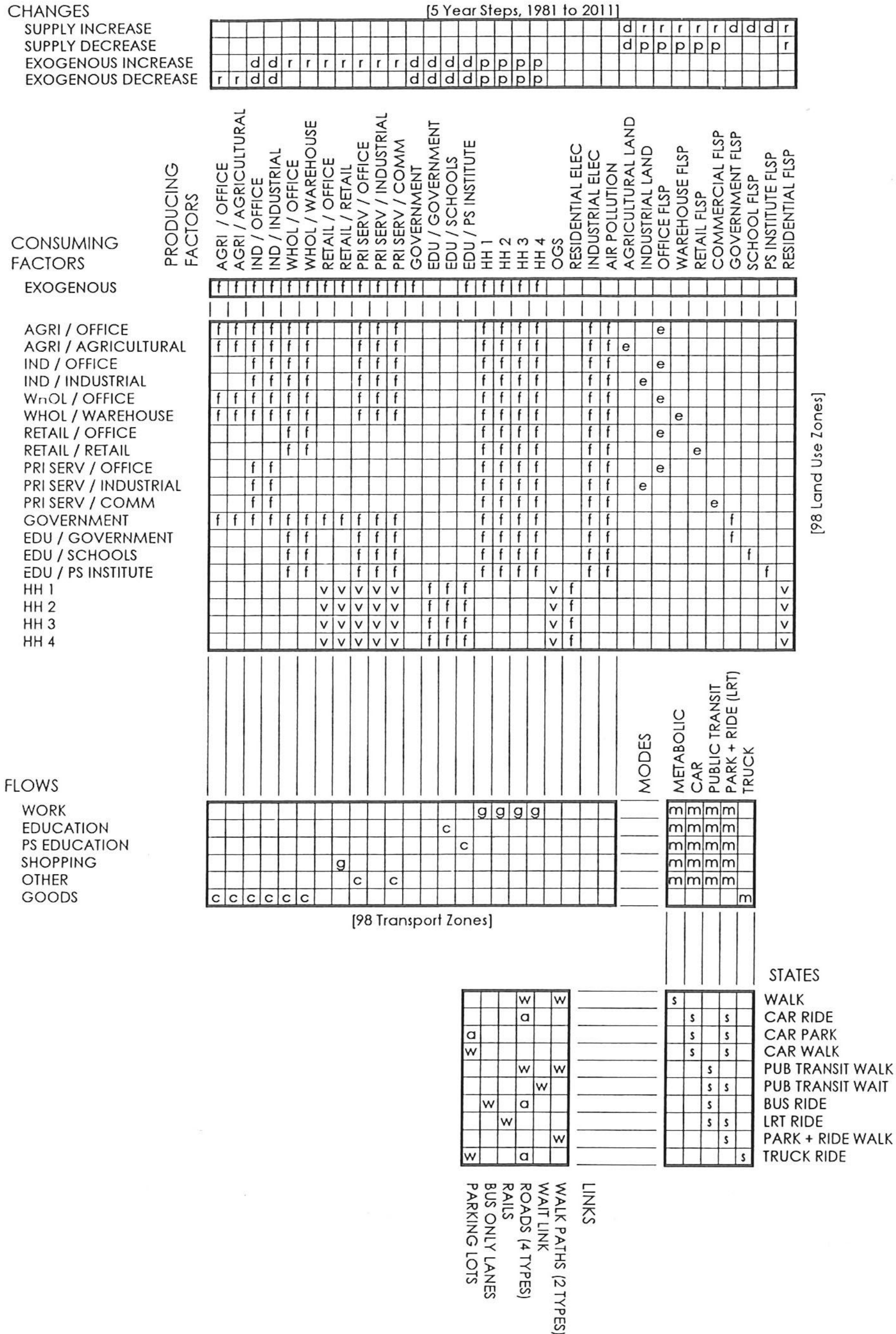

Figure 2 **Structure of the Edmonton MEPLAN model, showing the categories and mathematical forms used in the various model components**

The row separated from and slightly above the largest matrix in Figure 2 indicates the factors that have some of their production demanded exogenously, always according to a fixed rate. In the Edmonton model all employment categories and household categories, except for education/government and education/schools, have a portion of their output demanded exogenously.

