Enchancement of DVRPC'S
Travel Simulation Models

TASK 12

# REVIEW OF LAND USE MODELS AND RECOMMENDED MODEL FOR DVRPC

PREPARED FOR
DELAWARE VALLEY REGIONAL
PLANNING COMMISSION
BY
URS CONSULTANTS, INC.

September 1996

Delaware Valley Regional Planning Commission

Enchancement of DVRPC'S
Travel Simulation Models

TASK 12

# REVIEW OF LAND USE MODELS AND RECOMMENDED MODEL FOR DVRPC

PREPARED FOR
DELAWARE VALLEY REGIONAL
PLANNING COMMISSION

BY
URS CONSULTANTS, INC.

September 1996

Delaware Valley Regional Planning Commission
The Bourse Building
111 S. Independence Mall East
Philadelphia, PA 19106-2515

*This report has been prepared by URS Consultants, Inc., in partial fulfillment of the contract between the Delaware Valley Regional Planning Commission and URS Consultants,Inc., to enhance DVRPC's travel simulation models. Funding for the project was provided by the Federal Highway Administration and the Pennsylvania and New Jersey departments of transportation. URS Consultants, Inc., however, is solely responsible for its finding and conclusions, which may not represent the official views or policies of the funding agencies.*

*Created in 1965, the Delaware Valley Regional Planning Commission (DVRPC) is an interstate, intercounty and intercity agency which provides continuing, comprehensive and coordinated planning for the orderly growth and development of the Delaware Valley region. The region includes Bucks, Chester, Delaware, and Montgomery counties, as well as the City of Philadelphia, in Pennsylvania; and Burlington, Camden, Gloucester, and Mercer counties in New Jersey. The Commission is an advisory agency which divides its planning and service functions between the Office of the Executive Director, the Office of Public Affairs, and four line Divisions: Transportation Planning; Regional Planning; Regional Information Services Center, and Finance and Administration. DVRPC's mission for the 1990s is to emphasize technical assistance and services, and to conduct high priority studies for member state and local governments, while determining and meeting the needs of the private sector.*

*The DVRPC logo is adapted from the official seal of the Commission and is designed as a stylized image of the Delaware Valley. The outer ring symbolizes the region as a whole while the diagonal bar signifies the Delaware River flowing through it. The two adjoining crescents represent the Commonwealth of Pennsylvania and the State of New Jersey. The logo combines these elements to depict the areas served by DVRPC.*

# DELAWARE VALLEY REGIONAL PLANNING COMMISSION

## Publication Abstract

| TITLE | Date Published: September 1996 |
|---|---|
| **Review of Land Use Models and Recommended Model for DVRPC** | **Publication No.** 96008 |

**Geographic Area Covered :**

Delaware Valley Region

**Key Words :**

Land-use models, Integrated Land-use transportation models, Mathematical model, Operational model, Use of land-use model by MPO's.

## ABSTRACT

*This report reviews existing land-use modeling practice for integrating transportation and land-use models. Three operational models (DRAM-EMPAL, MEPLAN, and METROSIM) were selected based on completeness, use by the professional community and theoretical contents. DRAM-EMPAL has the highest user base among U.S. MPO's.*

*Through telephone interviews with MPO's using DRAM-EMPAL model, land-use modeling experiences are described in terms of land-use zone systems, transportation zone systems, household and employment categories, control totals, use of forecasts and implementation-application issues. A competitive test of the above three models is recommended for a final model selection. The cost of implementing DRAM-EMPAL at DVRPC, as well as detailed data requirements are specified to illustrate the magnitude of this project.*

*For More Information Contact:*

**Delaware Valley Regional Planning Commission**
**Regional Information Services Center**
**The Bourse Building**
**111 South Independence Mall East**
**Philadelphia, PA 19106-2515**
**Telephone: (215) 592-1800 Fax: (215) 592-9125**

## TABLE OF CONTENTS

**APPENDICES**

# EXECUTIVE SUMMARY

This report reviews current land-use modeling practice and recommends a land-use model for DVRPC. The analysis has been based on a review of relevant literature on land-use modeling augmented by telephone interviews of MPO's regarding their experiences using land-use models. In this report the interaction between land-use and transportation is explained by emphasizing that enhancements to the transportation system improving the accessibility of some zones making them more attractive for some households or firms. Since this change in accessibility and the resultant change in the pattern of households and activities are not accounted for in traditional four-step transportation models, an integrated model of the transportation and land-use systems becomes necessary.

Three operational models, DRAM-EMPAL (S.H. Putman); MEPLAN (Marcial Echenique); and METROSIM (Alex Anas), were reviewed in detail with respect to their completeness, user base and theoretical contents.

The DRAM-EMPAL is the model used most extensively by U.S. MPO's. This model system is a Lowry-derivative type model using maximum entropy formulation. The author of the model has a plan for enhancing the model in an evolutionary form by structuring the component models and using a GIS-based data structure for easier interaction between component models as well as accessing mapping and statistical routines.

MEPLAN is another Lowry-derivative model which uses economic base theory in an input-output model framework with price function. An input-output model is applied to represent flows between activities in the form of demand for space. The coefficients of the input-output model are used to calculate prices in an elastic form to represent land allocation within zones. Random utility is used to represent an explicit spatial system where households and firms decide where to live and locate in a utility maximization or a cost minimization framework within specified constraints. This allows market land prices to be considered in the model explicitly. On the same basis, the price of transport might be formulated in terms of time penalties representing congestion. The model is used in London, Cambridge and Stevenage in the U.K., Santiago de Chile; Sao Paulo, Brazil; Tehran, Iran; and Bilbao, Spain. Its most recent application has been for the South East England region.

METROSIM, takes an economic approach to modeling housing and land-use location. The model embodies the discrete choice method with economically specified behavior and a market clearing mechanism. The model is formulated in three market equilibria: 1) labor market equilibrium and job assignment, 2) housing market equilibrium and 3) commercial space equilibrium. The model iterates between these markets and the transportation system for equilibrium of land-use and transportation flows. This model has evolved from applications in Chicago consisting of residential location-housing and mode choice sub-models. In implementing the model in the New York Region, non-work travel choices and commercial real estate markets were added. The METROSIM model is a relatively new formulation and has not been applied to any other MPO.

To document experiences of MPO's with land-use models, a telephone interview was conducted with five MPO's who use the DRAM-EMPAL model. Questions were asked about calibration-forecast years, land-use zone and transportation zone systems, transportation software, household and employment categories and methods of projecting control totals. Review processes of forecasts made and use of such forecasts were also questioned. The main finding of the telephone interview is that the majority of users are satisfied with the DRAM-EMPAL model; however, there is a need for improvement. The consensus opinion is that efforts should be made by the author of the model as well as by the user community to enhance the model system rather than starting a new model altogether. Those MPO's who have been successful with the model attribute this not only to the model system but also to their own efforts, especially in providing a sound employment location database. One MPO is actively looking for a replacement.

It is essential that DVRPC benefit from the experiences of other MPO's with existing operational land-use models. Also, improvements to the model system should be possible as the component modules become available. We propose a two-step selection and implementation phase: short-term and long-term. In the short term, we recommend that limited versions of the DRAM-EMPAL, MEPLAN and METROSIM models be acquired for competitive testing in prototype use, policy analysis and impact assessment. For long-term needs, the model system should be modular to allow the insertion of better component modules as they become available.

To fulfill the terms of our contract with DVRPC, we defined the data needs and estimated the cost of implementing the DRAM-EMPAL. This model has been applied by most U.S. MPO's as of this writing, is fully operational and is less data intensive in comparison with the other two models. The DRAM-EMPAL does not use specific economic variables in a systematic form in its market-clearing mechanism, and thus its forecasts can be questioned by "pure" theorists. The estimated total cost is \$600,000: \$140,000 for the model license and independent consultant costs plus the equivalent of \$460,000 for DVRPC's senior modeler and staff time.

## INTRODUCTION

This report, prepared for the Delaware Valley Regional Planning Commission (DVRPC), reviews existing land-use modeling practice regarding the integration of transportation and land-use models. The study consists of two related sub-tasks of literature review and recommendations of the most appropriate land-use model for the Commission's needs.

In this report the need for Land Use - Transportation interaction is explored, followed by the description of four classes of models. This discussion leads to a synthesis of inventory of land-use models for agency use followed by current land-use modeling practice at MPO's. Section I concludes by describing in some detail the most commonly used operational land-use models: DRAM-EMPAL and MEPLAN. In addition, details of a newer model which uses micro-economic theory in model formulation, METROSIM, is added as representative of promising approaches in land-use modeling.

Section II provides analyses of land-use model experiences through randomly selected telephone interviews with MPO's using the DRAM-EMPAL model. This includes information on calibration, land-use zone system, transportation zone system and software, household and employment category uses, ways of providing control totals, forecast review processes, use of forecasts, computer system used, model selection process and implementation and application issues.

Sections III and IV specifie desired characteristics of a land-use model for DVRPC on the basis of Section 1, literature review; and Section II, land-use model experiences. Instead of selecting a particular model among the three models which are operational and have known theoretical underpinning, this report recommends that a prototype policy and implementation test be performed before final selection. The cost of implementing the DRAM-EMPAL at DVRPC is estimated and its data requirements are defined to illustrate the magnitude of this effort.

Appendix A provides details of the telephone interviews conducted for this report.

The principal author of this report is Kazem Oryani, Ph.D., URS Consultants. Appendix B, a parallel paper written for this report by Professor Britton Harris, subconsultant to this study, provides a perspective on land-use models by tracing model development efforts with regard to theory and implications of the use of such models at the MPO level. The ideas presented in Appendix B are related to and supportive of the conclusions of the main report, but do not presume to anticipate or preempt those findings.

# I. LITERATURE REVIEW: LAND USE – TRANSPORTATION MODEL INTEGRATION

## I-1 Need for Land Use - Transportation Interaction

Traditional transportation models consist of four stages: trip generation, trip distribution, mode choice and trip assignment.

The number and types of trips estimated in the trip generation phase for each traffic analysis zone is matched with trips attracted to zones by purpose through a zone-to-zone impedance matrix (time, distance, cost) in the trip distribution step. Mode choice converts person trips to auto and transit trips based on a relative cost/availability/preference function. Auto trips and transit trips are loaded onto the transportation network, usually through the equilibrium method, using congested travel time in such a way that no individual trip maker can reduce his or her path costs by switching routes (Wardrop's equilibrium).

The above is a simple, yet concise, depiction of practice in traditional transportation modeling. Considering that planning deals with the future and forecasts of travel patterns and land use are the heart of the planning endeavor, what is lacking in the above picture is the impact that enhancements to the transportation system have on land-use. Enhancements, such as the addition of new facilities, or upgrading of existing facilities increase the accessibility of some zones. Such zones then become more attractive for households or firms. This increase in accessibility which leads to more households or firms locating in the more accessible zones is not accounted for in the trip generation step. On the land-use side of the equation, the increase in population or activity in zones requires further facility enhancement, but this is not considered in the assumed transportation systems used in the location models.

Changes to a land-use pattern, which is spatial distribution of activities, usually have some time lag in response to transportation improvements. Also, the response of policy makers to congestion is not instant. Nevertheless, an interrelationship of land use and transportation does exist. As Mackett (1994) states, "There is little doubt that land use does change in response to changes in transportation infrastructure and thereby causes secondary effects on travel demand in addition to the direct effects caused by route and mode switching."

This requires the use of congested travel times from a transportation model as an input to a land-use model. The subsequent possible changes in the land-use pattern, which was assumed fixed in the trip generation phase, must be evaluated. This requires a feedback loop between the transportation system and land-use system in such a way, that after several iterations of the model system, an equilibrium state is reached between transportation and land use as an integrated system.

In summary, this dynamic relationship between land use and transportation and the inter-connection between these sub-systems is not considered in static four-step transportation planning models. There is a need for linking and/or integrating transportation and land-use models through feedback mechanisms or joint determination of system components. Such connections make these models more realistic in their depiction of the system under study and the subsequent use of these models as policy analysis tools.

## I-2 Class of Models:

### I-2-1 Lowry and Lowry Derivative Models

Modeling urban form, as represented by location (land use) models, was primarily conceived by Lowry in his Model of Metropolis (1964). This model is based on the assumption that, everything else being equal, the place of employment determines the place of residence. Place of work (<u>basic</u> employment location) implies the place of residence (population and dwelling units). The resident population requires "<u>services</u>", therefore, place of <u>service</u> employment is determined by resident population. The <u>service</u> employees themselves require housing in relation to their place of work. This additional population requires further services which will be fulfilled by additional <u>service</u> employment. The new service employees require <u>housing</u> in relation to their place of work. This round of reasoning continues until there are no further service employees or households to be located.

Households and employment are constrained by regional employment and household totals. The heart of the model for placing households is a gravity model relating employment location to an impedance function of power form. One of the derivatives of Lowry's model is the TOMM model (Time Oriented Metropolitan Model) which introduces an element of time in the model. The original Lowry formulation, as Lowry himself puts it, generates an "instant metropolis" (Lowry 1964).

The MEPLAN model of Marcial Echenique and Partners introduces elements of relative rent for land (comparative prices) and Putman's Disaggregated Residential Allocation Model (DRAM) introduces disaggregation of activities by employment type and household income quartiles. Analogy with the laws of gravitational force was the initial principle used in constructing these urban models. Wilson (1967, 1970, 1971) introduced principles from information theory to estimate a typical trip table which is used to create a series of spatial interaction models. DRAM, a reformulation of Projective Land Use Model (PLUM, Goldner 1968, in Putman, 1979), is based on the use of the explicit determination of a trip table using Wilson's maximum entropy formulation.

