Travel Model Improvement Program Land Use Modeling Conference Proceedings

February 19-21, 1995

TMIP

Travel Model Improvement Program

Department of Transportation
Federal Highway Administration
Federal Transit Administration
Office of the Secretary

Environmental Protection Agency

Department of Energy

U.S.Department of Transportation

U.S.Environmental Protection Agency

Travel Model Improvement Program

The Department of Transportation, in Cooperation with the Environmental Protection Agency and the Department of Energy, has embarked on a research program to respond to the requirements of the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act of 1991. This program addresses the linkage of transportation to air quality, energy, economic growth, land use and the overall quality of life. The program addresses both analytic tools and the integration of these tools into the planning process to better support decision makers. The program has the following objectives:

1. To increase the ability of existing travel forecasting procedures to respond to emerging issues including: environmental concerns, growth management, and lifestyle along with traditional transportation issues,

2. To redesign the travel forecasting process to reflect changes in behavior, to respond to greater information needs placed on the forecasting process and to take advantage of changes in data collection technology, and

3. To integrate the forecasting techniques into the decision making process, providing better understanding of the effects of transportation improvements and allowing decision makers in state governments, local governments, transit operators, metropolitan planning organizations and environmental agencies the capability of making improved transportation decisions.

This program was funded through the Travel Model Improvement Program.

Further information about the Travel Model Improvement Program may be obtained by writing to

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Federal Highway Administration
U.S. Department of Transportation
400 Seventh Street, SW
Washington, DC 20590

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Final Report
February 1995

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Sponsored by
US Department of Transportation
Federal Highway Administration
Federal Transit Administration
Office of the Secretary
US Environmental Protection Agency
US Department of Energy

Distributed in Cooperation with
Technology Sharing Program
Research and Special
Programs Administration
US Department of Transportation
Washington, DC 20590

DOT-T-96-09

Contents

Preface

The travel forecasting models currently in widest use today were developed more than 25 years ago, primarily to evaluate alternative major highway capital improvements. In the 1970s the models were adapted for use in planning major transit capital facilities. These current models were not intended to evaluate congestion pricing, transportation control measures, alternative development patterns, or motor vehicle emissions; so it is not surprising that they are not well suited to the tasks needed to meet the planning and air quality requirements of the Intermodal Surface Transportation Efficiency Act (ISTEA) or the Clean Air Act Amendments (CAA).

To address current model deficiencies, the Federal Highway Administration, the Federal Transit Administration, and the Office of the Secretary, U.S. Department of Transportation; the U.S. Environmental Protection Agency; and the U.S. Department of Energy have initiated a major program to enhance current models and develop new procedures. The Travel Model Improvement Program (TMIP) is a cooperative effort among organizations involved in transportation, land development, and environmental protection. TMIP will seek active technical involvement and financial participation from state departments of transportation (DOTs), local governments and metropolitan planning organizations (MPOs), environmental agencies, and private sector entities.

The objectives of the Travel Model Improvement Program are:

- To increase the policy sensitivity of existing travel forecasting procedures and their ability to respond to emerging issues including environmental concerns, growth management, and changes in personal and household activity patterns, along with the traditional transportation issues.

- To redesign the travel forecasting process to reflect today's traveler behavior, to respond to greater information needs placed on the forecasting process, and to take advantage of changes in data collection technology;

- To make travel forecasting model results more useful for decision makers.

- To improve land use and development forecasting procedures to provide better information for travel demand forecasting and to assure that feedback occurs between transportation service and land use in the modeling process.

Improvements to existing travel models and the new generation of models being developed will require more sophisticated land use forecasts. Simply estimating the number of employees or residents in a zone is not likely to provide adequate data for activity based travel models, which require detailed information on household demographics and employment characteristics as well as precise locations. Many policy initiatives also require detailed and sophisticated land use/activity forecasts. Additionally, the ISTEA requires that transportation planning consider "the likely effect of transportation policy decisions on land use and development and the consistency of transportation plans and programs with provisions of all applicable short- and long-term land use and development plans". As a result, planning agencies are increasingly having to analyze the relationships between land use and transportation decisions.

The sponsors of the Travel Model Improvement Program organized the Land Use Model Conference to bring together experts and practitioners in an effort to identify:

- The needs for land use forecasting to meet the ISTEA requirements;
- Other planning needs and mandates for land use forecasts;
- Required improvements in existing procedures to address those needs;
- Advances needed beyond improving the existing procedures; and,
- Research and development to accomplish the advances.

The conference occupied two full days, with brief thematic presentations in plenary sessions followed by small group workshops. On the first day of the conference, attention was focused on the examination of how well existing land use modeling and forecasting methods address the current issues and mandates, the advantages and disadvantages of existing models and how they can be improved to address the current needs. On the second day, discussions were centered on new land use modeling and forecasting techniques. Approaches and techniques that have recently been developed, but need to be implemented and others that are still conceptual were discussed. Additionally, issues surrounding data requirements, model architecture and the model development process were examined. Workshop groups also developed priority recommendations for research and the development and implementation of land use models and forecasting techniques.

This report presents a summary of the conference presentations and of the six workshop groups' discussions and recommendations. This report will be used to develop a research agenda to facilitate the land use modeling improvements needed to satisfy the ISTEA requirements as well as other planning needs and mandates for land use forecasts. It is anticipated that future conferences will be held to provide continuous outreach and direction to the TMIP.

Summary of Workshop Observations and Recommendations

Cynthia Weatherby, Texas Transportation Institute, Arlington, Texas

Six workshop groups were convened during the conference. On the first day each group examined how well existing land use modeling and forecasting methods address the current issues and mandates, the advantages and disadvantages of existing models, and how they may be improved to address the current needs. The second day's discussions centered on new land use modeling and forecasting techniques. Approaches and techniques were discussed that have recently been developed but have not yet been implemented or validated in "real world" applications and others that are still conceptual. Additionally, issues surrounding data requirements, model architecture and the model development process were examined.

Workshop Tasks

There was a facilitator and a recorder in each of the six workshops. The discussions in each workshop were documented by the facilitator, utilizing notes taken by the recorder, and the reports are included in this report. Each workshop group was asked to address a comprehensive list of questions about current land use forecasting model practice and the specifics to be considered in the development of new land use models. Also noted by the workshop groups were suggestions for the research needed to facilitate the further refinement of existing models and the development of new models.

Key Common Observations

For the short term, there was a broad consensus reached by workshop participants that there is a need for a comparative description of the theory, variables and parameters of currently available models that would allow agencies to make informed choices for model applications. A need for guidelines and advice on the process in which the models are used was also noted by the groups. Pilot programs were recommended that would implement a range of land use forecasting techniques from which experience and guidance could be developed.

Extensive research needs were identified that would address improving the precision, accuracy and usefulness of model output. Participants indicated that the models should address a wider range of policies and their impacts, account for environmental constraints, and consider the actions of individuals, governments, developers, businesses and investors. There was also agreement among the groups that there should not be an attempt to develop a single model to accomplish all tasks. Rather, any new model system should be modular, with each piece having a specific purpose, to allow for intervention to adjust data and information and to accommodate varying levels of spatial resolution and temporal dynamics. It was also uniformly agreed by the workshop groups that modeling efforts should take full advantage of geographic information systems (GIS) capable of bi-directional interaction with transportation and environmental models.

The need for research on data collection/ acquisition strategies, employment data, and the generation and use of synthetic data were recognized by all of the workshops. Additional research on individual and business location choice decision processes and the use of stated preference and revealed preference surveys was also identified by the participants as necessary to model refinement and development.

Review of Existing Land Use Models

Below is a summary of the observations made by the workshop groups specifically about existing land use models. The shortcomings discussed should be considered both in refining existing models and in the development of new models.

- Many of the newer land use models have been developed outside the United States or in academia and have not been validated and tested in U.S. metropolitan areas. There is a lack of comparative, experiential knowledge about the models and a concomitant absence of long-term credibility that will only come with multi-time, real-world validation.

- Most existing models are not sufficiently sensitive to policy issues nor are they geared to understanding by non-modelers.

- The existing models do not adequately incorporate the land development decision-making process, nor are they sufficiently linked to consumer choices.

- Current land use models are not adequately linked to transportation models or environmental models and do not allow a valid assessment of the interaction among land use, transportation and environmental impacts.

- There are many incompatibilities of zonal structure systems being used, with aggregation and disaggregation of data, and the related data reliability a major issue. The fact that most land use models and transportation models use differing zonal systems is a particular problem. There are also significant inconsistencies in the use of classification strategies (such as the categories of employment data) between land use and transportation models.

- Data, especially employment data, is a tremendous problem for existing models. The inability to disaggregate household data by type is an example of difficult data issues to be addressed. The overwhelming demand for data to feed the developing micro simulation models is another data issue.

- There is an absence of a clear, describable basis of theory for current land use models, as well as agreement on how they are to be used. Also missing are comprehensive guidelines on the use and application of existing models.

- Generally, land use models are far too dependent upon transportation modeling output and assumptions, and there is insufficient interaction between the two.

- Public transit is not adequately represented in land use or transportation models.

- In general, there is too little behavioral content to the existing land use models.

- The existing models require a high level of effort and resources and substantial time for execution, thereby limiting their use and appropriate application.

- The existing models are not capable of accounting for urban development as an incremental process, but are static cross-sectionally.

- Current modeling and analytical processes appear suitable for predicting urban sprawl, but are unable to assess controlled growth.

Suggestions for Improvements to Existing Models

Below is a listing of some of the specific recommendations for improving existing models as a result of the workshop group discussions.

- More direct links are needed between GIS technology and land use models.

- A better understanding of the models available is required before existing models can be improved. There should be an investment in a comparative description of the models, including multiple dimensions of evaluation.

- There should be a serious effort at time-series validation of the models, either by "back-casting" or by building a strategy to track forecasts and tests in the future.

- Improving the quality and availability of employment data is almost certainly the single highest priority for short-term improvement of land use models. Perhaps increased access to small-area geocoding of establishment data from the Bureau of Labor Statistics would be beneficial.

- There is a need for more rigorous analytical techniques to provide for a systematic way to judge the reasonableness of current model results.

- Guidance on the use of transportation models for sketch evaluation of land use effects of transportation actions should be prepared.

- There is a need for improved feedback between existing land use, transportation, and environmental models.

Suggestions for Development of New Models

The workshop groups then turned their attention to suggestions to be considered in developing new model systems. A summary of these suggestions is listed below.

- Modeling efforts should move fairly quickly toward random utility-based models.

- New models must be behaviorally based, and the theory used should be clearly stated. Major and significant research is required about the nature of the behaviors of the actors involved.

- The new models should place a greater emphasis on their use for policy analysis, planning and sensitivity testing within an integrated land use, transportation, and environmental framework.

- The models should be more sophisticated about varying temporal and geographic scales relevant to different processes in urban development.

- The models must be capable of bi-directional aggregation/ disaggregation. Additionally, there should be research into the coupling of various levels of model structure, including, perhaps a "nested" model structure.

- In developing new models, the cost-effectiveness of the modeling strategy as a whole should be studied.

- Micro-simulation holds promise, although its hunger for data may be prohibitive. Research into synthetic household data at the micro level and use of other existing databases will be required. The issue of privacy must be addressed, especially as related to capturing data from commercial transactions.

- While most of the groups agreed that micro-simulation (TRANSIMS) should be considered in any new modeling system, it was agreed that it should not be the only approach considered. The differences among metropolitan areas, and the varying size of the areas, indicates that a one-size-fits-all land use model would not be successful or cost-effective.

- Because there has been so much reliance placed on transportation modeling in the past, it was noted that development of new models should be sure to incorporate the involvement of economists, geographers, logistics managers, computer scientists, statisticians, and planners.

- Any new model processes developed must be modular in nature. No "one" model should be pursued to deal with all requirements.

- GIS must be used in any new models developed. Research is also needed in the use of remote sensing to determine land use and change in land use.

- With travel costs becoming less important determinants of location choices, and amenities and other factors becoming more significant, new models should not be structured to use travel costs as the principal influence on location.

- One group judged that a reasonable time-frame for development of a new modeling system would be a minimum of five years.

Miscellaneous Comments/ Suggestions

There were a number of comments submitted by the workshop groups that have relevance to both short- and long-term model system improvements. A summary of these suggestions is shown below.