The matrix at the top the figure concerns the structure of the incremental allocation models. It indicates the types of characteristics taken into account in the spatial allocation (among land-use zones) of increases and decreases in the supply of space and the exogenous demands.

There are two matrices just below the large matrix in the middle of Figure 2. The matrix on the left indicates the structure of the interface between the land-use and transport submodels. Each row in this matrix concerns one of the matrices of transport demand, that is, one of the flows. It indicates the producing factors (in the corresponding columns in the matrix above) whose matrices of trades are related to that flow.

The three matrices to the right and below this matrix concern the structure of the transport model. The matrix directly to the right concerns the modes available to each flow. Each row relates to a given flow and indicates the modes available to that flow. The matrix below this, on the right at the bottom of the figure, indicates the travel states making up each mode. Each column concerns a given mode and indicates the states that comprise that mode. The matrix to the left shows how each travel state is treated on the links in the transport network. Each row concerns a given state, indicating the links that can be used when in that state.

Functional form specification

The general process of determining an appropriate form for a given mathematical function in the model is to start with the simplest acceptable form and move to more complex forms as the calibration process continues and the need for additional representation becomes apparent because of lack-of-fit difficulties.

The simplest acceptable functional forms are dictated by (a) convictions, beliefs, and personal experiences regarding what will provide an accurate representation of behaviour and (b) what is required to address policy concerns. The functional forms indicated in Figure 2 are the initial set of simplest acceptable forms, which will be altered as calibration progresses.

ESTIMATION OF PARAMETERS IN THE EDMONTON MODEL

Calibration of the model involves estimation of the model parameters, modification of the model structure and re-estimation of the model parameters in the search for an appropriate simulation behaviour. A lack-of-fit between model and known reality may lead to the modification of model structure in order to improve the fit: the form of a function may be altered or the categorisations may be changed. Inconsistencies in the data that become apparent only after starting the calibration process may also lead to changes in model structure. Thus, the development process is iterative in nature, where the task of calibration—itself iterative in terms of both the estimation of model parameters and the modification of model structure—gives rise to the need to revisit the model design in order to ensure that model is able to perform as intended in the initial design. The selection of model structure and the estimation of model parameters are finished when the design and calibration are complete. This entire process is unavoidably complex and requires considerable time and resources.

Many of the parameters in a MEPLAN model are ''heuristic' in their estimation in that they are determined using data synthesised by the model and therefore must be re-estimated each time the model is adjusted. Note that the synthesised data used elsewhere in the model are used only as *inputs* to other submodels; they are not used as proxies for observed values.

In general, a trial-and-retrial process is used to 'break into' the framework's circular interaction between land use and transport. The process is one of starting with arbitrary 'best-guess' values for the heuristic parameters; constraining the model to reproduce appropriate observed zonal totals and zonal interactions concerning household, employment and travel categories (known as 'targets'); getting the circular interaction to operate; and then removing the constraints one by one while making adjustments to the parameters to compensate, so that the 'targets' are still being matched as well as possible. This process can be viewed as a form of multistage estimation that is a search for the vector of parameters for all model components together that provides a best fit overall. Using a trial-and-retrial process in this way represents a compromise on the ideal, where all the parameters would be estimated simultaneously.

What follows is a list of the heuristic parameters in the Edmonton model together with an indication of the output most directly influenced by the parameter and the data source for the associated target in each case:

Household consumption utilities

output: total household expenditures

data source(s): Family Expenditure Surveys 1981-1991

Household consumption price sensitivities

output: household expenditures proportions

data source(s): Family Expenditure Surveys 1981-1991

Floorspace unit price sensitivities

output: observed zonal floorspace use densities as a function of zonal floorspace prices (expressed as imputed rents)

data source(s): Property Sales Price Observations 1981-1991; and the current Tax Assessor Records (late 1992)

Modal split dispersion parameters

output: public transport price elasticities

data source(s): Edmonton Transit Patronage Surveys

Modal split mode-specific constants

output: mode shares

data source(s): Household Travel Survey 1991

Route choice dispersion parameters for public and private modes

output: screenline and location counts

data source(s): Road Traffic Classified Screenline Counts 1981-1991; Road Traffic and Public Transport Location Counts 1981-1991

Goods movement truck trip to trade ratios

output: screenline and location counts

data source(s): Road Traffic Classified Screenline Counts 1981-1991; Road Traffic and Public Transport Location Counts 1981-1991