### I-2-2 Optimization Models

The second class of urban activity allocation models uses optimization theory in describing the process of urban form. These models assume that the pattern of households and employment locations can be described as allocations of new land uses in such a way as to optimize an objective function which consists of transportation costs and activity establishment costs. The models have constraints intended to ensure that zones are not filled beyond capacity and that all activities are allocated. Technique for Optimum Placement of Activities into Zones (TOPAZ) uses a non-linear objective function (for more detail see Oryani 1987). It is one of a small number of optimizing models which have been used by planning agencies to define extremes of alternatives.

The Herbert-Stevens (1961) model attempted to simulate market conditions for redistributing locations. It based its formulation on the economic theory of trading time for lower densities and other amenities in suburban development. This model was extended by Harris (1962) and Wheaton (1974) to form a non-linear programming model in which transport cost is part of the objective function.

Boyce (1986, 1990) is a leader in the development of combined models of location and transportation using non-linear programming (constrained optimization). His investigations of the practical use of such constructs in planning agencies are performed in an academic setting.

### I-2-3 Econometric-Regression Models

The third class of activity allocation model takes its roots from econometric models with simultaneous systems of equations. EMPIRIC, the first large scale linear urban form model, was developed for the Boston Region (Hill, Brand and Hansen 1965, in S. H. Putman, 1979, pp. 19-29). This model uses regression analysis and simultaneous systems of equations for drawing relationships between different types of land uses. Unlike the other classes of models described earlier, EMPIRIC-type models do not represent a coherent urban form theory. Model coefficients are estimated by using existing land uses in the region.

### I-2-4 Economically-Based Land Use Market Models

Economically-based models of residential choices began with Wingo (1961) and Alonso (1964) with emphasis on the location of housing in addition to other characteristics where households trade-off added travel for space and amenity. These analyses were based on mono-centric places of employment where concentric rings of residential land market can be defined with lower densities as one moves toward the outer rings. As Harris explains in Appendix B of this report, this conceptualization led to the National Bureau of Economic Research (NBER) model. NBER took into account the attraction of numerous large employment centers; and, for the first time in any major study, analyzed household residential preferences in detail.

Anas (1975, 1987) expanded on the economic approach to modeling housing and land-use location from the Wingo-Alonso school of economic models. He used the discrete choice method, developed by McFadden (1973), into models with economically specified behavior and a market clearing mechanism. A detailed description of the latest variant of the Anas model, METROSIM, is provided in Section I-4 of this report.

## I-3 Inventory of Land Use Models for Agency Use

Models applicable to agency practice with different degrees of being operational include:

1. DRAM Model: Disaggregated Residential Allocation Model, behavioral-entropy maximizing, Lowry type model

2. TOMM Model: Time Oriented Metropolitan Model: Lowry type with dynamic formulation

3. MEPLAN Model: Echenique, Lowry type with comparative land price components

4. LUTRIM: Land Use Transportation Integrated Model: Lowry type integrated to the traditional transportation planning models as the fifth step

5. TOPAZ: Technique for Optimum Placement of Activities into Zones: Non-linear optimization model

6 TOPAZ82: retains the mathematical structure of TOPAZ while incorporating the dispersion capability of a spatial interaction model.

7. Herbert-Stevens Model: Linear optimization incorporating economic base theory

8. Harris-Wheaton Model: Non-linear optimization with economic base theory

9. EMPIRIC: A regression-based model of simultaneous systems of equations

10. METROSIM: Discrete Choice Model of Housing Location by Alex Anas

Except for TOPAZ and TOPAZ82, both of which originated in Australia, and MEPLAN, which is a British model, all of the above models originated in the United States.

In a demonstration project to develop methodologies for evaluating alternative land-use patterns for air quality implications, the following fourteen land-use models were identified:

| | | |
|---|---|---|
| 1. | TOPAZ | Australia |
| 2. | MEP | U.K. |
| 3. | ITLUP (DRAM-EMPAL) | U.S.A. |
| 4. | LILT | U.K. |
| 5. | AMERSFOORT | Netherlands |
| 6. | CALUTAS | Japan |
| 7. | IRPUD (Dortmund) | Germany |
| 8. | OSAKA | Japan |
| 9. | SALOC | Sweden |
| 10. | MEPLAN | U.K. |
| 11. | TRANUS | Venezuela |
| 12. | TRACKS | Australia |
| 13. | TRANSTEP | Australia |
| 14. | TOPMET | Australia |

Source: "Making the Land Use Transportation/Air Quality Connection", Volume 1, October 1991 prepared for the Organization of 1000 Friends of Oregon, Cambridge Systematic, Inc., with Hague Consulting Group

Most of the above models are not available commercially for agency use. Available models include TOPAZ, TOPAZ82, MEPLAN, ITLUP, TRANUS, TRACKS and TRANSTEP. Among the available models only ITLUP (DRAM-EMPAL), MEPLAN, and TRANUS have sufficient installation sites to enable users to share experiences to shorten the learning curve in modeling applications.

A survey of MPO's covering the twenty largest Metropolitan Statistical Areas in the United States, and two additional agencies known to be on the leading edge of model use, was made by the same 1,000 Friends of Oregon study. Information about land-use data and land-use procedures in travel demand modeling was provided by 19 of these 22 agencies.

The survey found that eight agencies use land-use data in the traditional form in trip generation. None of these "traditional" agencies had a land-use model for allocation of development activities to zones.

A second group of five agencies, called “innovative” by the Oregon study, used land-use allocation models to provide input data to the trip generation phase of their transportation models. Except for one agency which used its own specific technique, the other four agencies utilized DRAM-EMPAL models.

The third group included four agencies which are in transition from "traditional" to "innovative" approaches in land-use data. Except for one agency, which is in the process of creating its own land-use model, the three other agencies are in different stages of implementing DRAM-EMPAL as their land-use model.

The fourth group consists of two agencies. One uses a variant of DRAM-EMPAL models integrated into transportation modeling with necessary feedback mechanisms between the transportation and land-use models. The other agency, the Association of Bay Area Governments, has created its own land-use model, POLIS, which is described on the next page.

Modeling is a powerful tool and additional models are constantly being developed and are described in the literature. In a 1994 study by Michael Wegener entitled "Operational Urban Models: State of the Art," the following 12 models are identified as being operational. He made no judgements on the quality of the models, but the criteria of being applied to real cities and being operational had been satisfied:

1. POLIS: the Projective Optimization Land Use Information System developed by Prastacos for the Association of Bay Area Governments

2. CUFM: the California Urban Future Model developed at the Institute of Urban and Regional Development of the University of California at Berkeley

3. BOYCE: Combined models of location and travel choice developed by Boyce

4. KIM: the non-linear version of the urban equilibrium model developed earlier by Kim et al.

5. ITLUP: the DRAM-EMPAL Integrated Transportation and Land Use Package developed by Putman

6. HUDS: the Harvard Urban Development Simulation developed by Kain and Apgar

7. TRANUS: the transportation and land-use model developed by de la Barra

8. 5-LUT: The 5-Stage Land Use Transport Model developed by Martinez for Santiago de Chile

9. MEPLAN: the integrated modeling package developed by Marcial Echenique & Partners

10. LILT: the Leeds Integrated Land-Use/Transport Model developed by Mackett

11. IRPUD: the model of the Dortmund region developed by Wegener

12. RURBAN: the Ransom-Utility Urban Model developed by Miyamoto

In the most recent paper by Wegener, (1995) the following model is added to the above list:

13. METROSIM: the new microeconomic land-use transportation model by Anas

## I-4 Current Land Use Modeling Practice at MPO's

The most important comparison of operational models worldwide took place during the early 1980s to early 1990s. It was conducted by the International Study Group on Land Use Transportation Interaction (ISGLUTI). The group included modelers from the U.S., U.K., Germany, the Netherlands, Australia and Chile. They exchanged data sets and tested their models against a set of policy concerns selected collectively by the group. The results of these comparisons of the models with common data sets were contained in ISGLUTI publications and have been mentioned in various papers (Mackett, 1994 and Wegener, 1994 for example). Beyond the use of models in theoretical settings, Mackett (1994) describes two applied examples of land-use models in the British tradition to show their usefulness in policy analysis.

Mackett's first example is the use of modeling in congestion pricing. This is a new land-use model being developed by Marcial Echenique and Partners (author of MEPLAN) which is being linked to the London Transportation Studies (LTS) model, a conventional four-stage transportation model. Below the LTS model, there is an operational traffic simulation model used for localized studies. The second example is the use of the LILT (Leeds Integrated Land Use Transport) model to find trip distribution and modal split patterns allowing the choice of residence and employment to vary for some population sub-sets. The transit trip pattern was assigned to a transit network assessing location of stations and service frequency for an evaluation of a new rail route (see Mackett, 1994 for more detail).

The LILT model, as well as the Boyce model (Boyce, 1990) mentioned earlier, are combined equilibrium models of location and transportation.

The latest Survey of Land Use and Travel Data of the Metropolitan Planning Organizations of the 35 Largest U.S. Metropolitan Areas (Porter et al., 1995) contains information about land-use forecasting procedures and the use of land-use models. According to this survey:

Twelve MPO's are using DRAM-EMPAL models;

Five MPO's are using their own models (POLIS, PLUM, and three local models);

One MPO is in the process creating its own model; and

Two MPO's use the Delphi (exchange of expert opinion) Technique.

Fifteen agencies do not use land-use models but use qualitative procedures. This group allocates land use to Transportation Analysis Zones on the basis of forecasts of population and employment.

In all review papers and surveys regarding land-use models, it appears that DRAM-EMPAL is the most used model and has the highest number of installations among the MPO's. MEPLAN is used in numerous applications abroad. A third model, METROSIM, which embodies discrete choice modeling in a market clearing framework can be used as an equilibrium model of housing and land-use location. These three models are commercially available for agency use. For this reason, we are providing in-depth analyses of these three models. It should be noted that licensing and participation of model authors are necessary for their use.

### I-4-1 ITLUP: DRAM-EMPAL Models

The Integrated Land Use Transportation Package (ITLUP) of S. H. Putman Associates consists of two main sub-models, the Disaggregated Residential Allocation Model (DRAM) and the Employment Allocation Model (EMPAL). A third main program (CALIB) produces maximum likelihood parameter estimates for DRAM and EMPAL.

These models, as mentioned earlier, are Lowry derivative types using maximum entropy formulation. These models have been available since the early 1970s and have been incrementally improved over time. According to the author of the models, they are the "most widely applied models" (Putman, 1995) of their type. The models have been used by more than 20 public agencies for policy analysis. Putman states that currently there are 16 regional agencies which are licensed users of this modeling system.

DRAM is a singly-constrained residential allocation model which forecasts household location by household types (employed residents) in relation to employment locations in a future year and the probability of work trips between zones in the future year. The probability function has two distinct parts: transportation impedance (time or cost) and a measure of attractiveness of zones used for allocating households. Location of employment is defined either outside the model or by use of the EMPAL model to forecast location of employment. The travel cost is usually a two parameter gamma function and the attractiveness of the zones uses the following variables per zone for the base year:

1. Vacant, buildable land in origin zone
2. Percentage of buildable land which is already built
3. Residential land
4. Percentage of households in the lowest income quartile
5. Percentage of households in lower middle income quartile
6. Percentage of households in upper middle income quartile
7. Percentage of households in the upper income quartile

The attractiveness measure is a multiplicative power function of a Cobb-Douglas form. In most applications of the model, three-to-five household categories are considered. Assuming three parameters (vacant, buildable, residential) for the land component of the attractiveness measure and four income quartile parameters, in addition to the two-parameter travel cost modified Gamma function, there are nine parameters to be estimated for each income group. In case of a four-income quartile application, the number of independent parameters to be estimated will be thirty-six.

EMPAL is also a modified singly-constrained spatial interaction model for forecasting employment location by type in relation to an attractiveness measure and a lagged employment type. The attractiveness measure consists of an impedance matrix (travel time or cost) between zones, with population distribution in the base year and total area of zones in the forecast year. The model forecasts employment location for four to eight sectors.

There is one parameter for area size, one parameter for total employment and one parameter for weighing of the lagged employment. If the two parameters from the impedance matrix cost are added, there are five parameters per employment type to be estimated. In a four-employment type application, the number of independent parameters to be estimated is twenty. Employment types considered in the Washington, D.C. Metropolitan Area application of the model (Putman, 1983) were:

1. Finance, insurance, and real estate
2. Wholesale and retail trade
3. Manufacturing, transportation, communication and public utilities
4. Government

In Houston, four employment types were applied (Putman, 1990):

1. Industrial
2. Institutional
3. Office
4. Retail

In both of these applications of the model, four household types (Low-Income, Lower-Middle-Income, Upper-Middle-Income and High-Income quartiles) were used. There was no explicit economic variable used in the allocation of land uses such as price or land value. However a mix of income quartiles and the placement of industry-type in a zone, in a limited way, might be construed as an implicit consideration of land value.

Calibration of the model for different urban areas has shown that for the most part, the signs and magnitudes of model parameters remain within normal ranges.

CALIB is the automatic calibration program which is used to estimate the equation coefficients in both DRAM and EMPAL. This is one of the prominent features of the model system. Many land-use modeling efforts with other models could not be applied because the model system could not be calibrated properly. CALIB produces estimates of parameters in a systematic way, making it possible to compare values with those of similar regions as an additional degree of comfort for modeling and policy analysts.

In addition to maximum likelihood estimates of the equation coefficients, CALIB provides goodness-of-fit statistics, asymptotic t-tests of the statistical significance of the coefficients and point elasticities for sensitivity analysis. The procedure used for estimation of the parameters is a gradient search procedure. This automatic calibration program is an innovative feature of the ITLUP package which makes the modeling system unique among its rivals.

This land-use model was one of the models included in the ISGLUTI modeling comparison. (See page 13.)

The DRAM-EMPAL models are being extended into a new system called METROPILUS. This is an evolution of the DRAM-EMPAL package. According to Dr. Putman, the author of both models, it will combine employment and residence location, and land consumption in a single comprehensive package. The structure of the individual components will be based on logit, and where appropriate, nested logit formulation.