- Several workshop groups addressed the need to review the role that models play in the decision-making process. It was suggested that current models are not being used to plan, but rather to test and evaluate and understand the consequences of actions.

- Any enhanced or new models must have a clear, graphical orientation, allowing for more clearly informing policy makers. Linking to a broader set of issues related to police, health care, water/sewer, open space, and schools, would also be very useful.

- New modeling tools should consider the interactions of central city and suburban economies.

- Modeling tools should allow for the development and testing of different land use scenarios. They should also allow for citizen involvement, incorporating graphical "output".

- Both improvements to existing models and new models should be done in a competitive environment -- open to a wide range of researchers and consultants. Research teams should be multidisciplinary with a diverse membership.

- Research into the standardization of validation statistical techniques and reporting methods is needed. There is also a need for development of consistent evaluation indicators for current and future models, to assess the quality of the predictions.

- A comprehensive research effort is necessary in the area of employment data.

- Research into the use of stated preference surveys and revealed response panel surveys should be pursued, including an evaluation of the cost-effectiveness of the techniques.

- There should be facilitated collaboration between metropolitan planning organizations (MPOs), academics, federal and state agencies, and private consultants in the development of new models and procedures. A focused program should be developed to facilitate this involvement. One group suggested the establishment of "land use research centers" similar to transportation research centers, where there would be also be an emphasis on MPO staff training and the dissemination of information. Several other groups suggested funding eight to ten MPOs across the country to implement model improvements and new models, with the experience then serving to guide others.

- Incorporating better information about the modeling process into higher educational programs was also suggested. Tutorials, internships, and other such methods to extend the information base and corps of educators and practitioners in the U.S. were suggested.

- Workshop groups also suggested that the U.S. Department of Housing and Urban Development and the U.S. Environmental Protection Agency should continue to be involved in the research process investigating better interaction among land use, transportation and environmental models.

For more detailed comments and varying perspectives on the issues, please refer to the reports from each of the workshop groups.

Land Use Model Conference Keynote Address

Elizabeth Deakin, Ph.D., University of California, Berkeley

Thank you. This is an assignment that I have inherited. Grace Crunican was our first choice to give the talk tonight. We wanted Grace to give this talk because we felt that it would be very important to try and set the tone, to look at the political and institutional factors, some real world decision making, and how decisions are actually made by the people who make them. So that is why there is an academic standing before you tonight.

One of the issues, of course, that several of you have already asked me is "Why are we having a conference on land use models?" Why are land use models important to us again? It seems to me that we have at least five reasons for beginning to look at land use models. I would like to talk tonight about those reasons and why I think it makes a difference what we do here in the next two days. Then finally, talk about whom we have to be thinking about, who will be using our products. That will give us something to aim for as we go through this whole process.

First, why are we here? Why are we concerned about land use models? Again, after many years of not paying too much attention to land use modeling, except as a rather esoteric area of specialized practice, I think there are five reasons. One is the Intermodal Surface Transportation Efficiency Act of 1991, ISTEA, which includes a requirement that transportation planners consider the likely effect of transportation policy decisions on land use and development, and the consistency of transportation plans and programs with provisions of all applicable short- and long-term land use development plans. We have a mandate, and that is a mouthful of a mandate.

We also have the Clean Air Act Amendments of 1990, which also gave us a mandate to look at relationships between transportation and air quality. It has become apparent that to look at these relationships in many metropolitan areas, we also have to consider the connection to land use and land development and urban form. We know, for example, as we begin to debate what kinds of transportation investments we are making, that increasingly the questions about whether those transportation investments will restructure the urban area, will change urban form, will become critical questions and ones that are becoming quite contentious in metropolitan areas. The argument goes: if, perhaps, our policies and investments will, in fact, change the opportunities for people to choose where they will live and work, patterns that we have not taken into account in our analyses, that as a result, our transportation analyses are being called into question about whether we have done an adequate job of representing the full set of effects in doing air quality analysis. This is something that is particularly critical because the Clean Air Act requires that we do consistency analyses and show that we are actually reducing emissions over a steady stream of the emissions reductions over time. It also provides some penalties, both in terms of actual losses of funds and in terms of potential for other requirements being imposed and perhaps even litigation, if we fail to do an adequate job in these areas.

Thus, the Clean Air Act is another set of mandates that have made land use analysis much more important than it was in previous years.

It seems to me though that even if we did not have those federal mandates, even if those federal mandates were to disappear tomorrow, many, many metropolitan areas would find themselves with equal pressure to do a better job than we have been doing to look at land use and urban form. Simply saying that these are federal mandates, that maybe the federal mandates are about to go away, doesn't eliminate this set of issues.

For example, in many metropolitan areas there are proposals to build beltways or to build outer belts. The same questions that are reflected in the ISTEA legislation or reflected in the Clean Air Act legislation are brought up in local meetings about these projects. They are brought up by environmentalists, they are brought up by interests from downtown, by interests from the suburbs and by rural interests. We all want to know what the effects of these major new capacity expansions are going to have on the shape of their city, where people choose to live and work, on the economy of their metropolitan area and region and on the state as a whole. So these questions are coming from local levels.

Similarly, we are making investments in rail transit, light rail transit, heavy rail transit and major new busways. The same kinds of questions come up about those projects. There are claims made that these projects will, in fact, help us to restructure and reorder our cities. Will help improve the economies of local places that are benefited by the location. Will encourage compact development and will otherwise provide the infrastructure around which land use plans can begin to make a difference in the way we live and work. Those claims are challenged by others and our ability to be able to address those questions with systematic analysis is something that we are increasingly being asked to refine and develop further.

So for many local reasons, we are finding that we have policy questions that are not going to go away regardless of what the feds have to say to us. There will continue to be policy questions that planners and engineers will have to address and, hopefully, will address though analysis and systematic evaluation of data and forecasting in an intelligent way. So those are some reasons. Those are mandate reasons. There are two other reasons that are really critical for us.

One reason, as we know from our own experience with models that we are using, is that there is a lot of room for improvement. We can do better. We actually know how to do better and have not necessarily implemented our new knowledge in our modeling systems. We know, for example, that trip distribution models that assume that all workers can choose equally among all the work destinations, and that the only factors that are impedances are travel time and travel costs, are certainly wrong. Yet we continue to use those sorts of models in the way we go about doing our forecast, knowing that those models are wrong.

We similarly know that developers respond to opportunities and problems presented by changes and access, changes in accessibility. No one claims that the changes in access in themselves are the only determinacy, even the primary determinacy of development, or that there is some sort of simple relationship. We also know that in some instances the investments we made in transportation systems are capitalized in land values. Through the capitalization process we have a feedback effect on choices of locations and how the transportation system will function. This is an interesting and complicated set of issues. Few of our models really are reflecting those kinds of sophisticated decision-making processes or help us think systematically through how to do that kind of evaluation.

We know we can do better. We know we have opportunities to do better. We actually have some ideas about how to go about making these kinds of improvements. The task still lies ahead of us to begin to do those things.

Finally, there is a wonderful opportunity that has been presented itself. Gradually it is now becoming apparent to many of us that those are the opportunities presented by better data. You begin to get GIS systems available at relatively low costs. There are new worlds of data being opened up to us. Both public sources and private vendors are providing better information systems. This new data will enable us, for example, to use the XY coordinate to describe very specific locations of activities. It will enable us to talk about parcels or points in space in ways we were never really able to do before. Rather than relying on very large areas and very general descriptions of urban activities, we can now begin to talk about very specific land uses and very specific activities in these places in ways we could not before.

On the other hand, this is by no means an easy thing to do. We are finding as well that the Tiger files are full of mistakes. That one GIS system won't necessarily talk to another GIS system. That we lose PIC cells in some of our methods and, therefore, lose information as we are going along with it. In general, it is going to take an awful lot of work before we are able to fully grasp these wonderful opportunities presented by these new forms of data. These new forms of data also will make it possible, by the way, for us to begin to address some of those very detailed design questions also arising at the local level. Will it make a difference in my city, if I invest in beautiful sidewalks and landscaping, to the quality of the urban environment, therefore, to the travel choices that people make in that environment? Will they walk more? Will they ride bikes if we make these investments? These questions often require the kind of micro level data that we are now able to actually develop and store and manage in a systematic way that we haven't been able to do before in an effective way.

There are numerous institutional concerns that accompany these issues, of course. When we talk about whether we are going to see more advanced models, we also need to talk about whether we are going to have money to pay the staff. Who are going to be able to run those models? We need to talk about whether the commitments are there on the part of the government agencies that have been funding some of the data collections to keep collecting this data. Many areas are struggling to be able to keep travel surveys, whether they are activity surveys or whether they are travel surveys of the more conventional sort, going. We all know that the panel data would be a good idea and allow us to do a lot of new things that we have not been able to do. The ability to get funding for panels has really been in question, especially in the metropolitan areas. The ability to maintain an adequate panel has been an issue in a number of areas. The commitment of the government organizations and the institutions at the federal, state and local levels is another issue that we are going to have to deal with in looking at this whole set of problems and opportunities.

We have embarked, as part of the Travel Model Improvement Program, on major improvements to existing travel models. We are starting today to talk about major improvements in the land use component of the modeling systems that will do many more things than we have been able to do in the past. Those travel model improvements, by the way, will require some changes in the way we think about land use and activity data. We are not going to be able to be as gross and inexact in our descriptions of places and people's activities as we have been in the past if we are going to support these models. These models we are developing in the transportation side will be only as good as the land use activity input that we can put into them. So it is going to become critical-- critical that through this kind of meeting, we get started on a really serious effort to improve our land use and activity databases. Figure out how to manage those databases. Figure out how to pay for the long-term management maintenance of those databases, and figure out how to use all these tools that we have within our grasp in an effective way to produce better information.

There are some other concerns we also have to deal with. It is my view that we will not be using these models as technocratic, rational, positives to the decision-making tools. If we look at these as technocratic, rational, positives to these decision-making tools, I think we will find that we will fail again. If we cannot communicate what it is we are up to, if we cannot get the information across to those decision makers, whether they are developers or politicians, or even heads of agencies, who may not be technically trained in the specifics of the models that we are using, why this matters. Why this data matters. Why these analysis tools matter. Why these models matter. If we cannot communicate that and figure out how to translate what are going to be very complicated technical issues into language that will be understood by bright, but not technically trained people, I think we are going to fail.

Another task before us is how we are going to communicate. What we know. What we are learning. What we are developing in ways that are effective, persuasive and powerful. With that though, I think we can do that. I think we can begin to do that. We don't have to have simple tools to be able to have clear explanations of what those particular tools are. That is the distinction that I hope we will be able to draw. We can be complicated. We can be sophisticated. We can be state of the art, but we still ought to be able to speak English while we are doing it.

Here are the challenges before us. At this conference what we are asking you to do is to look at what it is we need to do, what are the policy motivators driving us to look at land use modeling, land use analysis, and land use data in a more sophisticated way than we have in the past.

Given those needs and mandates at the local, federal and the state levels. -- By the way, I don't mean that just at the government level, because developers also make use of this information. Then we ought to be able to figure out what we need to do in the short term to make better use of what we have available and to make incremental improvements to the available tools and techniques and databases, and over the long term, what kinds of needs we ought to be thinking about.

Here I would like to say that I hope you will think not just about computer models or databases but also about basic theories. Basic research and ideas about the way urban systems work. About the way people make decisions about where they live, where they work, about where they locate their businesses. About what kinds of places they want to live in, and really get down to some very serious discussion in the next two days about these basic issues, as well as how we begin to translate that into the more practical applications of those ideas into forecasting tools and analysis tools. Those kinds of advances are something that is going to take us awhile to come up with, and we need to also be thinking about the processes for implementation. So what I hope you will also do over the next couple of days is to spend some time thinking about how we would take our ideas about what we need to do and communicate them to people who will be making the decisions about that.

One way to begin thinking about that is to think about who the users are. I will end by talking about who I think would use the products of what we do here and what we do afterward if we are successful.