Parameters specifying sensitivity of trips per unit trade to transport disutility

output: distribution of trip distances for specific trip type

data source(s): any 24-hour Household Travel Survey

Dispersion parameters associated with the distributions of production for factors

output: average trade distance for specific factor

data source(s): Labourforce Survey 1991; Population Census 1981-1991 for work trips; Household Travel Survey 1991 for other trip purposes

Full set of exogenous zone specific constants for production allocation for each transportable factor

output: volume of transportable factor produced in each zone

data source(s): Population Census 1991 for household totals; Labourforce Survey 1991 and various small-scale surveys of specific employment sectors 1977-1989 for employment totals; School Attendance 1991 and College/University Attendance 1991 for education totals

Zonal floorspace price corrections added to the zonal shadow prices for residential floorspace determined by the model

output: private housing unit price and public housing unit price in each zone

data source(s): Property Sales Price Observations 1981-1991 and the current Tax Assessor Records

Various impacts of supply characteristics of transport services coded as network attributes, including auto parking times and public transport walk and wait times

output: screenline and location counts

data source(s): Road Traffic Classified Screenline Counts 1981-1991; Road Traffic and Public Transport Location Counts 1981-1991

CONCLUSIONS

The MEPLAN framework is highly flexible and can be used to develop a model that addresses specific issues of concern and takes into account a wide range of influences in a consistent manner. The model can by design provide a consistent representation and evaluation of the interaction between land use and transport. It can also represent the nature of various environmental impacts arising from both transport and land use, as well as the impacts of environmental quality on activity levels and prices. As such, it can be used to facilitate planning considerations that take into account not only land use and transportation, but also the overall situation regarding environmental impacts rather than just selected components of these impacts.

The very wide range of possible MEPLAN models can make it difficult to know where to begin in developing a specific model. This paper describes the design considerations and data needs concerning a specific MEPLAN model of Edmonton. Various aspects of the structure of the Edmonton model are presented, but the final model and its simulations are not presented. In fact, the process has not yet been followed to completion and final simulations are not yet available.

Notwithstanding, it is the design and development process and its linkage with data needs that are of general applicability and therefore of more general interest. They have evolved over the development of a number of MEPLAN models and have already been shown several times to provide models that are useful tools in policy analysis (Hunt and Echenique, 1993). In this context, a presentation of the simulations from the Edmonton model would merely provide further confirmation of the ability to establish a good model fit to observed behaviour. The intent with this paper is to focus on the design and development process and to indicate its current form and some of the considerations involved in its application in a given instance. Consistent with this intent, some conclusions are offered concerning the process and its application in a given instance.

The data needs associated with the thorough development of a MEPLAN model are extensive. The use of a design process as described here is very helpful in providing a structure for the identification and collection of the required data in a given instance. The highly synthetic nature of the MEPLAN model means that much of what the model uses is generated internally by its submodels. This has the implication that a model can almost always be developed to some level of accuracy given a relatively small minimum level of data—but if particular required elements are not collected, the model cannot be set up appropriately to address specific issues of concern.

The extensive effort that is required to collect the data and calibrate the model does bring about a desire to reduce consideration of alternative functional forms for the submodels. The task of identifying the parameters for just one form is sufficiently large that it alone can put a strain on resources. The structure imposed by the process helps counter this desire.

The process also provides a structure for more automated processes to be developed and added. Much of what is done in the development process uses various forms of trial-and-retrial. The process does eventually move towards a model that addresses policy concerns and provides a reasonable reproduction of key aspects of known reality, but the movement can be slow. Increasing the automation of various tasks would be advantageous. One of the benefits of the process is that it provides a structure into which such automation can be incorporated. This structure is providing a starting point for work that is underway to develop software that will perform the 'ideal', estimating all the parameters simultaneously.

Finally, the magnitude of the time and resources required to develop a MEPLAN model receives considerable attention—and for good reason. From this perspective, it is very important that the magnitude of the potential benefits arising with better-informed planning also be kept in mind. The time and resources requirements seem very extensive indeed when compared with those for the development of other, much more limited modelling frameworks; but a fully-developed model making extensive use of the MEPLAN framework has so much more to offer planners in terms of assisting in the consistent consideration of a wide range of effects and issues. These additional benefits come at an additional cost; and expectations regarding a specific MEPLAN model need to allow for the development effort that is required.

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