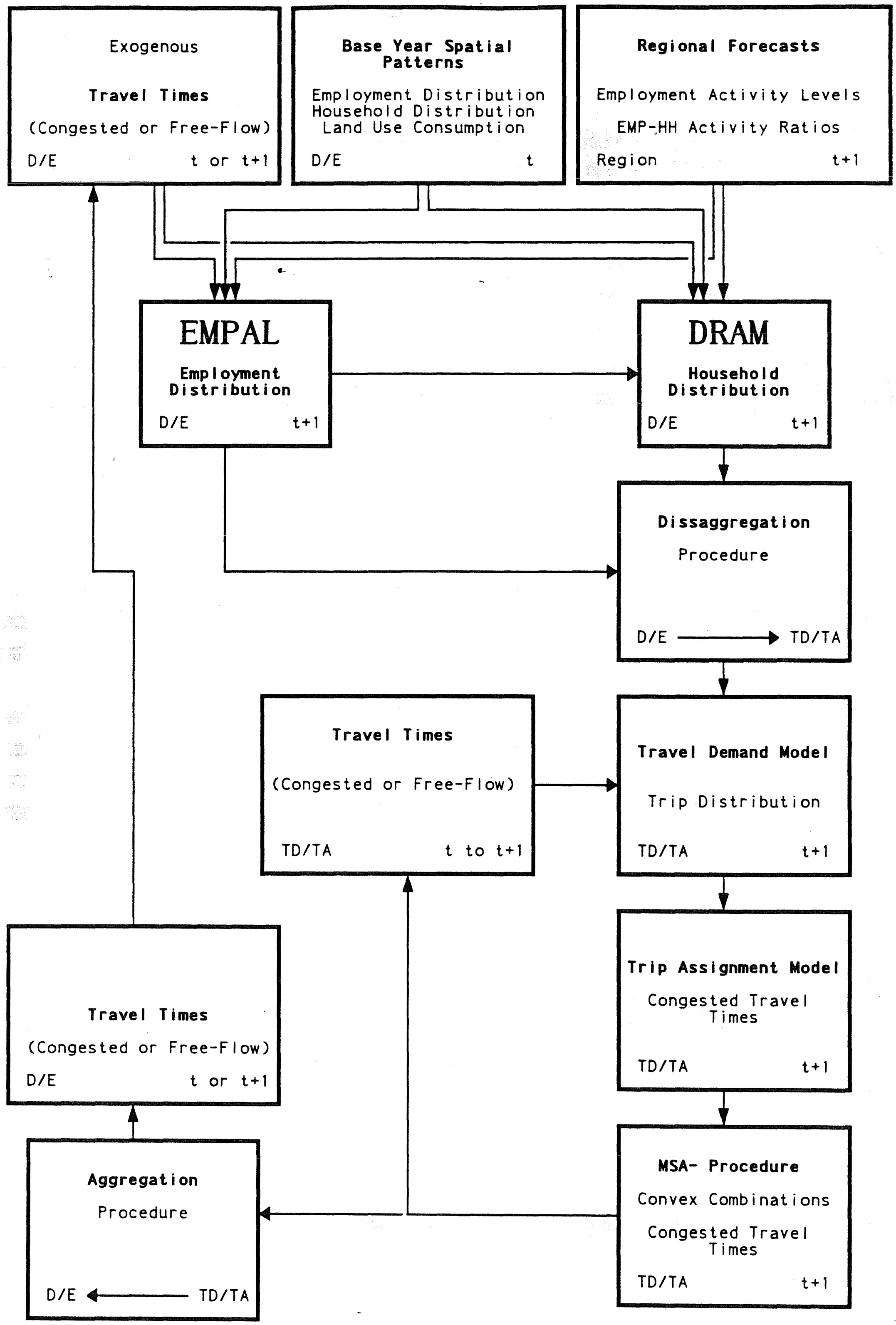
The model will use location surplus notion to arrive at a DRAM-type formulation. The addition of a lagged variable of households in DRAM to increase its reliability is one component of METROPILUS. Adding "land value" in the attractiveness measure of DRAM is also under consideration. This proposed "land value" will be relative house prices, possibly in the form of a multi-variate house index giving consideration to single and multi-family structures.

In terms of implementation, according to the author of the model, it will be made available in phases. First, a data platform was selected to facilitate model component relationships and access to a common database. ARCVIEW is the GIS-based data structure which current DRAM-EMPAL-CALIB will use to interact between model system components as well to access mapping and statistical routines. This ARCVIEW-based

DRAM-EMPAL package will be an intermediate product. METROPILUS will use this data structure and will reformulate DRAM and EMPAL with the location surplus notion as mentioned above. This will allow enhancement to component models without sacrificing un-affected routines and sub-models.

In terms of implementation, if this model is selected and if DVRPC approves, it should proceed with DRAM-EMPAL. As Dr. Putman stated, all DRAM-EMPAL licensees will be converted to METROPILUS through a seamless transition. Availability of METROPILUS is estimated to be one-year to eighteen months from the date of this report.

# Linked Models of Land Use - Transportation




t = time
D/E = DRAM/EMPAL Zone System
TD/TA= Trip Distribution/Trip Assignment Zone System

**Source: Equilibrium Condition in Land Use Travel Forecasting, March 1995, S. H. Putman Associates, Inc.**

### I-4-2 MEPLAN Model

The MEPLAN model of Echenique, as mentioned earlier, is a Lowry derivative model which was constructed using economic base theory. The model uses places of basic employment to calculate household locations and then calculates the service employment needed to serve these households. What differentiates this model from other Lowry derivatives is the way the land-use module or, as its author puts it, the economic module, operates (Echenique, 1994). The economic module incorporates three economic concepts, i.e. input-output model, price function and random utility.

MEPLAN consists of three main modules (Echenique, 1994) with an evaluation module as a fourth module (Making the Land Use Transportation Air Quality Connection, Modeling Practices, Vol. 1, 1991, p. 28). These are: LUS, the regional/urban land use - economic module which estimates the demand for inputs for basic production in zones following Lowry reasoning; FRED, the interface module which converts flows from production and consumption points (zones) into flows of goods and people; and these are allocated to modes and routes by TAS, the freight/passenger transportation module. Several iterations of the model system are required to balance the land-use and transportation modules with feedback in the form of costs (prices and congestion). The additional fourth module, EVAL provides evaluation of land use and transportation effects through cost-benefit analyses of a particular policy versus a base case (Williams, 1994).

An input-output model is applied to represent flows between activities in the form of demand for space. The coefficients of the input-output model are used to calculate prices in an elastic form to represent land allocation within zones. Random utility is used to represent an explicit spatial system where households and firms decide where to live and locate in a utility maximization or a cost minimization framework within specified constraints. This allows market land prices be considered in the model explicitly. On the same basis, the price of transportation might be formulated in terms of time penalties representing congestion.

MEPLAN and its close parallel TRANUS (TRANsporte Uso del Suelo) of de la Barra (Wegener 1995, p. 20) have evolved from the early 1970s application of a floor space model within a Lowry-Wilson framework to the city of Reading, U.K. (see Echenique, 1994). The model uses land prices to balance supply and demand for land consumption in zones. These models "focus directly on competition and resulting rents as a means to confront available supply of land with the various demands of the different activities. This increases the potential power of the models, but at the cost of a high burden of data need and computational difficulty." (Making the Land Use Transportation Air Quality Connection, Modeling Practices, Vol. 1, 1991, p. 13).

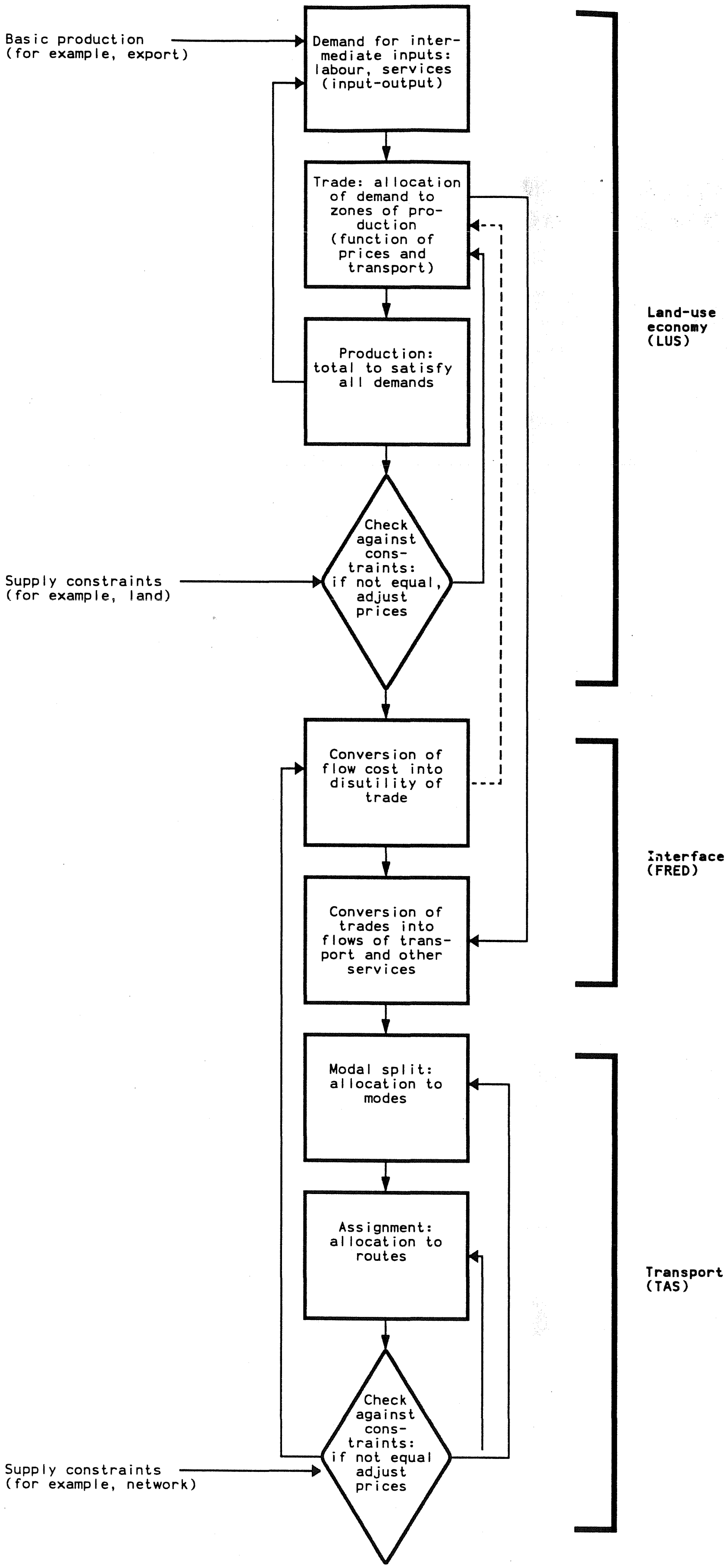
The solution mechanisms of the model are based on market mechanisms. "Supply and demand in this model are linked by land price. On the transport side, supply and demand are linked by time/congestion. Activity demand affects transportation demand;

transportation supply affects land supply through accessibility" (Travel Model Improvement Program, USDOT Conference Proceedings, 1995, p. 90).

In addition to the application of the model in Reading mentioned above, various versions of the model are used in the cities of Cambridge and Stevenage in the U.K. (near London); Santiago, Chile; Sao Paulo, Brazil; Tehran, Iran; and Bilbao, Spain. Its most recent application has been for the South East England Region. The model has been used to analyze the land use and transportation impacts of the introduction of a new domestic service along the Channel Tunnel rail link to London. It was also used to analyze the influence of future strategic transport infrastructure investments on demand for locations by firms and households within the area. The transport component of the model was used as a starting point in the creation of a specialized model for the assessment of congestion pricing (for more detail see Williams, 1994).

MEPLAN was also one of the models evaluated in the ISGLUTI modeling comparison.

# MEPLAN MODEL




**Typical operartion of the MEPLAN model in a given time period**

Source: "Urban and Regional Studies at the Martine Centre", M. Echenique, 1994

### I-4-3 METROSIM Model

The METROSIM model of Anas, as we mentioned in section I-2-4, takes an economic approach to modeling housing and land-use location. The model embodies the discrete choice method with economically specified behavior and a market clearing mechanism. This model has evolved since the early 1980s. According to the author of the models, these efforts were:

1. CATLAS developed and applied to the Chicago area in the period 1981-1985. This model includes residential location, housing and mode choice submodels.

2. NYSIM developed and applied to the New York Region during 1990-1993, extended CATLAS by including non-work travel choices and commercial real estate markets.

3. CPHMM which is a dynamic prototype model of the housing market developed and applied by the Chicago, Houston, Pittsburgh and San Diego MPO's between 1987 and 1993.

The solution approach of METROSIM considers the direct and indirect effects of land use and transportation systems in simultaneous determinations of land use and transportation costs.

There is no separate calibration program for the model because it uses macro-economics as the underpinning of the model. However, the author claims that well-established econometric techniques can be used to calibrate and estimate the model.