Obviously, modelers, transportation modelers, need better land use inputs. So that is an obvious market for our tools. But that certainly isn't a sufficient market for our tools. If that were all we were able to do, I suspect we would fail. So we need to be cognizant of what travel modelers need, but we also must think about the bigger picture. What is it the decision makers would like to know? What is it that they need to know? Here I believe we start thinking about what uses we make of this information. There are lots of uses for this information that are not related to modeling. For example, suppose we had a really sophisticated, easy to use, well designed land use database and activity database. We might be able to get our friends in planning, who worry about wildlife, to use that database to do habitat conservation planning. That is a possible use of these kinds of data because you begin to look at coverage, habitat, slope and other factors here. So many people we usually don't even think of as being part of the audience in the Transportation Research Board meeting or meeting of land use modelers may well find benefits from the kinds of databases, the kinds of platforms and the kinds of analysis capabilities that we need to set together over the next few days.

What other kinds of uses? Certainly, if we begin to collect land use data, parcels at the XY coordinate level, you can imagine that this data could be used by fire departments, which have to plan how to provide fire service, and by police departments which are trying to figure out how to provide police service. They could be used by tax assessors and tax collectors. There are probably endless uses that local governments could make of a good land use database -- a good database to organize this information. The same kinds of uses could be made of much of the census data, again, if it were put into more usable form, which we would need to do in any event in order to be able to use it for our more esoteric purposes.

It also seems to me that we can think about how private developers might use these databases. Developers do have to perform pro forma and must assess what the real potential is for a particular kind of development. One of the things we often look at is how many comparable developments are there in this area? How many jobs are there in this area? How many buildings are there and the particular types we are concerned about in this area? The kinds of data that I think we are going to be talking about over the next few days may well lend themselves to private sales -- to private developers who would, in fact, find them extremely useful for their own private purposes. There may be other uses of that sort to which these databases can be put. Some of you come from entrepreneurial MPOs who already are selling some of your data to the private sector and know that, in fact, there is great potential for doing more of this, if that the data can be brought along in a way that it is actually reliable enough to be trustworthy. So again, think about the uses we can make of this. Who would be our audience for these better products?

Finally, local government decision makers. I come back to this because I think in many instances it will be at the local level, the city councils and planning directors and other people who will be making decisions, who are going to have to be part of the supporters. Not simply the federal government, which I hope we have on board already for these purposes; but also the local people in your own communities who have to see a value the products we are working on, if we really are going to sustain our activities over the longer term. So one of the things we have to work on, in the next couple of days, to think about and keep in mind through our discussions, is who is going to get any benefit out of this? What value will they see in this? How can we help address their questions, not just our questions, but their questions in what we do?
There is a substantial market for these tools and these activities. They might not be the conventional ones which we have put them in the past. There may be ones that are exciting and open new ways of thinking about how we do our business, as well as useful to these other parties.

We have an exciting two days ahead of us. I am delighted to see this many people here, so many different walks of life and branches of professions represented in the audience. I am looking forward to the next two day. Thank you.

Current and Future Land Use Models

Michael Wegener, Ph.D., Institute of Spatial Planning, University of Dortmund, Germany

The urgency of the environmental debate has renewed the interest in the application of integrated models of urban land use and transportation. In the United States new legislation inspired by growing environmental awareness such as the Intermodal Surface Transportation Efficiency Act of 1991 requires that transportation planning must consider the interaction between transportation and land use in a consistent fashion---as it can be done only by land use transportation models.

However, this new interest in land use models also presents new challenges to the land use modelling community. A new generation of activity-based travel models and new neighborhood-scale transportation planning policies require more detailed information on household demographics and employment characteristics and the location of activities. Moreover, the models need to be able to predict not only economic but also environmental impacts of land use transportation policies. Today there exist several operational urban land use transportation models which have the potential to respond to these challenges. At the same time there exist exciting opportunities to incorporate new theoretical developments and methodologies into the field.

The paper reviews the current state of the art of operational land use transportation models using criteria such as comprehensiveness, overall structure, theoretical foundations, modeling techniques, dynamics, data requirements, calibration and validation, operationality and applicability and evaluates their suitability with respect to the new requirements and speculates about the most promising avenues to further improvement and diffusion of this kind of model.

Introduction

The idea that computer models of urban land use and transportation might contribute to more rational urban planning was born in the 1950s and culminated in the 1960s. The new tools for planning (Harris 1965) were thought to be a major technological breakthrough that would revolutionize the practice of urban policy making. However, the diffusion of urban models faltered soon after the pioneering phase for a variety of reasons (see Batty 1994; Harris 1994). The most fundamental probably was that these models were linked to the rational planning paradigm dominant in most Western countries at that time. They were perhaps the most ambitious expression of the desire to understand as thoroughly as possible the intricate mechanisms of urban development, and by virtue of this understanding to forecast and control the future of cities (Lee 1973). Since then the attitude towards planning has departed from the ideal of synoptic rationalism and turned to a more modest, incrementalist interpretation of planning; that has at least co-determined the failure of many ambitious large-scale modelling projects.

However, today the urgency of the environmental debate has renewed the interest in integrated models of urban land use and transport. There is growing consensus that the negative environmental impacts of transportation cannot be reduced by transportation policies alone but that they have to be complemented by measures to reduce the need for mobility by promoting higher-density, mixed-use urban forms more suitable for public transport. In the United States new legislation inspired by growing environmental awareness such as the Intermodal Surface Transportation Efficiency Act of 1991 requires that transportation planning must consider the interaction between transportation and land use in a consistent fashion---as it can be done only by land use transportation models.

However, this new interest in land use models also presents new challenges to the land use modelling community. A new generation of travel models such as activity-based travel demand models require more detailed information on household demographics and employment characteristics, and new neighborhood-scale transportation planning policies to promote the use of public transport, walking and cycling require more detailed information on the precise location of activities. In addition, the models need to be able to predict not only economic but also environmental impacts of land use transportation policies, and this requires small area forecasts of emissions from stationary and mobile sources as well as of immissions in terms of affected population.

Today there exist several operational urban land use transportation models which have the potential to respond to these challenges. There is a small but tightly knit network of urban modelers dispersed across four continents. There are a dozen or so operational urban/ regional models of varying degrees of comprehensiveness and sophistication that have been and are being applied to real-life metropolitan regions for purposes of research and/or policy analysis. Rapid advances in information and computing technology have removed technical barriers besetting earlier generations of land use transportation models. At the same time there exist exciting opportunities to incorporate new theoretical developments and methodologies into the field.

This paper reviews the current state of the art of operational land use transportation models using criteria such as comprehensiveness, overall structure, theoretical foundations, modeling techniques, dynamics, data requirements, calibration and validation, operationality and applicability and evaluates their suitability with respect to the new requirements and speculates about the most promising avenues to further improvement and diffusion of this kind of model.

The Map of Urban Modelling

Before proceeding, it is necessary to define the type of model considered in this paper. The first distinction is that the term model is used here to indicate *mathematical* models implemented on a computer and designed to analyze and forecast the development of urban or regional land use systems. The second distinction is that the models must be *comprehensive,* i.e., they must integrate the most essential processes of spatial development; this implies that they must include at least urban land use, where land use denotes a range of land uses such as residential, industrial and commercial. This excludes partial models addressing only one subsystem such as housing or retail. It is essential that the links from transport to land use is considered in the models; transportation itself may be modelled either endogenously or by an exogenous transportation model. The models must be *operational* in the sense that they have been implemented, calibrated and used for policy analysis for at least one metropolitan region.

The number of real-world applications of models falling under the above definition has increased steadily over the last decade. There are more than twenty university laboratories, public agencies or private firms on four continents where research and development in urban and regional modeling is actively being conducted, and there are a dozen or so operational urban/regional models of varying comprehensiveness and sophistication that have been or are being applied to real-life metropolitan regions for research and/or policy analysis.

In this section the geographical distribution of contemporary urban modeling research all over the world is presented. Figure 1 shows the map of active urban/regional modeling centers in the late 1980s and early 1990s and the names of their principal researchers.

The twenty centers in Figure 1 are numbered from west to east and are associated with the following individuals and modeling projects (more detailed information is contained in Wegener 1994):

1	San Francisco	Landis, Prastacos
2	Urbana	Boyce, Kim, Rho
3	Chicago	Anas, Boyce
4	Buffalo	Anas, Batty
5	Cambridge, MA	Kain, Apgar
6	New York	Oppenheim
7	Philadelphia	Putman
8	Caracas	de la Barra
9	Santiago de Chile	Martinez
10	London	Mackett
11	Cambridge	Echenique, Williams
12	Stockholm	Lundqvist, Anderstig, Mattson
13	Dortmund	Wegener
14	Paris	Pumain
15	Turin	Bertuglia, Rabino
16	Seoul	Rho
17	Tokyo/Yokohama	Nakamura, Miyamoto
18	Nagoya/Gifu	Hayashi, Miyagi, Morisugi
19	Kyoto	Amano, Toda, Abe
20	Melbourne	Brotchie, Roy, Young

Figure 1. The map of active urban modeling centers.

1 *San Francisco.*

The Bay Area is the home of the Projective Optimization Land Use Informations System (POLIS) of the San Francisco Region, developed for the Association for Bay Area Governments (Prastacos 1986) and of CUFM, the California Urban Futures Model (Landis 1992; 1993; 1994), a successor to the classic BASS (Goldner 1971), developed at the Institute of Urban and Regional Development of the University of California at Berkeley.

2 *Urbana.*

At the Department of Civil Engineering of the University of Illinois at Urbana-Champaign nonlinear programming equilibrium models of transportation and location were developed by Boyce (Boyce et al. 1983; 1985; Boyce 1986) and Kim (1989) and Rho (Rho and Kim 1989).

3 *Chicago.*

Chicago has been modeled by Anas at Northwestern University in the Chicago Area Transportation and Land-Use Analysis System CATLAS (Anas 1982; 1984) and for the Chicago Area Transportation Study (Anas 1983b; Anas and Duann 1985) and by Boyce at the Urban Transportation Center of the University of Illinois at Chicago (Boyce 1990; Boyce et al. 1992).

4 *Buffalo.*

At the State University of New York at Buffalo, Anas developed NYSIM, the New York Area Simulation Model (Anas 1992) and CPHMM, the Chicago Prototype Housing Market Model (Anas and Arnott 1991) and a new model, METROSIM, unifying the techniques and concepts of CATLAS, NYSIM and CPHMM. Also in Buffalo, at the National Center for Geographic Information and Analysis, Batty has developed interactive urban models in his research on geographical information systems (Batty 1992).

5 *Cambridge, MA.*

HUDS, the Harvard Urban Development Simulation (Kain and Apgar 1985) was the first large-scale urban simulation model employing microsimulation techniques.

6 *New York.*

Oppenheim of the City University of New York has produced several equilibrium activity-allocation models (Oppenheim 1986; 1988; 1989).

7 *Philadelphia.*

Putman's adaptation of the Lowry modeling framework ITLUP (Integrated Transportation and Land Use Package) has been used for more actual agency policy applications than any other spatial model (Putman 1983; 1991).

8 *Caracas.*

TRANUS (Transporte y Uso del Suelo) (de la Barra et al. 1984; de la Barra 1989) has been applied for Latin American cities and for modeling energy use of cities with Rickaby of the Open University of Milton Keynes, United Kingdom (Rickaby 1991).

9 *Santiago de Chile.*

Martinez (1991; 1992a; 1992b) developed the '5-Stage Land-Use Transport Model' calibrated for Santiago de Chile.

10 *London.*

Mackett at University College, London applied the Leeds Integrated Land Use/Transport model (LILT) to several British and foreign cities (Mackett 1983; 1990c; 1991a; 1991b) and developed a microsimulation model for Leeds (Mackett 1990a; 1990b).

11 *Cambridge.*

MEPLAN, the latest in a sequence of models built on multiregional input output techniques is being applied to numerous urban regions in the world (Echenique et al. 1990; Hunt and Simmonds 1993; Echenique 1994; Williams 1994; Hunt 1994).

12 *Stockholm.*

Stockholm has been the study area of TRANSLOC (Transport and Location) developed at the Royal Institute of Technology (Lundqvist 1978; 1979; 1989) and more recent models (Anderstig and Mattson 1991) as well as of other models reviewed in this paper (Anas et al. 1987; Boyce and Lundqvist 1987; Lundqvist et al. 1992).

13 *Dortmund.*

At the Institute of Spatial Planning of the University of Dortmund (IRPUD), Wegener developed a model of the Dortmund region (Wegener 1985; 1986a; Wegener et al. 1991).

14 *Paris.*

The Institut National d'Etudes Demographiques applies dynamic models in the tradition of Allen (Allen and Sanglier 1981) to French cities (Pumain et al. 1984).

15 *Turin.*

The Polytechnic of Turin was the origin of a number of models of Piedmont and Rome (Lombardo and Rabino 1984) and of a large dynamic urban model still under development (Bertuglia et al. 1990).

16 *Seoul.*

After his work with Kim in Urbana-Champaign, Rho has established an urban modeling group at Hanyang University in Seoul.

17 *Tokyo/Yokohama.*

The group of Nakamura at the University of Tokyo implemented the Computer-Aided Land Use Transport Analysis System (CALUTAS) for the Tokyo metropolitan area (Nakamura et al. 1983) and later spread to Yokohama, where Miyamoto developed the RURBAN model (Miyamoto et al. 1986, Miyamoto and Kitazume 1989).

18 *Nagoya/Gifu.*

Hayashi at Nagoya University developed a land use transportation model of Nagoya (Hayashi and Doi 1989; 1992) and a microsimulation model of residential mobility (Hayashi and Tomita 1989). Equilibrium models of transport and regional development have been developed by Miyagi (1989) and Morisugi et al. (1992) at Gifu University.

19 *Kyoto.*

Kyoto University has been the origin of an urban model of Kyoto (Amano et al. 1987; 1988) and of a model for the Kanto Region, by Ando (1991).

20 *Melbourne.*

The Commonwealth Scientific and Industrial Research Organization (CSIRO) generated the TOPAZ (Technique for Optimal Placement of Activities in Zones) model (Brotchie et al. 1980) and the modeling work of Roy (1992). At Monash University Young and colleagues developed the urban gaming simulation LAND (Gu et al. 1992; Young and Gu 1993).

Several of the above modelers were members of ISGLUTI, the International Study Group of Land Use Transport Interaction, which between 1980 and 1991 under the direction of Webster, Bly and Paulley of the United Kingdom Transport and Road Research Laboratory, conducted the largest and most thorough comparative evaluation of large-scale urban models (Webster et al. 1988; Webster and Paulley 1990; Webster and Dasgupta 1991; Paulley and Webster 1991). Today, the role of ISGLUTI has been taken over by the

Special Interest Group "Land Use and Transport" of the World Conference on Transport Research, and by smaller, more informal associations in Europe and Japan. Urban modeling has a firm place at conferences of the Regional Science Association, the Association of Collegiate Schools of Planning (ACSP), the Association of European Schools of Planning (AESOP), or more recently at the International Conferences on Computers in Urban Planning and Management. There has been a continuous reflection of purpose, direction and theoretical basis of land-use transportation modeling as witnessed by volumes edited by Hutchinson et al. (1985) and Hutchinson and Batty (1986) and by reviews by Harris (1985), Wegener (1986b; 1987), Kain (1987), Boyce (1988), Berechman and Small (1988), Aoyama (1989), and Batty (1994), Harris (1994) and Wegener (1994).

Model Comparison

This section attempts to assess the current state of the art in urban modeling. To do this, first a framework for the classification and evaluation of urban models is established. Then thirteen contemporary operational urban models are evaluated, using as criteria comprehensiveness, overall structure, theoretical foundations, modeling techniques, dynamics, data requirements, calibration and validation, operationality and applicability. As the previous section, this section is an updated summary of more detailed information presented in Wegener (1994).

A Model of Urban Models

For the evaluation of operational urban models, an idealized urban model will first be sketched out as a benchmark by which the existing models can be classified and evaluated. Eight types of major urban subsystems are distinguished. They are ordered by the speed by which they change, from slow to fast processes (see Figure 2):

- *Very slow change: networks, land use.* Urban transportation, communications and utility *networks* are the most permanent elements of the physical structure of cities. Large infrastructure projects require a decade or more, and once in place, they are rarely abandoned. The *land use* distribution is equally stable; it changes only incrementally.

- *Slow changes: work places, housing.* Buildings have a life span of up to one hundred years and take several years from planning to completion. *Work places* (non-residential buildings) such as factories, warehouses, shopping centers or offices, theaters or universities exist much longer than the firms or institutions that occupy them, just as *housing* exists longer than the households that live in it.

- Fast change: employment, population. Firms are established or closed down, expanded or relocated; this creates new jobs or makes workers redundant and so affects *employment.* Households are created, grow or decline and eventually are dissolved, and in each stage in their life cycle adjust their housing consumption and location to their changing needs; this determines the distribution of *population.*

- *Immediate change, goods transport, travel.* The location of human activities in space gives rise to a demand for spatial interaction in the form of *goods transport* or *travel.* These interactions are the most volatile phenomena of spatial urban development; they adjust in minutes or hours to changes in congestion or fluctuations in demand.

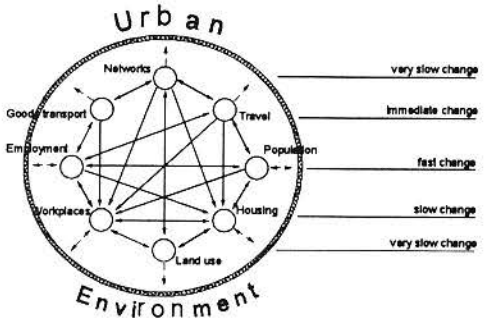

Figure 2. A model of urban models.

There is a ninth subsystem, the *urban environment*. Its temporal behavior is more complex. The direct impacts of human activities, such as transportation noise and air pollution, are immediate; other effects such as water or soil contamination build up incrementally over time, and still others such as long-term climate effects are so slow that they are hardly observable. Figure 2 illustrates the main interactions of the eight subsystems and their multiple links with the urban environment. It can be seen, for instance, that the location of work places, i.e., non-residential buildings such as factories, warehouses, office buildings and shops, depends on the location of other firms and of clients and workers, on access to goods transportation and travel by customers and employees, and on the availability of land, utilities and housing. All eight subsystems affect the environment by energy and space consumption, air pollution and noise emission, whereas locational choices of housing investors and households, firms and workers are co-determined by environmental quality, or lack of it. All nine subsystems are partly market-driven and partly subject to policy regulation.

Thirteen Urban Models

For the comparison, thirteen models were selected from the work at the twenty modeling centers described above. The selection does not imply a judgment on the quality of the models, but was based simply on the availability of information. These are the thirteen models:

- *POLIS:* the Projective Optimization Land Use Information System developed by Prastacos for the Association of Bay Area Governments (Prastacos 1986).
- *CUFM:* the California Urban Futures Model developed at the University of California at Berkeley (Landis 1992; 1993; 1994).
- *BOYCE:* the combined models of location and travel choice developed by Boyce (Boyce et al. 1983; 1985; Boyce 1986; Boyce et al. 1992).
- *KIM:* the nonlinear version of the urban equilibrium model developed by Kim (1989) and Rho and Kim (1989).
- *METROSIM:* the new microeconomic land use transportation model by Anas.
- *ITLUP:* the Integrated Transportation and Land Use Package developed by Putman (1983; 1991).
- *HUDS:* the Harvard Urban Development Simulation developed by Kain and Apgar (1985).

- *TRANUS:* the transportation and land-use model developed by de la Barra (de la Barra et al. 1984; de la Barra 1989).

- *5-LUT:* the '5-Stage Land Use Transport Model' developed by Martinez for Santiago de Chile (1991; 1992a; 1992b).

- *MEPLAN:* the integrated modeling package developed by Marcial Echenique & Partners (Echenique et al. 1990; Hunt and Simmonds 1993, Echenique 1994; Williams 1994; Hunt 1994).

- *LILT:* the Leeds Integrated Land-Use/Transport model developed by Mackett (1983; 1990c; 1991a; 1991b).

- *IRPUD:* the model of the Dortmund region developed by Wegener (1985; 1986a; Wegener et al. 1991).

- *RURBAN:* the Random-Utility URBAN model developed by Miyamoto (Miyamoto et al. 1986; Miyamoto and Kitazume 1989).

These thirteen models will be classified according to the following criteria: comprehensiveness, overall structure, theoretical foundations, modeling techniques, dynamics, data requirements, calibration and validation, operationality and applicability. Table 1 summarizes the comparison for the most important of these criteria.

Comprehensiveness

All thirteen models are comprehensive in the sense that they address at least two of the eight subsystems identified in Figure 2 (the urban environment will be discussed later). Only TRANUS and MEPLAN encompass all eight subsystems. METROSIM, LILT and IRPUD address all subsystems except goods transport; KIM models goods movements but not physical stock and land use; HUDS has a housing supply submodel but does not model non-residential buildings. Half of the models make no distinction between activities (population and employment) and physical stock (housing and work places). Four models (POLIS, CUFM, HUDS and RURBAN) do not model transportation and hence rely on input from exogenous transportation models. Only HUDS, LILT and IRPUD model demographic change and household formation.

Model Structure

With respect to overall model structure, two groups can be distinguished. One group of models searches for a unifying principle for modeling and linking all subsystems; the others see the city as a hierarchical system of interconnected but structurally autonomous subsystems. The resulting model structure is either tightly integrated, "all of one kind", or consists of loosely coupled submodels, each of which has its own independent internal structure. The former type of model is called "unified", the latter "composite" (Wegener et al. 1986). Five of the thirteen models (BOYCE, KIM, METROSIM, 5-LUT and RURBAN) belong to the unified category; the remaining eight are composite. The distinction between unified and composite model designs has important implications for the modeling techniques applied and for the dynamic behavior of the models (see below).

Table 1. Summary of comparison of thirteen land use models.

Model	Subsystems modeled	Model theory	Policies modeled
POLIS *composite*	employment population housing land use travel	random utility locational surplus	land use regulations transportation improvements
CUFM *composite*	population land use	location rule	land use regulations environmental policies public facilities transportation improvements
BOYCE *unified*	employment population networks travel	random utility general equilibrium	transportation improvements
KIM *unified*	employment population networks goods transport travel	random utility bid rent general equilibrium input-output	transportation improvements
METROSIM *unified*	all subsystems except goods transport	random utility bid rent general equilibrium	transportation improvements travel-cost changes
ITLUP *composite*	employment population land use networks travel	random utility network equilibrium	land use regulations transportation improvements
HUDS composite	employment population housing	bid rent	housing programs
TRANUS *composite*	all subsystems	random utility bid rent network equilibrium land use equilibrium	land use regulations transportation improvements transportation-cost changes
5-LUT *unified*	population networks housing	random utility bid rent general equilibrium	transportation improvements
LILT *composite*	all subsystems except goods transport	random utility network equilibrium land use equilibrium	land use regulations transportation improvements travel-cost changes
MEPLAN *composite*	all subsystems	random utility network equilibrium land use equilibrium	land use regulations transportation improvements transportation-cost changes
IRPUD *composite*	all subsystems except goods transport	random utility network equilibrium land use equilibrium	land use regulations housing programs transportation improvements travel-cost changes
RURBAN *unified*	employment population housing land use	random utility bid rent general equilibrium	land use regulations transportation improvements

Theory

In the last twenty years great advances in theories to explain spatial choice behavior and in techniques for calibrating spatial choice models have been made. Today there is a broad consensus about what constitutes a state-of-the-art land use model: Except for one (CUFM), all models rely on random utility or discrete choice theory to explain and forecast the behavior of actors such as investors, households, firms or travelers. Random utility models predict choices between alternatives as a function of attributes of the alternatives, subject to stochastic dispersion constraints that take account of unobserved attributes of the alternatives, differences in taste between the decision makers, or uncertainty or lack of information (Domencich and McFadden 1975). Anas (1983a) showed that the multinomial logit model resulting from random utility maximization is, at equal levels of aggregation, formally equivalent to the entropy-maximizing model proposed by Wilson (1967; 1970); he thus laid the foundation for the convergence and general acceptability of formerly separate strands of theory.