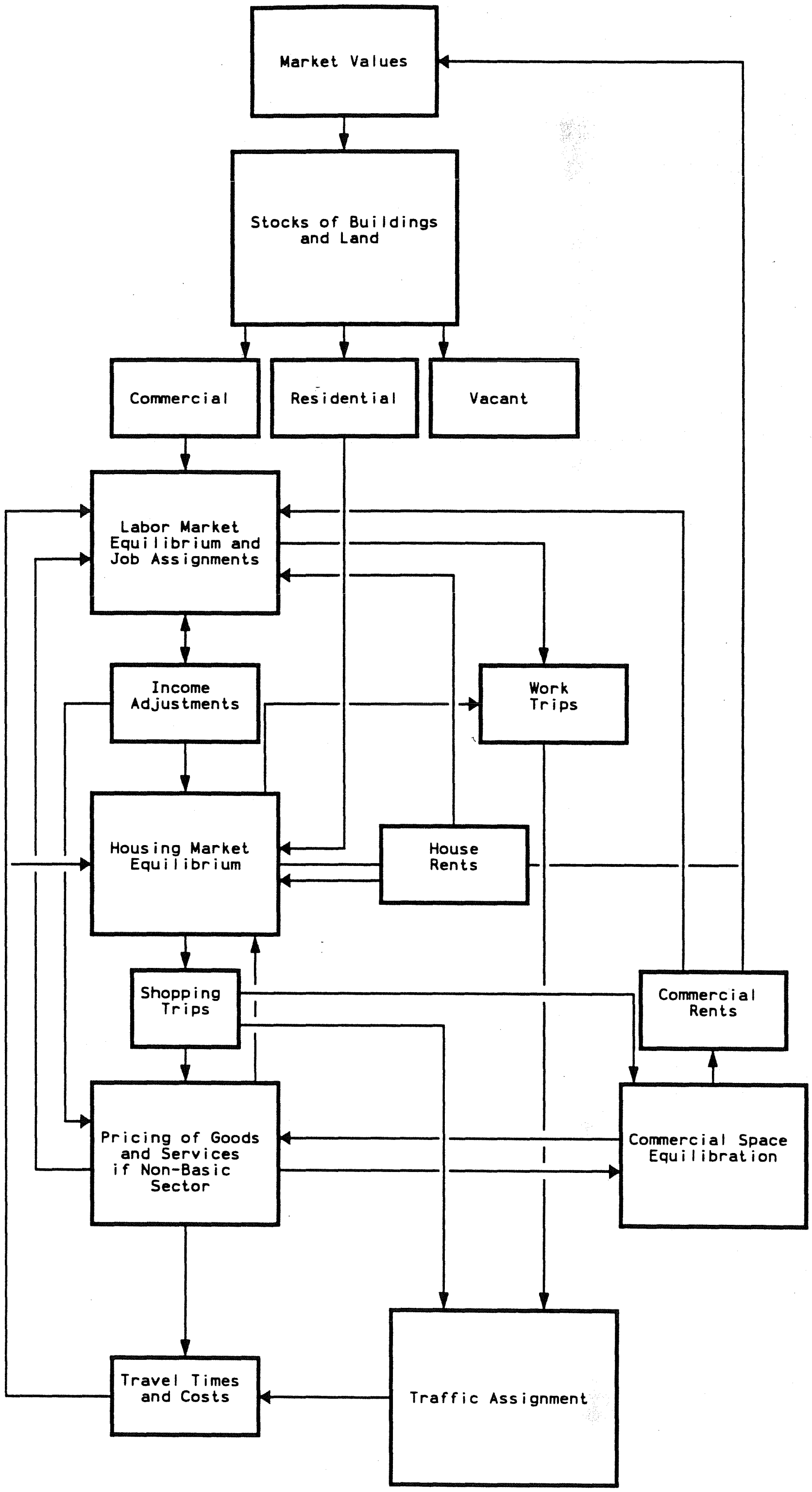
The model is formulated in three market equilibria: 1) labor market equilibration and job assignment, 2) housing market equilibrium and 3) commercial space equilibrium. The model iterates between these markets and the transportation system for equilibrium of land-use pattern and transportation flows. A generalized impedance function of time and cost can be used in the model system. These equilibria markets are defined through the following seven sub-models or sectors:

1) Basic industry
2) Non-basic industry
3) Real estate (residential and commercial)
4) Vacant land
5) Household
6) Travel demand for commuting and non-work travel
7) Traffic assignment

Although the model has its own assignment routine using stochastic assignment, in principle it can be linked to any transportation package in an iterative form. The model, in its NYSIM form is used for New York region but METROSIM has not yet been applied to any other MPO's.

The model system is written in FORTRAN and the participation of its author is necessary for its use. The relationship between the model system's submodels is shown in the following flow chart.

## Links and Feedbacks Among METROSIM Modules




Source: Alex Anas, Model Documentation

# II. LAND USE MODEL EXPERIENCES

## II-1 Land Use Model Experiences in Florida

### II-1-1 Tampa Bay Region Model (Resource System Group)

Resource System Group (RSG) has been involved in the application of a land-use model for the Tampa Bay region. The model structure closely follows the Lowry-Putman formulation but uses a nested logit formulation for calculating accessibility. The model is capable of using a composite multimodal impedance rather than a highway-based function. These types of improvements were first implemented for Seattle's DRAM/EMPAL model by Tim Watterson for the Puget Sound Council of Governments (Short-Term Travel Model Improvements, 1994, p. 3-3).

The framework of the RSG model is a five-step land-use transportation model with the first four steps being the traditional transportation model and the fifth step, the land-use model. This is used in a sequential format, meaning that output from the transportation model is fed to the land-use model through a manual method. The land-use model takes the congested travel time from the assignment step of the transportation model for the first approximation of land-use patterns.

Unlike the DRAM-EMPAL model, the RSG model does not have an automatic calibration program like CALIB. In addition, since it is a newer model, it does not yet have a large user group sharing experiences. Two other applications of the model have been in the Pease/Seacoast region of New Hampshire and the Chittenden County Regional Planning Commission in Vermont. No calibration results or outputs of these studies were available so that we cannot comment on the quality of the model (for a discussion of the model structure and parameter estimation see Marshal, 1993).

The RSG model is written in "C" language and participation of RSG is required in its implementation.

### II-1-2 Orlando Urban Area Metropolitan Model (S. H. Putman Associates)

DRAM and EMPAL models were applied to the Orlando Metropolitan Region, on the basis of data provided by the Orlando Area MPO, JHK & Associates and Real Estate Research Consultants (Putman, May 1995). The region consists of 207 regional zones for the DRAM-EMPAL application. DRAM uses four income quartiles for households and EMPAL uses three employment groups (services, industrial and commercial) roughly corresponding to regional land-use definitions. Data for 1985 were used as the "lagged" year and 1990 as the "current" year.

The calibration results for DRAM have been successful with the model being capable of capturing more than 85% of the variation in land use. Except for employment services, EMPAL calibration has not been successful. On the basis of the model's use in other regions, the author of the model attributes this difficulty to inconsistencies in the employment data sets for 1985, 1990 or both. Efforts to clean the database have not resulted in a significant improvement in the calibration so far. As the author of the model suggests (Putman, 1995, p. 26), use of the KFAC program is necessary to modify the attractiveness of those zones which have high proportion of unexplained residual.

The model system is being installed by the Orlando region's MPO. Local planners are being trained to use it and to satisfy the possible need for additional work on data, validation and recalibration of the model.

DRAM-EMPAL is written in FORTRAN and participation of the author or a licensing arrangement is required for implementation of the model.

## II-2 Telephone Interview with MPO's using DRAM-EMPAL

The DRAM-EMPAL model is used by 12 MPO's among the 18 agencies using land-use models. Therefore, it was decided to interview DRAM-EMPAL user agencies about their experiences with this modeling system. We selected six agencies at random (sample size of 50%). These were:

1. Atlanta Regional Commission
2. Northeast Illinois Planning Commission (Chicago)
3. North Central Texas Council of Governments (Dallas)
4. Houston-Galveston Area Council of Governments (Houston)
5. Southern California Association of Governments (Los Angeles)
6. Sacramento Area Council of Governments (Sacramento)

Telephone interviews were made with the above MPO's except for Los Angeles which has not responded despite repeated requests. The interviews of the five MPO's are summarized below and the details are presented in Appendix A of this report.

**Calibration and Forecast years**: All five MPO's used 1985 and 1990 as the calibration years. In addition, Dallas intends to perform another calibration in 1997 on the basis of 1990-1995 data sets.

The forecast period is 1990-2020 with five year intervals. Sacramento, which is in the process of completing calibration, has not yet begun forecasting.

**Land Use Zone System**: In terms of the number of Regional Analysis Zones (RAZ) used for the DRAM-EMPAL models, Sacramento has the smallest number with 127 in a four-county model. Atlanta has 417 RAZ in a ten-county model; and, Dallas intends to use the model in an 800 RAZ system.

**Transportation Zone System and Software**: Atlanta has the smallest number of traffic analysis zones with 960 zones in a nine-county model. However, this MPO will be adding counties. The highest number of TAZ belongs to Dallas with 8,000 TAZ. It should be noted that the Chicago model works on a 15,000-zone system called split-zone.

Atlanta is using TRANPLAN as the transportation modeling software. Chicago, Dallas and Houston are using their own developed software systems. However, Dallas is using TRANPLAN for additional analyses and Houston is in the process of converting to EMME/2 software. Sacramento is using MINUTP software.

**Household Categories**: Two MPO's are using four-quartile income groups while two MPO's are using five income groups. Only Chicago is using eight income octaves.

**Employment Categories**: Dallas is using five categories of employment. Chicago, Houston and Sacramento are using six categories of employment and Atlanta is using eight categories, the maximum that DRAM-EMPAL is currently capable of handling. These employment categories are based primarily on the two-digit Standard Industrial Classification system (SIC) but Houston uses its own classification on the basis of trip length characteristics.

**Control Numbers**: Four MPO's use regional econometric models of their own, or Bureau of Economic Analysis estimates, or use estimates of such models as the WEFA-DRI type model for forecasts of future employment and population. The employment location file used most frequently is the Employment Insurance file (ES202) augmented by field visits, telephone book searches and windshield surveys or actual surveys of sites with more than 400-employees (Dallas). It appears that those agencies which have devoted resources to employment data verification are more likely to be satisfied with model forecasts.

Land-use data provided by aerial photography can be augmented by the assessor's land data file. These sources are verified by site visits to sample locations. Most of these MPO's use ARC-INFO to maintain land-use data.

**Review Process**: A majority of the MPO's use a review process for the forecasts generated by the model. Atlanta previously was doing reviews of every five-year interval of the model output. This proved to be a time-consuming and difficult task. Now the final forecast year is sent to the participating agencies for review and comment.

Planning judgment is used to modify some of the projections. This process is mostly a zero-sum game for localities affected. Chicago and Sacramento have not put a review process in place since they are in the calibration-implementation phase of their models.

**Use of Forecasts**: In addition to long range plans, the models are used for impact assessment. Forecasts of the model are also used by city planning departments, highway and transit planning agencies, airport authorities, water and sewage boards, private developers and coastal zone management entities. In Chicago, the model might be used to settle a dispute concerning the proposed location of a new airport.

**Computer System**: Most of the installation platforms for the models are PC-based although the model can be used under UNIX and IBM mainframe systems.

**Model Selection Process**: No formal model selection process has been established. Most MPO's have selected the model on the basis of its being the only available operational model at the time of selection. In Atlanta, DRAM-EMPAL replaced EMPIRIC when the use of EMPIRIC's outputs for transportation planning became an issue. Implicit approval of DRAM-EMPAL by the Federal Highway Administration (FHWA) and Environmental Protection Agency (EPA) has also been a factor in model selection.

**Implementation and Application Issues**: Although there is need for improvement in the DRAM-EMPAL model, the users are satisfied with the model; except for one MPO which is actively looking for a replacement. It is the consensus opinion that instead of starting a new model altogether, efforts should be made by the author of the model as well as the user community to enhance the model system. Those MPO's who are satisfied with the model attribute their success not only to the model system but also to their own efforts, especially in providing a sound employment location database.

# III. DESIRED CHARACTERISTICS OF THE LAND USE MODEL FOR DVRPC

Nearly all of the models discussed in this report are flexible in their data requirements and in the arrangements which can be made for their use. Reports on the models from numerous sources (Echenique, Wegener, ISGLUTI, and in the interviews of this report) show a wide variation in use even among presumably identical models like DRAM-EMPAL.

Agency resources and preferences are more determinative of their models than are the models themselves. There are numerous decisions, many of them based on trade-offs, which any agency must consider. A good approach would be for an agency to define a tentative set of its requirements, and request suppliers to provide an estimate of the monetary, staff, and data costs of meeting these requirements. The suppliers should also be asked to describe the operating characteristics which result from these requirements and their interactions. The following is a partial list of the requirements and some of their implications:

Turn around time for model applications

Machine type and capacity

Number of zones for land-use and transportation modeling –
- Large numbers of zones greatly increase running time
- Disparate numbers may call for hard conversions

Basis for zone definitions –
- Disparate bases make for very difficult conversions
- Non-census bases make data preparation very difficult

Disaggregate employment analysis depends on local sources –
- Generally disaggregation is desirable, but is limited by costs, availability, and running time. Too little disaggregation will undermine accuracy and policy relevance.

Data transfer between models

Comparisons between models may be possible based on the agency's list of desired features, and supplier estimates of cost and running times. However, an actual competitive test would be preferred.

Using the above considerations, it is essential that the DVRPC model benefits from the experiences of other MPO's with existing operational land-use models. It also essential that DVRPC benefits from existing users of the model in data preparation, types of possible applications and desired applications. At the same time, improvement to the model system should be possible as more advanced component modules become available.

We propose a two-step selection and implementation phase: short-term and long-term.

Given that the DRAM-EMPAL is the model applied most often in U.S. and MEPLAN is the most used model abroad, we recommend that limited versions of both models be acquired for testing of prototype use, policy analysis and impact assessments. A third model, METROSIM, which is a newer model with a micro-economic basis should also be tested as representative of economically based models which are not yet applied. After limited-versions of these three models are acquired, a battery of tests should be made to enable the objective selection of a model for the short-term needs of the DVRPC based on ease of use, response to policy concerns and fulfillment of immediate needs.

The availability and cost of limited version models will be assembled by URS. Policies to be tested and the preparation of data for such analyses will be prepared by DVRPC. With a new scope of services from DVRPC, URS would conduct the tests. Matching funds financing might be available from FHWA.

For long-term needs, the model system should be modular to allow the insertion of better component modules as they become available. We recommend that DVRPC work with the author of the selected model in the development of new routines and enhancements for mid-term and long-term needs.

DVRPC should also have the capability of using staff resources or independent model builders to enhance its models for long term needs.

# IV DRAM-EMPAL DATA AND COST REQUIREMENTS

## IV-1 DRAM-EMPAL Data Requirements

To fulfill our contractual requirements with DVRPC, we defined the DRAM-EMPAL data needs and estimated the cost of its implementation at DVRPC. The DRAM-EMPAL is the model applied most frequently by U.S. MPO's as of this writing. It is fully operational and is a less data-intensive model when compared to the other two models. The experience of other MPO's with model calibration and policy tests can be utilized by DVRPC. However, since DRAM-EMPAL does not use specific economic variables in a systematic form in its market-clearing mechanism, its forecasts can be questioned by "pure" theorists. With these considerations, data requirements and cost estimates for implementation, policy analysis and implementation of the model is summarized below. A data requirement and software license cost estimate was prepared in consultation with Dr. Putman. Independent consultant costs and the equivalent of cost of DVRPC staff time were prepared by URS and updated by DVRPC.

These data items are desired at the Traffic Analysis Zone (TAZ) level. The availability of such data at Regional Analysis Zone (RAZ) is required.

1. Dr. Putman recommends using eight categories of employment corresponding roughly to the two-digit SIC system. The data should be complete for each RAZ. A range of 300400 RAZ is appropriate for the DVRPC land-use model. The 352 Minor Civil Division (MCD) seems appropriate but Philadelphia as one MCD needs to be disaggregated. In addition, all large MCD's should be divided into smaller MCD's. The final zone system will be dealt with in the implementation phase.

    a. Construction
    b. Manufacturing
    c. Transportation, Communications, and Public Utilities
    d. Wholesale Trade
    e. Retail Trade
    f. Finance, Insurance, and Real Estate (Fire)
    g. Service (also including agriculture, forestry, and mining)
    h. Government (public administration)

2. Household type: Four to eight household groups should be considered. The final selection will be specified in the implementation phase after conducting some preliminary statistical tests of household data. The data should be per RAZ. We might start with:

    a. Low-income
    b. Low-middle income
    c. Middle-income

d. Hi- middle-income
e. High-income

3. Land-use data per RAZ:

a. Residential land
b. Commercial land
c. Industrial land
d. Vacant, buildable land
e. Total land
f. Percentage of single and multi-family structures for possible DRAM-EMPAL enhancement

4. Impedance matrix in the form of TAZ zone-to-zone highway travel time, or a composite matrix of highway and transit time. This matrix will come from a transportation model. Any transportation package capable of creating zone-to-zone impedance in a standard ASCII form can be used with DRAM-EMPAL. Direct interface with TRANPLAN and EMME/2 is being developed and will be tested soon. This interface directly reads TRANPLAN and EMME/2 impedance matrices. Aggregation/disaggregation methodology will be decided by DVRPC, Dr. Putman and the independent consultant in the implementation phase.

The above data should be prepared for two time periods: 1990 and 1995. Year 1990 will be used for calibration and year 1995 for validation of the model.

Control totals should be prepared for year 2020 with five-year intervals from 1995 throughout the forecast period.

These control totals are:

a. Total projected households
b. Employment totals for each eight categories
c. Employment to household ratio.

This data can be projected based on the use of Public Use Microdata Sample (PUMS). This methodology was developed by Dr. Putman and will be used in the implementation phase.

## IV-2 Estimated Cost of the DRAM-EMPAL Model Implementation

1. License fee: with one year implementation support, including data preparation, preliminary calibration and model walk-throughs, the license fee is $50,000. The time frame is usually one year to eighteen months. After this implementation phase an additional 90 days of telephone support will be provided.

    License fee cost: $50,000

2. A successful implementation requires that one senior modeler and one junior staff be involved throughout. This staff can be from the data services department and should have familiarity with available data. The assumed DVRPC staff costs are $60,000 + $35,000 = $95,000 plus fringe benefits. Assuming a 2.5 multiplier, the equivalent cost becomes $237,500.

    DVRPC staff equivalent time = $95,000 x 2.5 = $237,500

3. Independent consultant (URS) to oversee the process (1/4 of an expert's time):

    $80,000 x 0.25 x 2.50 = $50,000

4. Contingency programming cost: $10,000

## IV-3 Policy Analysis and Maintenance of the DRAM-EMPAL Model

1. During the policy analysis phase and for maintenance of the model,0.5 person-year of a senior modeler is needed. An additional 0.25 person-year of a senior modeler is required for dissemination and review of model outputs. An additional half a junior staff person is required for policy testing.

    DVRPC 0.75 Senior modeler x $60,000 x 2.5 = $112,500
    DVRPC 0.5 Junior staff x $35,000 x 2.5 = $43,750

2. Independent consultant (URS) to oversee the process, 1/8 year person expert:

    $80,000 x 1/8 x 2.5 = $25,000

3. Yearly maintenance cost: To receive additional telephone support, DVRPC should have a site maintenance agreement with Dr. Putman. The current maintenance cost is $5,000 per year.

    Yearly software model maintenance cost: $5,000.

## IV-4 DRAM-EMPAL Model Cost Summary

Implementation:

License fee $50,000
DVRPC staff equivalent cost: $237,500
Independent consultant: $50,000

Sub-total = $337,500

Policy analysis and maintenance phase per year:

DVRPC staff equivalent cost: $112,500 + $43,750 = $156,250
Independent Consultant cost: $25,000
Contingency programming cost: $10,000

Yearly model software maintenance cost: $5,000

Sub-total: $196,250

Total cost: Implementation + one year of policy-maintenance cost =

$337,500 + $196,250 = $533,750 or about $600,000

The breakdown of the cost is about $460,000 for DVRPC staff equivalent time and $140,000 for software licence, yearly maintenance and independent consultant cost.

**References:**

Making the Land Use Transportation/Air Quality Connection, Volume 1, October 1991 prepared for the Organization of 1000 Friends of Oregon, Cambridge Systematic, Inc. with Hague Consulting Group

Short-Term Travel Model Improvements, Travel Model Improvement Program, October 1994, U.S. Department of Transportation, U.S. Environmental Protection Agency

Travel Model Improvement Program: Land Use Modeling Conference Proceedings, 1995, U.S. Department of Transportation, U.S. Environmental Protection Agency

Boyce, David E., 1986, "Integration of Supply and Demand Models in Transportation and Location: Problem Formulation and Research Questions," Environment and Planning A, Vol. 18, pp. 485-89

Boyce, David E., 1990, "Network Equilibrium Models of Urban Location and Travel Choices: New Research Agenda," New Frontiers in Regional Science. Essays in Honor of Walter Isard, edited by Manas Chatterji and Robert E. Kuenne, Macmillan, London, Vol 1, pp. 238-56.

Echenique, Marcial H., 1994, "Urban and Regional Studies at the Martine Centre: Its Origin, Its Present, Its Future", Environment and Planning B: Planning and Design 1994, Volume 21, pp. 157-533

Lowry, I. S., 1964, A Model Of Metropolis, Rand Corporation, Santa Monica, California, in S. H. Putman, Urban Residential Location Models, Martinus Nijhoff Publishing, 1979

Mackett, Roger, 1994, "Land Use Transportation Models for Policy Analysis," Issues in Land Use and Transportation Planning, Models and Applications, Transportation Research Record No. 1466, Transportation Research Board, 1994

Mann, William W., P. E., 1995, "Land Use/ Transportation Integrated Model: LUTRIM," TRB Paper No. 950158

McFadden, Daniel, 1973, "Conditional Logit Analysis and Quantitative Choice Behavior," in Frontier in Econometrics, Paul Zarembka, ed., Academic Press, New York, 105-142

Marshal, Norman L., Lawe, Stephen J. C., 1993 "Land Use Allocation Models for Multi-County Urban and Suburban Areas", Resource Systems Group, 4th National Conference on Transportation Planning Methods Applications, Daytona Beach, Florida

Oryani, Kazem, 1987, Performance of Behavioral Land-Use Transportation Models and Optimization Land Use Models, Ph.D. Dissertation, Department of City and Regional Planning, University of Pennsylvania

Porter, Chris; Melendy, Laura; and Deakin, Elizabeth, 1995, Land Use and Travel Survey Data: A Survey of the Metropolitan Planning Organizations of the 35 Largest U.S. Metropolitan Areas, Institute of Urban and Regional Development, University of California at Berkeley, Berkeley, CA

Putman, S. H., 1979, Urban Residential Location Models, Martinus Nijhoff Publishing

Putman, S. H., 1983, Integrated Urban Models, Policy Analysis of Transportation and Land Use, Pion Limited, London

Putman S. H., 1991, Integrated Urban Models 2: New Research and Application of Optimization and Dynamics, Pion Limited, London

Putman, S. H., 1995, "EMPAL and DRAM Location and Land Use Models: A Technical Overview," Urban Simulation Laboratory, Department of City and Regional Planning, University of Pennsylvania, Land Use Modeling Conference Proceedings, Dallas, TX

Putman, S. H., 1995, "EMPAL and DRAM Preliminary Model Calibration Results for The Orlando Metropolitan Region," S. H. Putman Associates

Wegener, M., 1994, "Operational Urban Models: State of the Art," Journal of American Planning Association, Vol. 60, No.1, Winter 1994, pp 17-29

Wegener, M., 1995 "Current and Future Land Use Models," Travel Model Improvement Program: Land Use Modeling Conference Proceedings, pp. 13-40, U.S. Department of Transportation, U.S. Environmental Protection Agency

Williams, I. N., 1994, "A Model of London and The South East," Environment and Planning B: Planning and Design, Volume 21, pp. 535-553

Wilson, A. G., 1967, "A Statistical Theory of Spatial Distribution Models," Transportation Research, Vol. 1, pp. 253-269

Wilson, A. G., 1970, "Advance and Problems in Distribution Modeling," Transportation Research, Vol. 4, pp. 1-18

Wilson, A. G., 1971, "A Family of Spatial Interaction Models and Associated Developments," Environment and Planning, Vol. 3, pp. 1-32

# APPENDIX A

## Telephone Interviews with MPO's Using DRAM-EMPAL

**MPO Land Use Model Telephone Interview**

**MPO**: Atlanta Regional Commission (Atlanta)

**Date**: January 25, 1995

**Person Interviewed**: Mr. Bart Lewis, Chief Socioeconomic Analysis Division, (404) 364-2540

**Additional Contact**: Dick Courkney

**Agency Phone Number**: (404) 364-2500

**Land Use Model**: DRAM-EMPAL

**Calibration and Forecast years**: 1985 and 1990 with 1985 being used as lagged year for 1990 DRAM calibration. They used lag variables in order to capture the dynamics of high activity growth areas. The forecast year is 2020 with 5-year intervals starting from 1990.

**Zone System**: 417 Census tract zones for a 10-county model. It is being expanded to a 13- county model with up to 500 zones.

**Transportation Model**: TRANPLAN, seven-county model with about 960 zones. The MPO is also expanding the transportation model to cover a 10- to 13-county system.

**Households**: Used census intervals of less than $20,000, $20,001-$40,000, $40,001-$60,000, $60,001 and more.

**Employment Categories**: Eight categories, the maximum that DRAM-EMPAL is currently capable of handling. These were based on the two-digit SIC system.

1. Construction
2. Manufacturing
3. Transportation, Communications, and Public utilities (TCP)
4. Wholesale trade
5. Retail trade,
6. Finance, Insurance, and Real Estate (FIRE)
7. Services (also included agriculture, forestry, and mining)
8. Government (public administration).

**Control Numbers**: They used the Interactive Population-Economic forecast System (IPES) which was created in San Diego about twenty years ago with a consultant's help. It is a cohort survival population model with simple econometric components to estimate migration of the work force. The regional forecast is based on Bureau of Economic

Analysis (BEA) numbers for major employment sites. Employment insurance data, ES202, created at state and county levels is then broken down to the census tract level.

Land use data are provided by aerial photography and digital land cover files. The MPO has updated the digital file every five years with the help of local planning staffs. Land ownership records have helped in designating land to be developable or to be considered vacant land for future years. Land belonging to a religious body or to a local government was rated to be kept vacant rather than to be developed. The data are kept in the GIS system using ARC-INFO. SPSS is used for regression analysis and Excel as a general tool for calculations.

**Review Process**: Previously a review process was performed, but getting a consensus on five-year interval forecasts of population and employment was difficult. Now the final forecast is shared with participating agencies with outside model adjustments for some developments which might have a less-likely chance of being done. In these adjustments, the MPO differentiates between trend analysis and policy forecasting which is more judgmental.

**Use of Forecasts**: The commission's projections are used by various agencies such as rapid transit, water and sewage departments and city planning departments. Data are in published form, in an electronic data file and currently on CD-ROM. These forecasts were updated every 10 years. With EPA and ISTEA requirements still un-announced, the MPO might update data more frequently.

**Computer System and Software**: MVS VAX system for transportation model but PC-based system for DRAM-EMPAL.

**Selection Process**: They used EMPIRIC in the 1980s. In the 1990s they found that with their expanded transportation requirements, EMPIRIC cannot produce the desired outputs. DRAM-EMPAL was selected because it was the only model with more than one application site with which the agency could share experiences. FHWA approval of the DRAM-EMPAL model was also a deciding point for this selection. Knowing the author of the model personally was also an added factor in selecting DRAM-EMPAL.

**Implementation and Application Issues**: The MPO does not favor the way the population to household conversion is now being done. The MPO would like to be able to differentiate between those households seeking a low density development and these households which are likely to select a high density development on the basis of their income level. The MPO cautioned that if residential land consumption is kept at the same ratio as in the base year, there might be no more land to be allocated in particular zones.

If DVRPC uses the ES202 data source for employment location, caution should be taken because the possibility exists for mis-allocations for some zones. Data can be improved through secondary sources such as telephone book searches, newspaper articles and site visits to work places.