Underneath that uniformity, however, there are significant differences between the theoretical foundations of the models. Seven models (KIM, METROSIM, HUDS, TRANUS, 5 LUT, MEPLAN, RURBAN) represent the land (or floor space or housing) market with endogenous prices and market clearing in each period; one (IRPUD) has endogenous land and housing prices with delayed price adjustment. These models are indebted to microeconomic theory, in particular to Alonso's (1964) theory of urban land markets or bid rent theory. The six models without market equilibrium rely on random utility maximization; however, two of the microeconomic models (5-LUT and RURBAN) are hybrids between bid rent and random utility theory. All models with transportation submodels use random utility or entropy theory for modeling destination and mode choice.

Only KIM and METROSIM determine a general equilibrium of transportation and location with endogenous prices. The other models are equilibrium models of transportation only (ITLUP, IRPUD), of transportation and activity location linked by delays (TRANUS, MEPLAN), or of transportation and location combined, but without endogenous prices (BOYCE, LILT). POLIS, CUFM, ITLUP and IRPUD apply concepts of locational surplus (POLIS), random utility (ITLUP, IRPUD) or profitability (CUFM) to locate activities. ITLUP may be brought to general equilibrium, but this is not normally done; METROSIM may produce a long-run equilibrium or converge to a steady state in annual increments.

Several other theoretical elements are built into some models. TRANUS and MEPLAN use export base theory to link population and non-basic employment to exogenous forecasts of export industries. HUDS, LILT and IRPUD apply standard probabilistic concepts of cohort survival analysis in their demographic and household formation submodels. IRPUD also utilizes ideas from time geography, such as time and money budgets, to determine action spaces of travelers in its transportation submodel.

Modeling Techniques

In all thirteen models, the urban region is represented as a set of discrete subareas or zones. Time is subdivided into discrete periods of between one and five years. This classifies them as recursive simulations.

In six models (BOYCE, KIM, TRANUS, LILT, MEPLAN, RURBAN), transportation and location are simultaneously determined in spatial-interaction location models, in which activities are located as destinations of trips; in the remaining models transportation influences location via accessibility indicators. In the nine models with network representation, state-of-the-art modeling techniques are applied with network equilibrium the dominant trip assignment method despite its well-known weakness of collapsing to all-or-nothing assignment in the absence of congestion. Only ITLUP, TRANUS and MEPLAN have multiple-path assignment allowing for true route-choice dispersion.

For representing flows of goods, multiregional input-output methods are the standard method. KIM, TRANUS and MEPLAN use input-output coefficients or demand functions for determining intersectoral flows and random utility or entropy models for their spatial distribution. TRANUS and MEPLAN have generalized this to incorporate industries and households as consuming and producing "factors" resulting in goods movements or travel.

With the exception of CUFM and HUDS, all models are aggregate at a meso level, i.e., all results are given for medium-sized zones and for aggregates of households and industries. CUFM and HUDS are disaggregate, i.e., apply microsimulation techniques. HUDS works on a sample of individual households in list form, whereas CUFM uses detailed land information in map form generated by a geographical information system. IRPUD starts with aggregate data but uses microsimulation techniques in its housing market submodel.

Dynamics

Recursive simulation models are called quasi-dynamic because, although they model the development of a city over time, within one simulation period they are in fact cross-sectional. This is, however, only true for strictly unified models. Composite models consist of several interlinked submodels that are processed sequentially or iteratively once or several times during a simulation period. This makes composite models well suited for taking account of time lags or delays due to the complex superposition of slow and fast processes of urban development (cf. Wegener et al. 1986). However, this feature is insufficiently used by most models, because the typical simulation period of five years has the effect of an implicit time lag---a too long time lag in most cases.

Data Requirements

The data collection for a model of a large metropolis has remained a major effort. However, in many cases the introduction of computers in local government has generated a pool of routinely collected and updated data that can be used as the information base for a model, in particular in the fields of population, housing, land use and transportation. Another factor reducing the data-dependency of urban models is the significant progress made in urban theory in the last decades. The models of today are more parsimonious, i.e., can do with less data than previous models. Examples illustrating this are the techniques to generate regional input-output matrices from national input-output matrices and regional totals through biproportional scaling methods; or techniques to create artificial microdata as samples from multivariate aggregate data.

Calibration and Validation

All thirteen models of the sample have been (or could have been) calibrated using observed data, using readily available computer programs and following well established methods and standards. In particular, maximum- likelihood estimation of the ubiquitous logit model has become routine. Yet, while calibration has become easier, the limits to calibrating a model with data of the past have become visible. Calibration of cross-sectional models, as it is practised today, provides the illusion of precision but does little to establish the credibility of models designed to look into the far future. There has been almost no progress in the methodology required to calibrate dynamic or quasi-dynamic models.

In the face of this dilemma, the insistence of some modelers on "estimating" every model equation appears almost an obsession. It would probably be more effective to concentrate instead on model *validation,* i.e., the comparison of model results with observed data over a longer period. In the future, the only real test of a model's performance should be its ability to forecast the essential dynamics of the modeled system over a past period at least as long as the forecasting period. There are only two models in the sample following this philosophy, MEPLAN and IRPUD. These models are partly calibrated not by statistical estimation, but by manual fine tuning in a long, interactive process.

Operationality

All the models in the sample are operational in the sense that they have been applied to real cities. However, only a few models are on their way to become standard software for a wider market. Among these, TRANUS stands out as a particularly advanced and well documented software with an attractive user interface in Spanish or English. The time seems not far when any planning office will be able to buy a complex and versatile urban model with full documentation, default values and test data sets for less than a thousand dollars.

Applicability

If one considers the enormous range of planning problems facing a typical metropolitan area in industrialized countries today, the spectrum of problems actually addressed with the thirteen urban models in the sample is very narrow. The majority of applications answer traditional questions such as how land use regulations or housing programs would affect land use development and transportation, or how transportation improvements or changes in travel costs would shift the distribution of activities in an urban area. These are and will continue to be important questions---questions that can only be answered with the models discussed here. However, other issues are likely to become prominent in the future, and it will be essential that the models are able to contribute to their rational discussion.

Future Land Use Models

The new interest in land use models essentially originates in the imperative to make transportation more sustainable and to halt or even reverse the trend to ever longer travel distances and goods movements. It has now become commonplace that sustainable mobility cannot be achieved by transportation policy alone, but that transportation planning has to be complemented by land use policies to promote higher-density, mixed-use types of land use more suitable for public transport, walking and cycling. This makes the integration of land use and transportation planning a necessity.

Models that are to support this integrated land use transportation planning process need to be more sophisticated than earlier models. State-of-the-art transportation models need to be able to model multimodal trip types such as park-and-ride, kiss-and-ride or bike-and-ride, semi-collective forms of travel such as car pooling or more complex forms of journey such as multi-destination trip chains. Requirements such as these have led to the development of behavioural, activity-based, micro-analytic travel models and the ascendancy of stated-preference over revealed preference approaches. Land use models that are to interact with these new types of travel model need to have the requisite variety, i.e., a corresponding level of behavioral, spatial and temporal resolution. Activity-based travel models require more detailed information on household demographics and employment characteristics. Similarly, neighborhood-scale transportation policies to promote the use of public transport, walking and cycling require more detailed information on the precise location of activities. In addition, the land use models need to be able to predict not only economic but also environmental impacts of land use transportation policies. This requires small area forecasts of emissions from stationary and mobile sources as well as of immissions in terms of affected population. The consequences of these requirements for future land use models will be discussed below.

Disaggregation

One conjecture is that future land use models will tend to become more disaggregate. The reasons for this are not only the need for higher behavioral, spatial and temporal resolution stated above, but also methodological reasons. Disaggregate models are easier to implement and calibrate (using stated preference techniques), more parsimonious in their data needs (because they can work with sample data or even synthetic micro data), more flexible with respect to testing new hypotheses or policies and easier to communicate to non-experts and decision makers. One further reason why land use models will tend to become more disaggregate is that geographic information systems (GIS) offer efficient ways to represent and manipulate spatially disaggregate data. There is an implicit affinity between microanalytic methods of spatial research and the spatial representation of point data in vector or raster GIS. Even where no micro data are available, GIS can be used to generate a probabilistic disaggregate spatial data base.

Disaggregate models are based on a decomposition of aggregate change into atomic subprocesses. A microanalytic theory of urban development, therefore, identifies these subprocesses and their structure. On a disaggregate level of explanation, urban development results from thousands or millions of human decisions, many small and some large, occurring over time as a broad stream of concurrent, unrelated or interrelated, individual or collective choices (Wegener 1986b). However, some processes are not decision-based but simply the result of time such as ageing and death. Figure 3 decomposes urban change into domains and atomistic process modules. Three types of modules are distinguished:

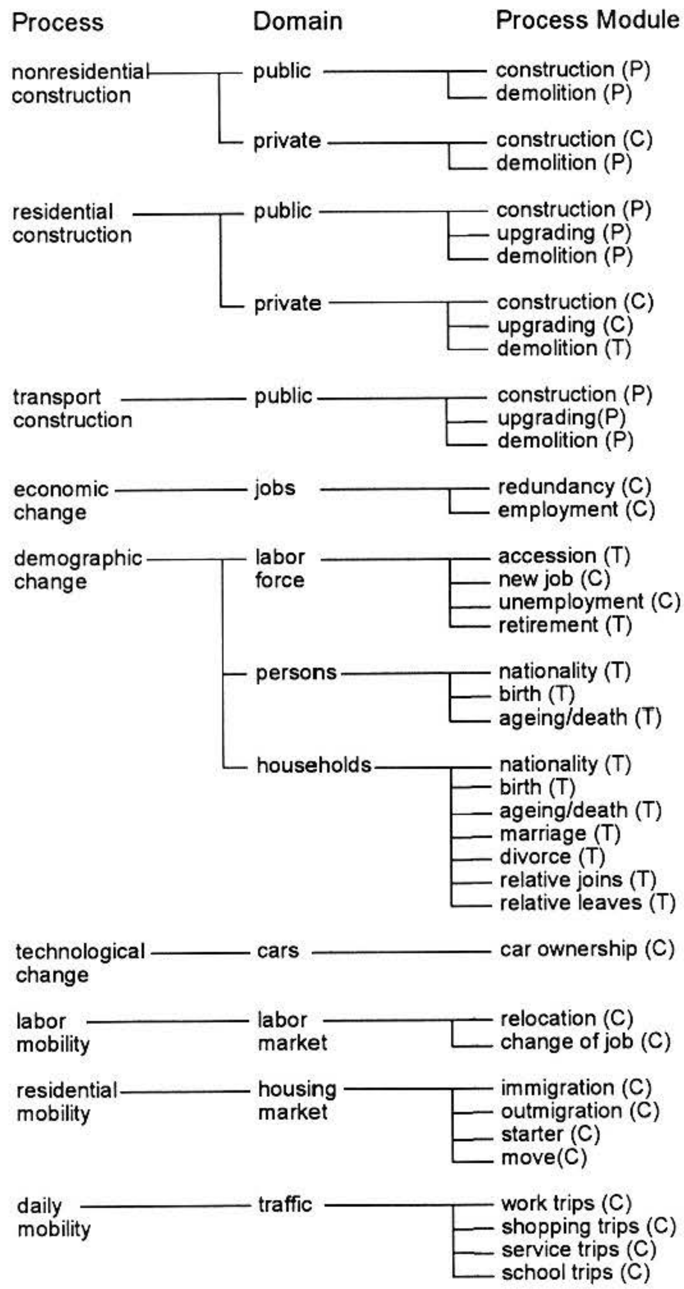

Figure 3. Process modules of urban changes: choices (C), transitions (T), policies (P).

- *Choices (C)*. A choice module represents a choice process. A typical choice module represents, for instance, the behaviour of a household looking for a dwelling in the housing market (Wegener 1985). Its propensity to move depends on its satisfaction with its present dwelling. It first chooses a neighbourhood in which to look for a dwelling, and this is not independent of its present residence and work place. The household then looks for a dwelling in that neighbourhood guided by the attractiveness and price of vacant dwellings there. Finally, the household decides whether to accept an inspected dwelling or not. It accepts the dwelling if it can significantly improve its housing condition. If it declines, it enters another search phase.

- *Transitions (T)*. A transition module represents a transition from one state to another. A typical transition, for instance, is the evolution of a household during a certain time interval during which it is promoted to another household category with respect to nationality, age, income or size, conditional on the relevant probabilities for events such as naturalisation, birth of child, ageing/death, marriage, divorce, relative joins or leaves household (Wegener 1985). Note that also choice-based events such as marriage or divorce may be treated as transitions if the causal chain behind them is of no interest for the purpose of the model.

- *Policies (P)*. Choice modules in which the decision maker is a public authority represent decisions by which the public authority intervenes in the process of urban development. Only policies resulting in physical change are indicated.

Most of the models in the sample are still aggregate, though to varying degree. HUDS is a pioneering early example of a consistently disaggregate model using a list-based data organisation. IRPUD in its present form is aggregate but changes into a disaggregate microsimulation in its housing market part. CUFM is highly disaggregate but emulates behaviour by decision rules, i.e., without modeling choice behavior. There are several experimental microsimulation models of urban land use and transport under development (Hayashi and Tomita 1989; Mackett 1990a; 1990b; Spiekermann and Wegener 1995).

Integration

A second prediction is that the formerly separate modeling traditions in transportation, land use and environmental forecasting are likely to converge. This is nothing new for land use modeling, which from its beginning has been based on the paradigm of the proverbial "land use transportation feedback cycle", which states that land use and transportation interact in pattern of circular causation (Figure 4): The spatial distribution of activities creates the need for travel; trip patterns create accessibility; accessibility influences the locational choice of developers, households and firms; and this in turn determines the spatial distribution of activities.

The two-way interaction between land use and transportation may be less commonplace for transportation modelers who are trained to take the land use forecasts provided by planning departments as something beyond doubt. Now transportation planners, obliged to think about the land use impacts of their proposals, call for land use models as add-ons to their trip generation, trip distribution, modal split and trip assignment models. Nothing could be more shortsighted. The land use transportation feedback cycle needs to work its way through several iterations to equilibrium or dynamic disequilibrium. Land use modelers have responded to this need by incorporating transportation submodels into their models. These transportation submodels initially were rather crude but over time became no less sophisticated than their transportation- only counterparts. The conclusion is that if transportation planners want land use forecasts, they have to integrate land use models into their models, or vice versa.

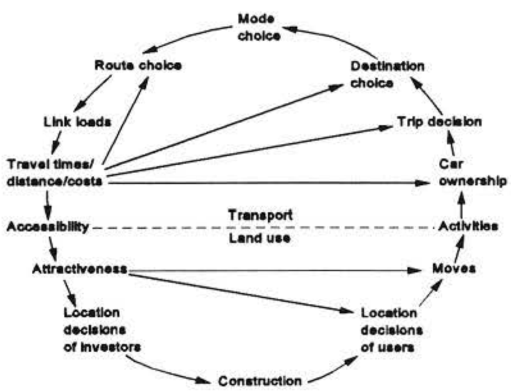

Figure 4. The 'land use transportation feedback cycle'.

A similar argument applies to environmental modeling. Here, too, exists a cycle of circular causation. Land use and transportation both generate environmental effects which in return affect land use in the form of development constraints or locational factors and, to a lesser degree, also affect transportation. It is therefore not sufficient to append a set of routines calculating environmental indicators to a land use transportation model; the issue is to model the feedback from environment to land use and transportation. This need has now been recognized by the land use modeling community; what used to be called land use transportation (LT) models is increasingly being termed land use transportation environment (LTE) models.

Modelling the Urban Environment

Ecological modelling has been an established field of scientific work long before the present debate about environmental sustainability. Important pioneering insights into the nature of complex dynamic systems originated in ecology (Lotka 1920; Volterra 1931; see Nijkamp and Reggiani 1992). Urban modellers, have for a long time ignored ecological aspects in their models and have only recently been prompted to redirect their attention from economic to environmental impacts of land use and transportation policies. The main reason for this is the threat of long-term climate change due to production of greenhouse gases by the burning of fossil fuels for heating and transport. A major additional thrust to include environmental impacts into urban models will come from the United States Intermodal Surface Transportation Efficiency Act (ISTEA) which shifts the criteria for new transportation investment from travel time savings to environmental benefits such as air quality or reduction of single-occupancy vehicle trips. To demonstrate these benefits requires different models.

In this section, a first overview of some pioneering efforts towards such models will be presented. It is difficult to get an overview of the state of the art in this rapidly developing field. Therefore, a quick, ad hoc mini-survey among some of the authors of the models reviewed in the first part of this paper was conducted, including two cases where models developed elsewhere are being adapted to produce environmental indicators. Most of the work is unpublished. The survey is not a comprehensive inventory of urban/regional LTE models in the world today. It can be assumed that particularly in the United States under the impression of the ISTEA legislation numerous new modelling activities are being launched by local governments of all sizes. Table 2 summarizes the main results of the survey.

There are clear priorities. Of the 24 models or model applications included in the survey, 13 calculate (or are considering to calculate) land consumption, as might be expected from land use models. Seventeen models calculate (or plan to calculate) energy consumption of transport. CO2 emission of transportation is modelled by 14 models, other air pollution by transport by 12 models. All other indicators are listed much less frequently. Energy consumption, CO2 emission and air pollution of land use are considered by seven models each. Surprisingly, only five models calculate traffic noise. Only between one and five models deal with water supply, vegetation, wildlife, micro climate, waste water, soil contamination, solid waste and industrial noise. Immissions are almost absent in present LTE models. Only seven models consider air dispersion, one noise propagation and two surface and ground water flows.

Another question asked in the survey (not shown in the table) was whether the environmental indicators are calculated only as output for later exogenous evaluation, or whether they are fed back into the land use or transportation parts of the models. The purpose of the question was to find out whether there exist two-way relationships between land use and environment and transportation and environment, respectively, just as there is a two-way interdependency between land use and transport. The survey indicates that there is no such symmetry. In only nine of the 24 models environmental indicators enter the attractiveness functions of land use location decisions. In two models transportation decisions are affected by environmental indicators, mainly energy cost.

In summary, most present land use transportation models are still far from deserving the name land use transportation environment models. Many environmental topics high on the list of controversial issues in contemporary cities have not been taken up by the models even though there exist suitable methods and data. In the majority of cases, the environmental indicators calculated are not fed back into the models and so have no impact on the behaviour of model actors. This is particularly surprising in the case of land use as it is well known that environmental quality has become a more and more important component of locational attractiveness not only for households but also for services and even for manufacturing. The little feedback from the environment to travel behaviour, on the other hand, is realistic and reflects one of the main problems of planning for sustainability: that the negative impacts of the automotive society are felt by everybody, but are not linked to individual behaviour: it does not pay to behave environment-ally. It is one of the key tasks of planning for sustainability to link the environmental indicators, through incentives and penalties, to the daily travel decisions of each individual. It is to be hoped that future urban LTE models will be able to model that kind of feedback.

Another problem encountered in the survey relates to dynamics. Most operational urban land use transportation models have relatively long simulation periods of five or more years. Environmental processes, however, have different time scales. Some processes such as air dispersion and noise propagation are very rapid and can be dealt with in cross-sectional sub models. However, the impacts of development on water supply, vegetation, wildlife and water quality have long response times, between several years and one or more generations. The problems arising from this for the temporal organisation of the models may be fundamental. The longer time perspective necessary for environmental analysis is likely to make equilibrium approaches less appropriate and may favour dynamic approaches allowing for a variety of different speeds of adjustment in different parts of the modelled system.

Finally, it must be noted that most existing land use models lack the spatial resolution necessary to represent environmental phenomena. In particular emission-immission algorithms such as air dispersion, noise propagation and surface and ground water flows, but also micro climate analysis, require a much higher spatial resolution than abstract zones in which the internal distribution of activities and land uses is not known: Air distribution models typically work with raster data of emission sources and topographic features such as elevation and surface characteristics such as green space, built-up area, high-rise buildings and the like. Noise propagation models require spatially disaggregate data on emission sources, topography and sound barriers such as dams, walls or buildings as well as the three-dimensional location of population. Surface and ground water flow models require spatially disaggregate data on river systems and geological information on ground water conditions. Micro climate analysis depends on small-scale mapping of green spaces and built-up areas and their features. In all four cases, the information needed is *configurational.* This implies that not only the *attributes* of the components of the modelled system such as quantity or cost are of interest but also their physical *location.*

This suggests a fundamentally new organisation of data of urban models. Geographic information systems, in particular raster-based GIS, promise to provide such organisation and so will have great importance for future integrated urban models. The tendency from zonal to spatially disaggregate raster-based data structures suggested by environmental modelling is in line with the enormously increased memory and computing capacity of modern computers but conforms also well with the trend towards disaggregate activity- based models in urban transport planning referred to above.

Table 2. Environmental impacts modelled by urban LTE models.

Models (Authors)	*Resources*							*Emissions*									*Immissions*		
Models (Authors)	Energy consumption by land use	Energy consumption by transport	Water supply	Land consumption	Vegetation	Wildlife	Micro climate	CO_2 emission by land use	CO_2 emission by transport	Air pollution by land use	Air pollution by transport	Waste water	Soil contamination	Solid waste	Industrial noise	Traffic noise	Air dispersion	Noise propagation	Surface/ground water
BOYCE (Boyce+)	○	○	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
ARCTRAN-AIR (Kim+)	·	·	·	·	·	·	·	●	●	●	●	·	·	·	·	·	●	·	·
ITLUP *(Putman)*	·	·	·	●	·	·	·	·	*a*	·	*a*	·	·	·	·		·	·	·
PSS *(Anjomani)*	·	·	●	●	●	○	·	·	·	·	·	·	●	·	·	·	·	·	·
LET *(Anjomani)*	·	●	●	●	●	○	·	·	·	·	·	·	●	·	·	·	·	·	·
TRANUS *(de la Barra+)*	●	●	·	●	·	·	·	○	○	○	○	·	·		○	○	·	·	·
TRANUS/CUFM[b]	●	●	·	·	○	○	·	○	○	○	○	○	·		·	·	·	·	○
MUS *(Martinez)*	●	●	·	·	·	·	·	●	●	●	●	·	·	·	·	·	●	·	·
LILT *(Mackett)*	·	●	·	●	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
SATURN *(Mackett+)*	·	·	·	·	·	·	·	·	●	·	●	·	·	·	·	·	●	·	·
MASTER *(Mackett)*	·	·	·	●	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
MEPLAN London *(ME&P)*	·	●	·	●	·	·	·	·	●	·	●	·	·	·	·	·	·	·	·
MEPLAN Helsiniki *(ME&P)*	·	●	·	●	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
MEPLAN Santiago (ME&P)	·	●	●	●	●	·	·	·	●	·	●	·	·	·	·	·	·	·	·
MEPLAN Vicenza *(ME&P+)*	·	●	·	·	·	·	·	·	●	·	●	·	·	·	·	·	●	·	·
START/DSCMOD*c*	·	●	·	·	·	·	·	·	●	·	·	·	·	·	·	·	·	·	·
CODMA *(Lundqvist)*	·	·	·	·	·	·	·	·	●	·	●	·	·	·	·	●	●	·	·
SALOC *(Lundqvist)*	●	●	·	●	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
IRPUD I *(Wegener)*	·	●	·	●	·	·	·	·	●	·	·	·	·	·	·	·	·	·	·
IRPUD II *(Wegener+)*	○	○	·	○	○	○	○	○	○	○	○	·	·	·	·	○	○	○	·
RURBAN *(Miyamoto)*	○	·	·	·	·	·	·	○	·	○	·	○	·	○	·	·	·	·	○
MAPLE *(Hayashi+)*	·	●	·	·	·	·	·	·	●	●	·	·	·	·	·	○	○	·	·
SUSTAIN *(Roy+)*	·	○	·	●	·	·	·	·	○	·	○	·	·	·	·	·	·	·	·
LAND *(Young, Gu)*	·	·	·	·	·	·	·	·	·	·	●	·	·	·	·	●	·	·	·

· *not modelled* ○ *under development or planned* ● *applied or operational*

\+ *et al.* *a* *links to standard EPA emissions models (MOBIL5)*

b *by de la barra (TRANUS) an Landis (CUFM), adapted by Johnston at UC Davis*

c *by MVA, adapted by Simmonds, Cambridge,* UK

Conclusions

This paper has been an attempt to review the current state of the art of operational land use transportation models in the light of the new challenges presented by the environmental debate. It has been shown that there have been immense achievements in land use and transportation modeling during the last two decades. There exist a dozen or so operational land use and transportation models which have been and are being used for real-life applications in cities all over the world. There are at least twenty active urban modelling centres on five continents in which new approaches are being generated and tested. There is a worldwide network of urban modelers who meet regularly to exchange ideas and experiences.