The MPO is happy with DRAM-EMPAL because the output reflects good employment data provided to the model. It has taken more than two years of research to provide employment location on a small-area basis, i.e., census tracts. Dr. Putman has been concerned that data at that level of detail might be too homogeneous to show much variation. However, they found that the model produces useful results using such data along with a composite impedance of transit and auto travel time.

**MPO Land Use Model Telephone Interview**

**MPO**: Northeast Illinois Planning Commission (Chicago)

**Date**: January 31, 1996

**Person Interviewed**: Max Dieber

**Agency Phone Number**: (312) 454-0400

**Land Use Model**: DRAM-EMPAL

**Calibration and Forecast Years**: Calibration years were 1985 and 1990. MPO has also calibrated the model using 1980-1985 data with 1990 used as the validation year. The forecast years were 1995-2020 with five year intervals.

The transportation model was created by the Chicago Area Transportation Study (CATS).

**Zone System**: 317 regional analysis zones in a six-county model. Each RAZ is about 12 square miles. The model area is then split into 15,000 zones.

**Transportation Model**: David E. Boyce's sketch planning model of combined transport and location. The regional allocation sub-model is 1,600 zones while the transportation model uses a 15,000 zone system.

**Households**: Eight household income octave

**Employment Categories**: Six employment categories:

Manufacturing
Retail
Finance, Insurance, Real Estate
Wholesale trade plus Transportation, Communication and Public Utilities
Government Institutions
Other categories, mostly construction

**Control Numbers**: Through the development of an input-output model by the University of Illinois and Federal Reserve Bank of Chicago, they have formed a Regional Economic Application Laboratory. It uses cohort analysis to estimate the needed migration to fulfill the employment need specified by the input-output model. The laboratory uses age-specific ranges for labor participation rates.

A 1990 land use inventory was based on aerial photos. It used 46 categories of land use types. Sites were sampled to confirm land use types recognized from the aerial photos. The MPO has used ES202 employment data sets supplemented with site work.

**Review Process**: Not implemented yet but it will be on the basis of a consensus building approach.

**Use of Forecasts**: The MPO intends to use the model as a tool for impact assessment rather than just as a forecasting tool. The model might play a role in assessment of the new proposed airport for the Chicago area whose location and approval are being disputed.

**Computer System and Software**: DRAM-EMPAL is run on a PC system. The Boyce combined model is installed on a UNIX workstation.

**Selection Process**: Selection was based on wide use of the model by others. The consensus among the user group community was to take the DRAM-EMPAL model and improve it over time rather than replace it with a new model.

**Implementation and Application Issues**: Any model, in the context of transportation, needs to be brought in, played with and be seen as a tool for forecasting. Having feedback between transportation and land use has become very important especially in the non-attainment areas.

**MPO Land Use Model Telephone Interview**

**MPO**: North Central Texas Council of Governments (Dallas)

**Date**: January 24, 1996

**Person Interviewed**: Lyssa Genkens, Manager of Research, (817) 695-9154

**Additional Contact** Ken Sevenka, Head of the Modeling Group

**Agency Phone Number:** 1-817-640-3300; 1-800-272-3921

**Land Use Model**: DRAM-EMPAL

**Calibration and Forecast years**: Calibration was performed for 1989 by agency staff. Another calibration on the basis of the 1990 Census was made with the help of Dr. Putman in 1994. The MPO intends to perform another calibration for 1997.

Forecast periods were 1995-2010 for the 1989 calibration and 1995-2020 for the 1994 and proposed 1997 calibrations.

**Zone System**: 191 districts based on census tracts for the nine-county region. An 8,000-zone (TAZ) called split-TAZ was used in the transportation model.

**Transportation Model**: Customized: North-Central Texas Model. The MPO also used TRANPLAN routines for additional analysis.

The configuration between the land use and transportation models is sequential, meaning outputs from DRAM-EMPAL are passed to the transportation model, and vice-versa, manually. The MPO has plans for a linked model with the 1997 calibration. One reason for this manual linkage is that when the MPO used congested times from 8,000 zones for DRAM, the distribution did not change. Now the MPO wants to expand an 191 zone system to 800 zones to see whether a macro level of detail helps the distribution of activities using congested travel time.

**Households**: Four quartiles. The MPO used a 1994 estimate based on 1990 census data.

**Employment Categories**: Five employment categories:

1. Mining-Manufacturing (less than SIC 40 except for construction and agriculture)
2. Wholesale trade, transportation, construction (SIC 40-51)
3. Retail-trade (SIC 52-59)
4. Service (SIC 60-89) except for education
5. Government (SIC 90) and education

The MPO has surveyed employment data for firms with more than 400 employees (100% sample). Commercial development is monitored for projects larger than 100,000 square feet. In sparsely-developed counties, the monitoring is done for development above a 50,000 square foot threshold.

The base year land use data is from aerial photography with an accuracy level of ± 5 acres.

The MPO uses a supply model to allocate new activities to vacant lands. Land consumption ratios such as 400 square feet per employee downtown and 1,500 square feet per employee in the suburbs are used for commercial development.

**Control Numbers**: Uses the Texas State Comptroller's estimates for household, population, and income by sector. This is based on WEFA-DRI type estimates for major economic sectors. Bureau of Economic Analysis (BEA) proprietary data are used to adjust the Comptroller's estimates.

**Review Process**: DRAM-EMPAL projections are subjected to a review process. Output is sent to 50 cities, covering 85% of the area, for local review. A Demographic Research Task Force with 20 members (mostly planning directors and assistant planning directors) then uses a Delphi technique, followed by K-factor adjustments. In the last forecast, only one city challenged the forecast which was reviewed by the task force. The challenge was rejected because the modified Delphi technique is a zero-sum game.

**Use of Forecasts**: Accepted forecasts are used for rapid transit planning, water planning and impact analysis assessment and by the airport authority.

**Computer System and Software**: SAS is used for the supply model. ARC-INFO is used for maintaining land use data but MAPINFO is also used for its ease in creating maps. The system is a SUN workstation under a UNIX operating system.

**Selection Process**: Although unclear, it is very likely that the model selected was chosen because it was the only operational model available at the time of selection.

**Implementation and Application Issues**: The most important task is local review of forecasts and their acceptance by member agencies. The MPO does not rely solely on DRAM-EMPAL or any other model outputs. Outputs are used as a plain view and augmented with local planners' expertise and judgements.

**MPO Land Use Model Telephone Interview**

**MPO**: Houston - Galveston Area Council of Governments (Houston)

**Date**: January 26, 1996

**Person Interviewed**: Max Samfield, Director of Data Services, (713) 627-3200

**Additional Contact:** Mari Lee Martin, Land Use Model Specialist, (713) 993-4529

**Land Use Model**: DRAM-EMPAL

**Calibration and Forecast Years**: Used 1985-1990 for calibration. 1995 through 2020 is the forecast period

**Zone System**: Eight-county region with 199 regional analysis zones.

**Transportation Model**: Texas Large Package, a UTPS-type model package. The MPO is in the process of converting to an EMME/2 model system with approximately 2,600 TAZ.

The MPO faced a disaggregation problem between transportation and land use models. The model system is not linked. It is being used in a sequential mode.

**Households**: Five household quintals.

**Employment Categories**: Six categories

1. Office
2. Education
3. Retail
4. Industrial
5. Institutional
6. Medical

**Control Numbers**: Has used an econometrics model to estimate employment levels. This is linked to a cohort-survival population model for estimating needed migration for the work force.

Texas DOT provides land use data for seven counties of the eight-county model. The MPO also uses secondary sources like assessor's records and remote sensing. Work is performed to reconcile differences in definitions among these data sources and problematic land use data are checked in the field.

**Review Process**: The agency has set up a Data Services Committee which has twenty-one members from public and private agencies including highway, transit, and county engineers. They have a demographer on the committee who could perform technical reviews. The committee has worked very well. This was the first long range plan for a long time.

The Transportation Policy Council did not like the forecast, especially in the CBD areas. After a series of meetings, it was concluded that these are long range forecasts which the Transportation Policy Council might use for scenario analysis.

**Use of Forecasts**: Economists, Water development board, Highway planning, Transit planning, Private developers, Utility companies and Coastal zone management agencies are users of the forecasts.

**Computer System and Software**:

PC 486/66 is used for DRAM-EMPAL.
Mainframe from Texas A&M but converting to HP 700 workstation which is the machine of choice among MPO's. EMME/2 is used for transportation planning.

**Selection Process:**

Data Services Department inherited the DRAM-EMPAL model from Texas DOT five years ago. After initial work, there were some problems with the forecasts which the author of the model attributed to data. The MPO makes adjustments to the model's output outside of the model because access to the source code of the model is no longer available. The MPO is actively looking for a replacement for its DRAM-EMPAL package.

The most needed feature of a replacement for the current DRAM-EMPAL version would be an aggregation-disaggregation routine to make it easy to transfer data between land use and transportation models.

**Implementation and Application Issues**: In selecting any model system, importance should be put on the relationships with the author or consultant for the model. As mentioned earlier, this MPO is actively looking for a replacement for DRAM-EMPAL.

**MPO Land Use Model Telephone Interview**

**MPO**: Sacramento Area Council of Governments (Sacramento)

**Date**: January 31, 1996

**Person Interviewed**: Gordon Garry, Transportation Analysis Manager, (213) 236-1800

**Agency Number**: (213) 236-1800

**Land Use Model**: DRAM-EMPAL (the MPO is in the evaluation -installation phase).

**Calibration and Forecast Years**: 1985-1990 for calibration. Forecast years not decided yet.

The agency did a recalibration for 1995 through reworking of the model parameters.

**Zone System**: The study area is Sacramento metropolitan area, a four county model with 127 regional analysis zones.

**Transportation model**: MINUTP-based model with 1977 zones. The MPO has not decided on the configuration for the model linkages. It is now a sequential linkage.

**Households**: Five income categories:

$0-$10,000 (considered as poverty line for auto ownership purposes)
$10,001-$20,000
$20,001-$35,000
$35,001-$50,000
$50,001 and more

**Employment Categories**: Six employment categories:

1. Retail
2. Office
3. Manufacturing
4. Medical
5. Educational
6. Other

**Control Numbers**: Existing forecasts of local governments especially their planning departments. The MPO has its own inventory of employment using published reports and monitoring employment changes. Field checks of significant employment changes are made. The MPO performs telephone and windshield surveys.

**Review Process**: No formal paradigm is used to create control totals. Consensus among agencies about control numbers is achieved by discussion.

**Use of Forecasts**: Not yet available for use.

**Computer System and Software**: PC for both DRAM-EMPAL and MINUTP

**Selection Process**: Not a formal selection process. DRAM-EMPAL was the natural choice since it has the implicit approval of FHWA and EPA and is the only operational model available.

**Implementation and Application Issues**: The MPO finds that the advice of Dr. Putman, author of DRAM-EMPAL, has been right all along. The key question is whether the MPO has good data, especially employment data. It has taken more than one year to disaggregate data from two categories of "retail and other" to the six categories mentioned above. This has been a much longer process than they had anticipated. The MPO used between 3 and 4 intern-years and between 1 and 2 person years of professional staff time to prepare a sound database for model use.

# APPENDIX B

# LAND USE MODELS IN TRANSPORTATION PLANNING

## A Review of Past Developments and Current Best Practice

# LAND USE MODELS IN TRANSPORTATION PLANNING

## A Review of Past Developments and Current Best Practice

Britton Harris
January 1996

Introduction

The problem of modeling land uses in conjunction with transportation is both old and new: the problem itself is old, but the means for dealing with it are in constant evolution and are only now coming within reach for many Metropolitan Planning Organizations (MPOs). Under these circumstances, transport planners who are considering the adoption of land use models need a perspective on these models, on their potentials, and on some of their problems. This paper tries to provide such a perspective, and the effort is facilitated by tracing very briefly the history of developments in the field of metropolitan land-use modeling. This approach means that the style and content of this document is somewhat at variance with conventional wisdom in consultancies.

While we start with somewhat general and perhaps abstract considerations, the patient reader will rapidly discover that we move ahead to some very practical and relevant conclusions about the process of adopting and using models. These ideas are related to and supportive of the conclusions of the main report, but do not presume to anticipate or preempt those findings.

This note reviews the following topics, each in an independent section:

1. The Problem of Land Use Projections in Transportation Planning.

2. The Development of Economically Based Market Models.

3. The Development of Gravity and Discrete Choice Models.

4. The Development of Integrated Models.

5. Current and Potential Best Practice in Land-use Modeling for Transportation Planning.

6. Recommendations of the Conference on Land Use Models convened by the Transportation Models Improvement Program.

7. Conclusions and Recommendations.

I- The Problem

Land-use and transportation are mutually interconnected (Mitchell and Rapkin, 1952). The use of the term "land use" is based on the fact that through development, urban space accommodates a great variety of human activities. Land is a convenient measure of space, and land use provides a spatial accounting framework for urban development and activities. The location of activities and their need for interaction creates the demand for transportation, while the provision of transport facilities influences the location itself. Land uses, by virtue of their occupancy, are taken to generate interaction needs (trip generation), and these needs are directed to specific targets by specific transportation facilities (trip distribution and modal split). The use of the transportation system creates congestion, which leads to user adjustments (recognized in a capacity constrained assignment).

In practice, most transportation studies have projected a fixed pattern of location and have calculated the demand for transportation services on the basis of this pattern. The Chicago Area Transportation Study, for example, had an elaborate trend projection of the location of future population and employment which was used throughout the study for various networks. (See Hamburg and Creighton, 1959.)

During the last two decades there has been a growing realization that land use changes cannot be projected in this way because they are influenced by the provision of facilities, and by the anticipation of this provision. When locators choose to take advantage of new facilities, they generate demands which were not foreseen if the facilities failed to influence the projections. As a result, new facilities are often overloaded from their inception. Examples include the Shirley Highway in Washington D.C. and the London Orbital highway in England. In recent years this situation has been exacerbated by the response of localities to the clean air requirements of the Federal Government (ISTEA), which include various measures of traffic control and transport demand restraints. These measures will influence not only user behavior in the transport system, but also the future location of land users and thus of demand.