However, the review has also exposed deficiencies and blind spots of current models and modeling practice. Many current land use transportation models are still too aggregate in substance, space and time to match the sophistication of contemporary activity-based travel demand models and to respond to the requirements in spatial resolution of neighborhood-scale spatial policies to promote public transport, cycling and walking as well as of state-of-the-art environmental modelling. Many models have remained captive in the tradition of economic equilibrium, which bears little resemblance with a world characterized by disequilibrium dynamics. Too much effort is still being spent on cross- sectional statistical estimation of parameters about which only one thing is certain, that they change; while too little attention is being given to methods for validating models against time-series data. Only a few models to date deserve to be called land use transportation environment (LTE) models, although efforts to incorporate environmental indicators into the models are increasing. However, only a very few models have yet implemented feedback from the environment to land use and transportation.

These deficiencies suggest the agenda for modeling research in the next decade. Future land use and transportation models will need to be more disaggregate, more integrated and more responsive to environmental issues.

This may imply a new quantum leap in terms of disaggregation of variables---possibly down to the individual---and spatial and temporal resolution. Fortunately, likely further increases in memory and speed of computers and the growing availability of spatially disaggregate data will make this feasible, even though the number and magnitude of conceptual problems still to be solved may be immense. The association, or even integration, of land use transporta-tion models with geographic information systems will become standard practice, although, given the lack of flexibility of current GIS to be linked with other software, this may be a sizeable research program in its own right.

A second field of research will have to be devoted to integrating the formerly separate traditions of transportation, land use and environmental models. Transportation models will have to be embedded into land use models (or vice versa) and environmental models into land use transportation models. The current practice of feeding land use and transportation indicators off-line into exogenous environmental models will only be an interim solution as it negates feedback from environment to land use and transport. This also disqualifies feeding transport indicators into separate land use models. The future urban/regional model will be an integrated land use transportation environment (LTE) model.

A third major task is to select environmental submodels suitable for integration into land use and transportation models and adapt them to the new framework. Environmental submodels, without doubt, will further increase the data requirements of land use transportation models, so careful consideration of what is essential is needed. For many standard indicators, public-domain software routines ready to be interfaced with land use transportation models might be provided by public agencies in order to avoid duplication of effort and to guarantee consistency and comparability of the indicators derived.

Other research needs apply to the way models are used and embedded into the decision-making process. One important field of research will have to address problems of evaluation of policy impacts and issues of equity. Predominantly economic evaluation techniques such as CBA need to be complemented by multicriteria methods capable of measuring non-monetary aspects of mobility and neighborhood and environmental quality and their distribution across privileged and disadvantaged socioeconomic and spatial groups. The feasibility of such disaggregate evaluation will be greatly enhanced by the availability of disaggregate land use and population data required by activity-based transportation models.

Finally, more efforts will be necessary to make land use transportation environment models a routine tool by a widening range of institutions and individuals, including non experts. This must be supported by the development of attractive and efficient user interfaces for interactive manipulation of inputs and inspection of results. The Windows-based user shell of TRANUS, Young's gaming simulation LAND (Gu et al. 1992) and Batty's model visualization system (Batty 1992) are leading the way in this direction.

The greatest challenge, however, seems to keep urban modeling open for new problems. Urban models have in the past been applied mainly to a very narrow set of planning problems, and have repeatedly failed to adapt to changing problem perceptions. The next decade will confront cities and regions in the developed world with complex new problems. Increasing social and spatial inequity, an ageing infrastructure and the need to significantly reduce energy consumption and CO_2 emission will require innovative solutions if social conflict is to be avoided. Only if the models prove that they are able to give meaningful answers to the urgent questions facing cities and regions can they establish for themselves a firm position in the planning process of the future.

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Draft: Data Requirements For Land Use Modeling: First Thoughts and a Preliminary Assessment

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Abstract

This paper provides a preliminary assessment of various data resources for land use modeling and forecasting. Since land use models were first applied to problems of large-scale metropolitan growth and structure in the 1960s, the idea of what now constitutes a good model conceptually, as well as the array of data resources needed to develop new models, have radically changed, as indeed have the data and data sources which can now be utilized for such modeling. This paper sketches what now might be possible. But it also voices many cautionary notes which imply that although more digital data now exists across a wide variety of spatial scales, this data does not appear to be very accurate, nor is it the kind of data which might be immediately applicable to a new generation of models. Indeed many traditional problems in data still exist, particularly those covering the urban economy in terms of the land market and employment.

Introduction

This paper is a first response to a general question concerning the feasibility of beginning a new generation of land use modeling in the United States to support the requirements of the Clean Air Act Amendments (CAAA) of 1990 and the Intermodal Surface Transport Efficiency Act (ISTEA) of 1991. Here we will explore some of these questions with respect to the data requirements which such models would need, attempting some overview of what might be available to metropolitan planning organizations (MPOs) to engage in such forecasting. Our analysis is preliminary, it is not comprehensive, and it does not present data sources in the kind of detail that would be necessary before a considered response to these questions can be formed. In this sense, then, it is simply a paper which raises questions concerning data rather than providing any kind of definitive catalog of requirements. We assume that if the prospects for new land use models look promising from a variety of other perspectives, including this one, then a much more detailed survey of relevant data requirements would then be launched.

Essentially, CAAA and ISTEA provide a detailed mandate for the consistent forecasting of emissions and air quality on a sufficiently fine scale to take account of very small-scale shifts in land use and economic activity insofar as they lead to significant changes in traffic patterns and flows. This will clearly require land use forecasting on a much more detailed scale than has hitherto been attempted in general, and it will also require detailed temporal forecasting over much shorter time intervals than has been the case. Relevant data requirements for transportation modeling are presented in Karash and Schweiger (1994) and in TRB (1992) and we will not review these here. At the same time, new varieties of land use model are being considered. However, in the last twenty years, there has been very little operational land use modeling or forecasting. Many of the current models have been developed in academic and research environments and have thus not been subject to the dictates of practice which require robust forecasting (Wegener, 1994, 1995).

During this period too, new sources of spatial and to a lesser extent temporal data have become available, some of which have clear relevance to the past generation of land use models, and it is thus necessary to assess the extent to which these new sources might provide resources for a new generation of forecasting of whatever kind. Since 1980, there has also been a veritable explosion of software dealing with geographical systems which we will loosely refer to as geographic information systems (GIS) software, and this is enabling the association of physical and socioeconomic data involving land use in ways which were not possible a generation ago. These four issues - the new legislative mandates, the new models, the new data sources, and the new software - have changed the way we might respond to such questions quite radically. Or have they? These are the issues we will seek to evaluate here, in somewhat impressionistic terms which we see as a prelude to more considered and more detailed surveys.

The 1960s generation of land use models were spatially aggregative, replicating urban activity locations at the level of traffic analysis zones, census tracts and the like, in the manner of Lowry's (1964) model for Pittsburgh which built up an "instant metropolis" based on something like 500 zones. These models were also largely static in the temporal sense, fitted to cross-sections in time, and when used in forecasting were operated in a comparative static manner. In short, they were based on a conceptual view of the world which saw cities as having a macro spatial order which evolved slowly and deterministically, always moving towards an equilibrium. In the cases where the time frame was explicitly recognized, this genre of models were simply extensions of their static equivalents to several time periods. The models were rarely built around explicit temporally-dynamic processes *per se*.

In fact, it would now appear that these models did not work very well due to their conceptual simplicity although at the time lack of relevant data and difficulties over their largeness tended to drown out these more basic concerns. The clear volatility of micro behavior at the urban scale was not reflected in these models; it was assumed that it was not relevant at the macro scale, for there was a widespread assumption that macro behavior was tractable and predictable. We now know differently. Nevertheless, from the 1960s, there came at least two streams of model improvement based on these ideas: first, that associated with the macro "physicalist" tradition seen in the work of Putman (1991) and Echenique (1994), for example; second, that associated with a more micro urban economic tradition as in the work of Anas (1987) and Kim (1989), for example.

The new models which did emerge, however, were of a somewhat different kind although they were loosely grafted onto the older traditions. Microsimulation was used as a technique for simulating spatial choice and location following Orcutt's early work (Kain and Apgar, 1985) while new forms of urban dynamics incorporating historical accident in random terms, seen for example in Allen's (1994) development of Prigogine's theories of physical self-organization, came to represent the state of the art. However, many of these models were developed in academia and where they were developed with real data, the applications were either very aggregative or quite small-scale and partial. In all of this, however, there was little emphasis on the faster dynamics of urban processes operating on diurnal or weekly cycles, for the emphasis still remained on the long-term evolution of city systems.

The CAAA and ISTEA require forecasts at a particularly fine spatial scale, as well as over temporal intervals which are much shorter than those used hitherto. In assessing air quality, forecasts at the level of parcels and street segments are necessary rather than at the level of census tracts and over links between the centroids of such tracts. In one sense, there has been a mild convergence between the kinds of land use models now regarded as state of the art and the mandates of recent legislation in terms of spatial scale. However, this convergence is coincidental. In the development of new sources and types of data too, there has been a stronger emphasis on finer spatial scales, particularly in the development of GIS with its concern for cartographic representation, parcel level data and so on. Various third party vendors who provide data for GIS are developing new sources of data at the micro spatial scale, while even federal organizations such as the Bureau of the Census are now making micro data available. The development of GIS, however, has been largely atemporal and good sources of dynamic urban data rarely exist.

It might seem like some sort of convergence, but it is far from that. New ideas concerning land use models are considerably more tentative than they were a generation or more ago. What models exist are largely conceptual or at best "pilot" demonstrations of how land use change might be conceived in micro-behavioral and dynamic terms. Data sources which are comprehensive are still fairly aggregative and usually cross-sectional, and it would appear that there has been no improvement in the accuracy associated with such data over the last twenty years. Indeed, error seems to be more prevalent now in urban data although this may simply be due to the fact that we are in a better position to recognize it. At present, our capability to develop robust land use forecasts based on better and more appropriate data is still severely limited.

There are two other problems which pervade the development of good land use forecasting techniques. The first is the tension between the need for simple, robust tools which are capable of being used and refined in practice, and the increasing conceptual complexity of the emerging generation of models which in turn have much greater data demands than hitherto. Second, there is the problem of developing good forecasting tools for the short term to meet the dictates of CAAA and ISTEA in contrast to the need to develop better tools which can only be evolved over the long term. One issue which we will not really address here is the ability of the current generation of operational land use models such as Putman's and Echenique's to provide good forecasting in association with these new legislative mandates. Cross-sectional data which informs these models is clearly becoming easier to obtain as in the recently released Census Transportation Planning Package (CTPP), and this could well lead to considerable improvements in these techniques. However, it seems unlikely that these techniques can be evolved much further with respect to micro-behavior and dynamics which suggest conceptually different models which cannot be made operational overnight.

In the main body of this paper, we will first identify several issues which are generic to any discussion concerning urban data. These will involve the level of aggregation, new sources, the accuracy of data and such like issues which recur across whatever data set we are examining. Then we will sketch a fairly standard classification of data which reflects conventional distinctions between socioeconomic and physical data in terms of stocks, flows and various activity sectors. This classification is simply a vehicle for assessing what data exists although it can be argued that existing classifications such as this one belie a viewpoint which is no longer appropriate in treating these types of problems. Nevertheless, this is our starting point. We will then demonstrate an example of new data sources for a metropolitan region - the Niagara Frontier - which shows what is now easily available but at the same time, illustrates severe problems of accuracy and the difficulties of stitching unlike data sets together. Finally, we will use our analysis to suggest the need for a much more comprehensive survey of data requirements and availability.

The Key Issues

We will identify eight central issues that run through all our discussion of data requirements. These involve spatial, temporal and sectoral levels for scales of resolution (detail) which we will refer to generally as the level of aggregation or disaggregation, the availability and cost of data from a wide variety of sources, levels of accuracy (including precision as well as error), questions of confidentiality and non-disclosure, the representation of data in various digital media, and the question as to whether data might be used for short-term analysis or longer term model development. We will deal with these in turn.