There is thus a feedback loop in which transport provisions and demand influence each other, and these feedbacks are sufficiently strong that they cannot be ignored. For this reason, transport planning agencies, as well as Metropolitan Planning Organizations, must take cognizance of this problem and study the best ways to deal with it. This intention requires an understanding of the nature of land use models in addition to the already well-developed understanding of transportation models.

We note, however, that even transport models are currently under review and revision, to adapt them to the current policy needs of transportation investment and management, under strong pressures for economy and for environmental protection. We assume in this discussion that the benefits of improved transportation modeling, moving in the direction of micro-simulation, will not be as great as they should be without the support of adequately detailed land-use projections, and without taking into account the impact of planned transport changes on land-use development.

## II- Economically-based Land Use Market Models

We start this examination of models with models of residential location, which dominated thinking about models in two very different styles, and is still overwhelmingly important. Residential land uses occupy about two-thirds of all urban land, just as home-based trips account for a large proportion of all vehicular and transit trips. In addition, the satisfaction of people with their home locations and with their connections with the rest of the urban environment are decisive components of both their budgets and their perceived well-being. Meeting their expectations in this regard is thus a major component of public policy as to housing markets, job location, and transportation.

Modern research on housing choice, with an emphasis on the location of housing in addition to its other characteristics, began with the publication of books by Wingo (1961) and Alonso (1964). In principle if not in detail these two works are virtually identical. They explain how, in a city with almost all employment in a single center (a mono-centric city), people in different income classes compete for residential land, and locate in concentric rings at densities which decline in relation to distance from the center. In the residential land market, households trade off added travel for added space and amenity.

This model was elaborated in a linear programming format by Herbert and Stevens (1960), and later further developed first by Harris (1963) and then by Wheaton (1974). These three treatments all moved slightly away from the assumption of monocentricity, and all brought out clearly the underlying assumption of *optimality* in a market-clearing model. In this linear programming format, no one could be made better off without making someone else worse off--just as postulated by Wingo and Alonso. Later work by a number of authors culminating in Mills (1972) extended these efforts, but without weakening the assumption of a monocentric city. Finally, a major effort by the NBER (see Ingram et al.,1972) produced a linear programming model of household residential choice which overcame several previous difficulties. This model took account of the attraction of numerous large employment centers; for the first time in any major study it analyzed households' residential preferences in detail; and it began to take account of housing conversion and redevelopment, although these had previously been studied in relative isolation.

All of these economically based optimizing market-clearing models (with the partial exception of the NBER model) suffered from one serious difficulty, which the economics community did not recognize or remedy until much later. In these models, all members of any one socioeconomic class behaved identically. Among other things, this meant that adjacent communities would tend to be identical in their socioeconomic compositions. While there is some truth in this conclusion, transport planners know from their experience with trip distribution that similar households do indeed behave differently. Other modeling trends did not neglect this aspect of behavior.

## III- Gravity and Discrete Choice Models

Well before the publication of the Wingo-Alonso models of residential choice, geographers and transportation planners had come to grips with a behavioral problem which was not yet recognized in residential location. It was well known that a population of trip-makers in a single area of origin would distribute their trips to various areas of destination, in proportion to the number of opportunities, but with decreasing probability at increasing distances. This behavior was plausible from a common-sense point of view, but lacked any clear economic explanation. For many years it was replicated by practitioners in an *ad hoc* fashion by the well-known "gravity model". This model provided a very good basis for prediction, but lacked any theoretical basis. Plausible explanations were offered by Stouffer (intervening opportunities, 1940), Wilson (maximum entropy, 1970), and McFadden (discrete choice, 1973). None of these or other explanations provided a genuine behavioral basis for the gravity model, and only McFadden's approach was sufficiently mathematically detailed to be accepted by economists.

This theoretical confusion did not prevent the successful application of the gravity model to trip distribution, and subsequently to residential location in the very important Lowry Model (1964). Lowry's model was also important for other reasons, which will appear in the next section of this report, but he was clearly the first to apply the gravity model to residential location.

Lowry supposed that most of the manufacturing activity in Pittsburgh was "basic industry", which had specialized site requirements and external markets, and was located independently of the resident population--that is, exogenously to the operation of his model. He assumed that retail trade and services were located in relation to residential demand, and that residences were located in relation to combined retail and basic employment. Hypothetically, workers started their trips to home from work, and distributed themselves at available residential sites *according to a gravity model,* which attenuated their trips over increasing distance. This vitally important feature of the Lowry model continues to dominate models of residential location in virtually all practical applications.

The Lowry Model had an appealing realism which caused it to be widely adopted, especially in British "structure planning", which combined strategic land-use and transportation planning. Other applications were widespread, and are summarized in Goldner "The Lowry Model Heritage" (1971). The many practitioners who applied this model overcame many of its initial shortcomings. Airline distances were replaced by actual transport times and costs. The attraction of land for those seeking residences was replaced by the attraction of diverse neighborhoods and housing types. At a later stage (see next section), industrial growth was made at least partially endogenous, and the form of the retail trade model location was improved. With these improvements, the Lowry Model became a serviceable means of predicting land-uses, but there remained one difficulty which was not successfully overcome.

Wilson's work on gravity models had pointed out that there were essentially three formal types--unconstrained, singly constrained, and doubly constrained. Trip distributions are doubly constrained, so that trips and opportunities are balanced at zones of departure and arrival. It can be shown, although it is not widely recognized, that the "balancing factors" in this model have an economic significance with regard to locational advantage which is analogous to the dual variables in linear programming, and which in the NBER model have similar meanings. The original Lowry model and most of its successors were, however, singly constrained: the trips originating at the place of employment were exactly distributed, but the arrivals at residential destinations were uncontrolled, and excess arrivals which could not be accommodated with available land were arbitrarily redistributed. Even when this model was doubly constrained, the economic significance of the constraints was not adequately recognized.

This difficulty began to be overcome in the early 1970s. Echenique (for a review of his work see the journal Planning and Design, 1994), working with the larger model systems discussed in the next section, recognized the need for constraints in the Lowry Model which he had been using, and made the key innovation of using land or housing rents as the constraint. It now seems obvious that well-located or well-designed residential precincts, which attract unusual numbers of residents, can charge higher prices or rents, and that it is precisely these user costs which prevent the areas from actually becoming overcrowded. This is exactly the way in which market-clearing models operate, but in this case the idea of rents was applied in a model which did not have uniform economic behavior, but rather the dispersed behavior of the gravity model. At about the same time, coming from the Wingo-Alonso-Mills school of economic models, Anas (1975, 1987) introduced discrete choice behavior into models with economically specified behavior and market clearing.

These approaches, from opposite schools of residential modeling, effectively unified ideas of market clearing and dispersed behavior to provide for realistic modeling of the residential land and housing market.

Similar modeling of retail trade and service location (for example, Harris and Wilson, 1979), and industrial location have begun to solve somewhat less difficult problems. These activities taken together lay the basis for large-scale unified models of metropolitan growth and function.

## IV- Integrated Urban Models

Large-scale urban models may be considered to be integrated in more than one sense.

Transportation demand models are integrated in that they consider almost all intra-urban transport modes and facilities as a unified system, in which different modes serve the same purposes, and different purposes use the same modes or facilities. (Rail and waterborne freight are usually omitted, as are most non-motorized trips except walking to work.) Unlike some land use provisions, the supply of transport services is not endogenous (internally generated) in most aspects of transport modeling; congestion, which affects supply, can however be endogenous.

Land use models are integrated when all uses of land are modeled as competing for available space, and their location is jointly determined. This may be done in many ways, but such location is usually to some extent iterative. Different activities (service, retail, industrial, residential) may be located sequentially and possibly by iteration, and the cycle may be repeated--or all locations may be adjusted on each iteration until the entire land market has been cleared. (This also implicitly clears the labor market and the trade and services supply market by trip distribution and balancing.)

Land use and transportation demand models are not usually iterated together at every step. The transport model may be iterated to create realistic congestion, and this congestion may serve as an input which influences activity location and land use. The projection of these land uses may in turn result in a new pattern of congestion, and the process may be repeated. This essential integration is, as we explained at the outset, the reason why transportation studies are now considering land use models as essential in their planning process. This integration may take place within an MPO, or through an arm's length relationship between a transportation and a land use planning activity. At the very least, a close working relationship between agencies is required.

Putman (1971, 1983) deserves recognition as the first clearly to emphasize in publications the importance of this final integration. His subsequent work has built on the Lowry model and has introduced recently new methods for dealing with industrial location. Echenique has continued to pursue his revision of the Lowry Model, and has for many years emphasized the importance of transport and transport modeling in his work. Anas has undertaken several modeling efforts dealing with all of these issues from a more or less rigorously economic viewpoint, with transportation inputs. His models of industrial location are less complete than those of Echenique, and his transportation modeling is not at the level of most transportation planning agencies. Putman has only recently begun to introduce constraints and product differentiation in his housing models.

This discussion has emphasized the work done by only three individuals and their associates, since they have played key roles in the development of the field. Echenique has some students who have produced models on their own account, and Putman has a few practitioner-students using and developing his models in US agencies. These three individuals and a few of their students are the only sources for commercially available integrated models, anywhere.

V- State of the Art

We start this section of this review with some mention of what it is that models of this kind will not do for the agencies involved in transportation planning.

They will not organize the data required for this work, although they may provide an organizing force which guides data collection and preparation. They will not replace skilled personnel in transport and land use-planning, although they may make their work easier and facilitate reaching improved results. Most important, they will not make planning decisions, although they will may it easier to assess the results of such decisions before they are made permanent.

We need to examine the reasons why transportation and land-use models do not actually make plans, and how this situation influences the planning process. Traditional planning of both types has refused to use mechanical means of producing plans through models, but this refusal often rested on prejudice or even ignorance. There is however an underlying difficulty which may have indirectly, and correctly, influenced these attitudes, and which requires brief attention here.

Efforts at network optimization have proved computationally intractable in spite of numerous efforts. Some efforts have partially succeeded in using a heuristic (or approximate) model of network optimization to produce effective marginal improvements to networks, but have failed to solve the larger problem of generating a good or optimal network from scratch. The CATS (1959) work on a Chicago network started from a specialized concept of the optimal spacing of expressways, but made very substantial changes and improvements to the original plan through exhaustive research and staff work. Several generally unsuccessful efforts were made to find methods which would generate optimal land-use plans from scratch. Limited success was achieved with TOPAZ, which can work only for marginal improvements, and suffers from other limitations.

It is now known that these difficulties stem from the structure of the overall network and land-use problems, which can have multiple local optima, on which improvement methods "hang up", with no possibility of further progress. This structural difficulty has been extensively investigated in Computer Science under the name of NP-Completeness, and no general solution for it has been found. Market forces and the market clearing models which simulate them cannot deal with the externalities, economies of scale, and indivisibilities which cause these hang-ups. For all these reasons, which are both conceptual and computational, and which replicate the real world, planning intervention is still needed to settle the larger issues of system planning in either field. Models can optimize subsystems like the residential land market or the congestion response to network utilization, but they cannot optimize whole complex systems either in transport or in land use, and certainly not in both together.

This situation implies that planners in both fields have to work with strategic scenarios, which postulate some types of major decisions, but can call on models to optimize subsystems and provide details of plans and their performance. In transportation, these scenarios contain major decisions about new facilities, demand management, traffic management, and constraints, incentives, and disincentives. Land use decisions at the same level involve major facility locations (terminals, parks, recreational facilities, and so on), and major restraints such as zoning, or incentives such as tax remission or subsidies.

It is important that these scenarios be considered in sufficient variety, so as to explore the effects of different combinations of policies. This is true in either field by itself, and even more so when transport and land use are considered to be interacting. The scenarios must deal with the fact that neither transport nor land-use planners can be certain about the final decisions in the other field. They must also provide sufficiently varied assumptions about the future to permit emphasis on the need for plans to be robust in the face of uncertain future developments.

Given this planning situation, we can identify both conceptual and practical requirements for land-use and transportation models, both separately and jointly. We take up these two types of considerations in that order.

Conceptually, models must be realistic: they must reproduce the behavior of system users and independent developers in the real world under varying conditions. They must accept as inputs not only the real influences on behavior, such as household income and the circumstances surrounding auto ownership, but also the policy inputs which are contemplated in both types of planning, such as parking policies, fuel prices, and various influences on land use. These inputs will interact strongly with the capability of models to produce realistic outcomes, and the variety and accuracy of these outcomes has still another role. The results of modeling must provide acceptable detail with respect to the policy objectives of the planning. In transportation this means that they must reflect not only cost and convenience, but also emissions and other environmental impacts. In land-use, the models must reflect the impact of plans on development, densities, and user satisfaction in various land and labor markets. Both types of plans can anticipate impacts in their own domain from the others' decisions, and both are concerned with overall objectives like amenity, environmental impacts, equity, desegregation, and the conservation of public and private resources.

All of these considerations lead to the possibility--even the necessity--of using increasingly disaggregated models, with very substantial detail in their operation. Such an approach comes into conflict with the realities of the planning process by increasing computational costs and turnaround time, by adding complexity which can lead to misunderstandings and error, and by adding to the difficulties of securing and using adequate data. These problems thus lead to a consideration of the practical aspects of using models in planning. Obviously, in selecting models, we will seek a compromise between perfectibility and their practicality of use.

There is only a handful of major practical considerations in model use, of which one is paramount.

The less salient considerations revolve around the user friendliness of the model, the ease with which new planning scenarios can be entered for testing, and the simplicity, relevance, and readability of the results. Another such consideration is the computational equipment which is required, and the turnaround time for experiments and plan testing. These matters should be tested by potential users in the process of model selection. Some such information is available without testing from model vendors, but should be carefully checked.

The most difficult considerations in choosing models revolve around the data requirements. Data is required on land-uses, including vacant land, employment, and locator behavior--all at a level of zone sizes which are suitable for transport planning. Transport networks are an obvious need which can be met in most transport planning offices, although not always in the exact form which might be desirable for land planning. There are several aspects of this problem which need brief discussion.

Many important needs for data can be met from the most current US census, but any reliance on Census data must be carefully considered and to an extent augmented. Here are some aspects of this problem:

> Transport planning area delimitation should, at some level of aggregation, be coterminous with Census tract boundaries; Otherwise, costly conversions will be necessary in having the two systems interact.
>
> Land-use information as such cannot be secured from the Census. Vacant land must be measured in every zone for purposes of determining the future potential for expansion. The measurement of land devoted to different purposes is necessary to determine densities and land requirements for future development. Distinctions should be made between industrial, commercial, service, retail trade, residential and other uses.
>
> Employment data by zone is needed for many reasons. Different trip types correspond in part with different types of employment, and employment may be the best available indicator of different levels of certain activities such as retail trade. For some metropolitan areas, the census has in 1990 tabulated employment by tract and by income, but this is not adequate for studying employment by industry type.
>
> Methods for calibrating models differ; cross-section calibration is simpler and requires less data. Calibration using multiple time periods can force a choice between the better detail of later censuses and the availability of more than one set of observations.
>
> Land-use models can be run for larger zones with less transport detail than transportation models. This requires the preparation of aggregated or spider networks, with some attendant difficulties in establishing capacities. Land-use models can generate trip-tables for the journey to work and for home and work-based shopping, but for input into a detailed transport model, these would have to be disaggregated.

## VII- Report of the Land Use Modeling Conference

Our recommendations in the next section after this one are generally in line not only with the previous discussion, but also with the results of a conference on land-use models, held in Dallas, February 19-21, 1995, under the sponsorship of the US Department of Transportation and the US Environmental Protection Agency as part of the Transportation Models Improvement Program. We present these findings briefly, relate them to our evaluation of the state of the art, and use them to examine the offerings of three providers of models. The overall summary of the conference provides us with the views which were generally accepted by all six working groups; these views are both general and specific. We have assembled and combined about forty-five recommendations, presenting them in our own words in the following summary.

> The behavioral basis of models is a major target for improvement, to satisfy both the realism of models and the ease with which they may be interpreted and understood. This realism should extend to the behaviors of individuals, governments, developers, and investors. Behaviors include land development and consumer choice. In general, the models must have a clearly stated behavioral basis, grounded in good theory which is drawn from a number of diverse fields.

Desired new or improved capabilities of models should include: the simulation of incremental processes rather than merely static pictures; the analysis of controlled growth; methods of analysis to test the reasonableness of forecasts; and the use of time-series for evaluation.

The policy aspects of the models relate to their use in transportation planning, land use planning, and environmental protection, requiring submodels in all three fields. But the policy aspects of the models should extend in a sensitive way to other objectives, including for example public health and safety, criminal justice, and poverty. Environmental concerns addressed in ISTEA and other federal programs call for environmental capabilities and for more analysis of the impacts of demand management, transit, and public transportation.

Data requirements are a major concern and several tentative proposals have been presented. Employment location is by far the most important unsolved problem, and here federal assistance may be required to solve the need for detail without violating confidentiality. Data definitions should be clear and consistent in any given model and across models; this need extends to area definitions, which should vary as little as possible among models of the environment, transportation, and land use. Means should be studied to permit aggregation and disaggregation of data classes and the areal units which contain them.

Modeling demands close attention to a variety of interfaces. These include the interfaces which facilitate the modeling of interaction between land uses, transportation, and the environment; interfaces with GIS and other capabilities which provide data and organize the output for tabular, graphic, policy-oriented presentations; interfaces to promote ease of use, and to facilitate understanding the modeling process by non-users; and interfaces with remote-sensing capabilities and aids to operational management.

Standards and design features are coupled with many of the above recommendations. These include:

Move to universal use of discrete choice models.

Establish pilot projects and research in modeling.

Undertake real-world testing under US conditions.

Design modular systems for varying and testing models.

Provide different models for different problems in various types and sizes of cities and suburbs.

Provide better comparative data on different models.

Use theory to provide guidelines for testing models.

Involve the public in the use of models.

The use and deployment of models is a matter on which the report is slightly self-contradictory. Several references to reducing computational time are somewhat in conflict with other recommendations for disaggregation and detail. More important, perhaps, one comment implies that models are not used as much as they should be for producing plans, while others suggest that models should be used mainly to analyze the impacts of various scenarios, both in transportation and land use, with the implication that the preparation of the scenarios is the way to conduct planning. *We are inclined to believe that these issues can be thoroughly addressed only when a variety of well-constructed models is available and in use, initially primarily to test scenarios.*

We find that these suggestions and requirements are in broad agreement with the state of the art at its most advanced level, but are far from fully effective in actual practice. Some of the difficulties and shortfalls need to be listed and discussed briefly.

None of the three major systems which we have discussed actually makes plans. This capability is far from achievement in the present state of the art, and will probably continue to encounter problems. Present knowledge suggests that actual planning cannot be done with models; they can at best evaluate the probable results of a plan, and draw implications for its improvement. This is an area where the existence of sound workable models which do not plan is a requisite for research in further extending their capabilities.

Most of the interfaces discussed above do not yet exist, largely because the various types of planning of land use, transportation, and environmental protection have proceeded in isolation from each other under different professional auspices. The interfaces with users are also difficult; most providers find it necessary to offer (at a fee) substantial user support. There are variations: transportation engineers understand massive models more easily than do professional land planners. Echenique has the best-developed in-house models package; Putman and Anas have so far relied on separately developed land use models, connected to existing transportation models. Discrepancies and differences in data and area systems continue to present difficulties in almost every application.

Discrete choice models are used almost everywhere. Some confusion may arise from overlooking the fact that the gravity model is also a discrete choice model. Anas's models are based on economic theory and some observed behavior; Echenique uses a loose economic framework including (uniquely) input-output analysis; Putman uses gravity models with some consumer disaggregation, but no clearly defined theory of behavior.

These models are not entirely static: changes resulting from highway construction and urban development are preserved from one period to the next. In general, the locators are all relocated without time-lags; thus the occupancy status has some similarity to a static equilibrium. Redevelopment and conversion are not well-handled explicitly in any dynamic fashion--partly because developer behavior is taken to be a simply conduit between demand and supply. Overcoming all these difficulties is a major long-term project, as is the formulation of truly dynamic models which are computationally feasible.

Various styles of disaggregation are practiced in the models which are commercially available. Echenique uses large residential zones and (together with Anas) more or less disaggregated housing stock. All three of the major potential suppliers disaggregate the population, but Putman does not use any housing stock or any modification of it over time.

Conducting analysis at different area scales between transport and land use presents a very difficult problem. Fine scale analysis with many zones is extremely computationally intensive. Larger zones may be used for residential and some industrial analysis, if there is disaggregation of system users and of the land and building stock. Then aggregating populations upward for transport analysis is simple, while disaggregating areas is extremely difficult, and for many cases there is no known solution of guaranteed accuracy.

Note: There are many interesting and useful discussions of model development which are not listed in our references. We have, however, included two which provide a very detailed discussion of several very diverse models, in Webster et al. (1988, 1991). Another review of great importance is more recent, and was prepared for the Land Use Modeling Conference discussed here: Wegener (1995). A second paper at that conference is also very useful: Batty et al. (1995).

## VII- Recommendations as to Model Selection

One outcome of the development of two streams of modeling, from the direction of economic analysis and from the direction of Lowry's simulation, has been a confusion of terminology. Lowry-type models have been modified by many people, especially including Marcial Echenique and Partners, so that they have many economic aspects and depend on market-clearing and hence on the equilibrium of various markets. An economic equilibrium also coincides with an optimum for each market. On the other hand, models of economic equilibrium have been modified, principally by Anas, to embody discrete choice in a market-clearing framework. Furthermore, many important models carry forward from one time-period to another the results of development and building in prior time periods. In a complete equilibrium model, as formulated by Mills and other adherents to the school of the "New Urban Economics", reiterating the model under new conditions would result in a complete reshuffling of buildings and other facilities. Thus most models are not truly equilibrium models. At the same time, calling them "partial equilibrium models" is also inappropriate in economic parlance.

In many cases, so-called "optimizing models" achieve an optimum allocation of locators subject to many constraints and assumptions built into the model and the way it is used. From the policy point of view, the results may not be optimal because the decisions which the model is testing are inferior to others which might be offered. Also, most optimizing models use a very restricted set of criteria, which may miss important elements of policy-making and require much additional interpretation.

This confusion is perhaps best overcome by giving up the use of old categories, and describing each model on a series of important dimensions like the following:

Discrete choice versus uniform behavior.
Market clearing or other constraints on behaviors.
Variables which influence locational choices of actors.
Definition of actor classes, and reasons for this.
Representation of the stock of buildings and improvements.
Nature of interaction among submodels: frequency, form of data transfers, degree of integration.

These are the types of characteristics which make it possible to distinguish clearly among models, and which together with many operational features should guide the choices of agencies using models.

The process of model selection is somewhat troublesome and difficult, and some aspects such as cost are deferred for discussion elsewhere, in the URS report. On the basis of the foregoing analysis, we can make several recommendations.

A model should be selected which is moderately disaggregated and whose underlying concepts are as realistic and as economically based as possible.

Transportation conditions and available choices as to housing, industrial sites, access to amenities and to the labor force, should enter intimately into all locational decisions which are modeled in the system.

An accurate delineation of choices implies that the model will distinguish among different types of housing and other developed space, or different types of land for development.

The model should be doubly constrained, and with meaningful constraints at both origins and destinations. Wherever possible, the equilibrium which is sought should be a form of "market clearing".

The degree of disaggregation should cover two to four types of households, probably separated by income level, Many types of housing (not all represented in a given residential area), and at least three types of employment, including manufacturing, retail trade, and other services, some of which should broken into subclasses.

Data requirements and methods of calibration should be well-specified by the vendor, with the co-operation of the users.

Running times and equipment requirements are very important, and special consideration must be given to trade-offs between speed and accuracy.

## REFERENCES

Alonso, William, 1964, Location and Land Use, Harvard University Press, Cambridge, MA.

Anas, Alex, 1975, "The Empirical Calibration and Testing of a Simulation Model of Residential Location", Environment and Planning A, **7**, 899-920.

Anas, Alex, 1987, Modeling in Urban and Regional Economics, Harwood Academic Publishers, Chur, Switzerland.

Batty, Michael, Carmelle J Cote, David Howes, Pat Pelligrini, and Xiaohua Zheng, 1994, Draft: Data Requirements for Land Use Modeling: First Thoughts and a Preliminary Assessment. Travel Model Improvement Program, Land Use Modeling Conference Proceedings, USDOT, Washington.

CATS, 1959, Final Report Volume 1, Chicago Area Transportation Study, Chicago, IL.

Goldner, W., 1971, "The Lowry Model Heritage", Journal of the American Institute of Planners, **37**. 100-110.

Hamburg, J. R., and J. R. Creighton, 1959, "Predicting Chicago's Land Use Pattern", Journal of the American Institute of Planners, **25**, 67-72.

Harris, Britton, 1963, "Linear Programming and the Projection of Land Uses", Penn- Jersey Paper No. 20, Philadelphia, PA.

Harris, Britton, and Alan G. Wilson, 1979, "Equilibrium Values and Dynamics of Attractiveness Terms in Production-Constrained Spatial-Interaction Model, Environment and Planning A, **10**, 371-388.

Herbert, John S., and Benjamin H. Stevens, 1960, "A Model of the Distribution of Residential Activity in Urban Areas", Journal of Regional Science, **2**, 21-36.

Ingram, Gregory K., John F. Kain, and J. Royce Ginn, 1972, The Detroit Prototype of the NBER Urban Simulation Model, New York, National Bureau of Economic Research.

Lowry, I. S., 1964, A Model of Metropolis, RM-4035-RC, The Rand Corporation, Santa Monica, CA.

McFadden, Daniel, 1973, "Conditional Logit Analysis and Quantitative Choice Behavior", in Frontiers in Econometrics, Paul Zarembka, ed., Academic Press, New York, 105-142.

Mills, Edwin S., 1972, Urban Economics, Scott Foresman, Glenview, IL.

Mitchell, Robert B., and Chester Rapkin, 1954, Urban Traffic: a Function of Land Use, Columbia University Press, New York.

PLANNING AND DESIGN, 1994, Special Issue on Urban and Regional Studies at the Martin Centre,**21**, 157-533.

Putman, Stephen H., 1971, "The Effect of Changing Transport Facilities on Regional Economic Development", Papers and Proceedings of the Regional Science Association, **27**, 151-166.

Putman, Stephen H., 1983, Integrated Urban Models: Policy Analysis of Transportation and Land Use, Pion, London.

Stouffer, Samuel H., 1940, "Intervening Opportunities: a Theory Relating Mobility and Distance", American Sociological Review, **5**, 845-857.

Webster, F. Vernon, Philip H Bly and Neil J Pauley, eds, 1988, Urban Land-Use and Transport Interaction. Policies and Models. Report of the International Study Group on Land-Use/Transport Interaction (ISGLUTI), Aldershot, Avebury.

Webster, F Vernon and Mira Dasgupta, 1991, Land Use and Transport Interactions. Report of the ISGLUTI Study. Crowthorne, Transport and Road Research Laboratory.

Wegener, Michael, 1995, Current and Future Land Use Models, Travel Model Improvement Program, Land Use Modeling Conference Proceedings, USDOT, Washington.

Wheaton, William C., 1974, "Linear Programming and Locational Equilibrium: The Herbert-Stevens Model Revisited", Journal of Urban Economics, **1**, 278- 287.

Wilson, Alan G., 1970, Entropy in Urban and Regional Modeling, Pion, London.

Wingo, Lowdon Jr., 1961, Transportation and Urban Land Use, The Johns Hopkins Press, Baltimore, MD.