The level of *Spatial Aggregation* is critical to land use forecasting in which the location of urban activities is central. Most urban analysis involving land use and socioeconomic activities has adopted, perhaps implicitly or unwittingly, the Census geography which begins at the level of the block (typically combining between 100 and 400 persons), and ranges across block group, census tract, civil division, county to state. However, data which is below the block level, at the parcel or street segment, is increasingly significant, particularly individual data which is referenced to some geocode such as the (5 digit) Zip or even Zip+4. As the sources of supra-block and sub-block data are different, there are usually severe problems of consistently linking data from these two sources. Indeed, a large part of the third party vendor community which has grown up around GIS is devoted to such reconciliation between Census data and data which is street addressable often coming from financial records.

A related point which has often been disregarded in land use modeling involves the link between "land uses" which are physical in nature and "urban activities" which are socioeconomic users of land use. Most land use models operate at the level of urban activities and the translation to land use is not seen as problematic. However in the drive to develop more micro-behavioral understanding of urban location patterns, this link between the socioeconomic and physical is ever more important. In a sense, the past and current generations of land use models are misnamed in that they are, strictly speaking, urban activity location models. In the quest for finer scale forecasting, this could well change.

Temporal Aggregation has been almost entirely neglected in previous land use modeling which, as we noted above, has been largely static based on cross-sectional data. Short term - fast dynamics - such as those involving diurnal activity cycles such as the journey to work, were also disregarded in previous modeling efforts. It was largely assumed that spatial interactions between activities could be simulated at a single point in time, usually the morning peak. Longer term dynamics - slow dynamics - involving changes in urban locations, migration and the like have not really featured within such modeling, apart from straightforward macro-economic and demographic forecasting based on trend analysis into which many comparative static land use forecasts have been nested.

Invariably, socioeconomic data is collected by public agencies at fixed points in time and there is little emphasis on tracking the dynamics of household processes and life cycle changes. Insofar as these can be derived, they are culled from temporal comparisons. Even the Public Use Microdata Samples produced from the long form questionnaire issued to around one sixth of all households at Census time does not really contain data which reflects dynamic decision processes. Where longitudinal data does exist, it is usually available for very small samples of the population and cannot be generalized across the nation at a spatial scale fine enough for land use forecasting. However, it is clear that new data sources involving temporal data are emerging. Remotely sensed data for the detection of urban change is improving dramatically at present (Budge and Morain, 1995), while financial transaction data is a possible source for detailed dynamics, particularly of household expenditures and preferences. Nevertheless, this kind of data and its exploitation is problematic in terms of the immediate requirements for better land use forecasting.

The general problem of temporal aggregation involves consistently linking data collected for short- and long-term dynamics across spatial scales and between individuals and aggregates of populations. The problem is illustrated best in terms of data which is captured through physical sensors which have fine spatial and temporal resolution but which cannot be easily linked to socioeconomic data to which they relate. Traffic counts and land use change are good examples which are difficult to link to household surveys of transport use, migration and housing choice.

Typically, land use and urban activity data are organized to reflect some rudimentary theory of how the city is structured in terms of urban economy and demography. We will refer to this as the level of *Sectoral Aggregation*. Sectors are largely associated with different types of socioeconomic data, but there is also a parallel set of distinctions that parallels these with respect to physical data pertaining to land use and land cover which tend to be classified similarly. We will use this distinction in the rest of this paper. In terms of the socioeconomic sectors, the demographic (associated largely with the Census) and the economic (associated with the collections of employment, unemployment and firm based data) are key. Characteristics of the population, health and education data, and some household income data fall under the demographic category.

Economic data has always been more problematic. Surveys are conducted more frequently than the decennial census, data has not been released at relevant spatial scales or in a comprehensive enough fashion for good spatial analysis. Economic data on linkages and commodity flows - on the spatial mechanisms of production - have traditionally been hard to come by, and this sector is dominated by methods of scaling down data from national and regional totals. Linking the demographic to the economic, spatially and temporally, is difficult, but is achieved through transportation surveys and, in particular, through the disaggregation and reclassification of the Census data for place of work (as in the CTPP).

Finally, physical data on land use involving development and land cover can be classified into general land use, which is usually based on a prior classification of land cover according to categories of use, physical buildings at the site or parcel level, and transportation infrastructure. Climatic and other geophysical data is somewhat separate in type from these although increasingly, physical land use data is becoming available from remote sensors which, of course, are also central to the provision of climatic and related data. We have already indicated the general difficulties of linking physical and socioeconomic data at the spatial and temporal levels, but it is worth noting that the only very comprehensive data sets available nationwide for land use forecasting on a completely comprehensive basis are the Census of Population (static and spatially disaggregate but in terms of areas) and land cover (dynamic and spatially disaggregate but in terms of points or cells). The difficulty of linking these two comprehensive sources involves the fact that their different attributes cannot be cross-classified and in any case are recorded on different spatial systems - in GIS terms, demographic data is associated with areas which are in vector form. Land cover is associated with areas which are rasters.

The *Availability of Data* involves several new data sources which have emerged in the last ten or so years. Traditionally, the public sector has been the main data provider but increasingly, the private sector is both collecting and processing data relevant to land use forecasting. The emergence of the third party vendors in the GIS industry is noteworthy and is based on three developments: the ability to add value through further processing of publicly available data, the linking of data from diverse sources, both public and private, and the processing of data from nontraditional sources, mainly from the commercial sector which involved the development of business geographics. There is also the development of the mainstream private sector in collecting and processing individual data from financial transactions but also from its own data collection activities, replicating and sometimes improving upon the activities of federal agencies such as USES.

There are consortiums of nonprofit making agencies, often universities, which are collecting data and adding value to it. For example, the provision of input/output data through IMPLAN is a case in point. Finally there are international agencies providing data such as the World Bank and IN, and the consortium of governments developed the Digital Chart of the World (DCW); these agencies, in fact, do have data that is culled from many sources and can be helpful at the regional level in land use forecasting. However, unlike a generation ago, data is no longer costless and this is an obvious factor in its use.

Accuracy is an important but often disregarded facet of data. There are many sources of error which affect accuracy; for example, errors in the sensing devices or in the responses by populations due to nonattributable causes occur. Bias in questionnaires or sensing in terms of sampling and in terms of the phenomena detected through this means, is common in both time and space. Nonresponses in socioeconomic data occur in censuses due to witting and unwitting causes, while errors due to psychological - physical actions of human processors or in computer processing, feature in most data. The causes are thus diverse, but the levels of error can be substantial. For example, the error due to the way the population was counted in the 1991 UK Population Census was in the order of 4 percent and this was entirely due to the inability of the designers of the Census to foresee problems of its administration. It is also worth noting here that positional accuracy is a major feature of physical cartographic data while nonresponse and bias is the main problem of socioeconomic data.

Problems of *Confidentiality* affect all data to differing degrees. There are clear rules at the state and federal levels with respect to the disclosure of public data, but the rights of individuals through the courts affects the way data collected from private sources is made available. Moreover, because data is collected from many diverse sources, it is increasingly possible using new techniques of matching, to recognize pattern across data and to begin to break the general rules of confidentiality by associating different characteristics and attributes from different data sets. There are limits, of course, to what is possible, but the private sector is more likely to be able to match data in this way due to its ability to devote more resources to and seek greater rewards from this kind of activity.

Most data is now provided in some *Digital Form*, but the media on which it is available differs widely and increasingly specialist software needs to be available so that data can be read. The CD-ROM is now the preferred medium and is the lowest cost media per unit volume shipped. However, it is very likely that more and more data will be available across computer networks. For example, the Lawrence Berkeley Lab holds the 1990 Census in its entirety (as well as the previous three decennial censuses) on CD-ROMs, and these can be downloaded over the Internet using browsers such as the Mosaic software which accesses the net through the World Wide Web. An example of this facility is illustrated in Figure 1. The address for the extraction of such data is http://cetr.lbl.gov/cdrom/lookup. Lists of data available from third party vendors are now available associated directly with these vendors or with the GIS software used in their display and processing. An example of data available in this way is reproduced from the ArcData book in the appendix.

The last main issue which runs throughout our discussion relates to the *Immediacy of Data Use*. In general, comprehensive data from the census, from third party suppliers such as those listed in the extract in the appendix, from agencies such as the USES and those who market satellite and other mapping data, are available immediately. The only restriction for MPOs is cost. Special purpose tabulations can be requested within confidentiality constraints, but it is impossible to generalize about the time required for these requests to be processed. Agencies and private vendors, however, are increasingly geared up to handle these quickly. Problems begin to emerge when data sets have to be stitched together from diverse sources or missing data has to be estimated. The collection of new data always poses problems and some of the early land use models begun in the 1960s clearly floundered because the efforts became bogged down in data collection. This will continue to be an important problem affecting the organization and management of such efforts.

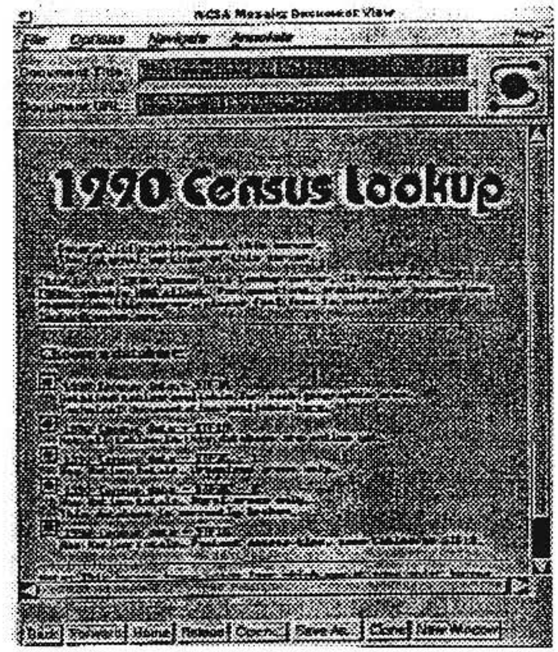

Figure 1: The LBL World Wide Web Census Archive

A Classification of Relevant Data

In this section, we will begin to assess the availability of diverse data for land use modeling in terms of sector, spatial scale and temporal resolution. Our classification is the standard one we anticipated in the last section, based on a distinction first between socioeconomic and physical data, thence based on the various sectors and their interaction which compose the urban system. We will then note the sorts of data which might be available for each of these categories, and we will provide a summary of the various problems which this analysis reveals. We cannot possibly provide a complete picture here, and we will avoid extensive detail that is possible with respect to what is well documented from public sources.

Our major focus will really be on the spatial scale at which data is available, as well as the gaps posed in terms of the various sectors. In general, we know that population data from the census is by far the best source of socioeconomic data, with employment still constituting a major problem when it comes to scale and to linking employment to the population. The most consistent set available which links the two sectors is the transportation data from the census (in the CTPP), and it is likely that this will still play a major role in any new wave of land use modeling to support the new legislative mandates. With respect to physical data, the major source is the USES which has good coverages of land use and natural cover in a comprehensive fashion for the US. Everything else - point data of various sorts in terms of the physical location of people and objects - tends to be non-comprehensive, and it is difficult to generalize about the availability of coverages.

Another major feature of our analysis and classification is the fact that it is almost entirely based on a conception of cities that is static, and that does not capture behavior *per se*. Most of what is collected at present is data which describes how things actually are and does not reveal directly any behavioral changes that affect land use. Of course, it is from this data that behavior might be inferred, but this is very different from the kind of data that might be collected in the first instance so that the dynamics of locational behavior can be captured and understood. This kind of data always requires special surveys, and it may well be that a new generation of land use modeling would require such data. Here we will not anticipate the argument except to say that there is little data collected at present which might engage this need.

We have organized our classification in terms of the socioeconomic structure of cities, first distinguishing between demography and economy and then noting the relations between these broad sectors in terms of physical and monetary movement/interaction of people and income, which in turn affect prices, wages and the like. We then extend our classification to physical data which we discuss in terms of natural and man-made land cover, distinguishing between building and transport infrastructure in the latter. We note the interaction between the socioeconomic domains and the physical in terms of the economy as it relates to the pricing of transport, land and buildings through various markets. Finally, we note the availability of cartographic data which is central to location, positioning, and mapping. We show this classification in Table 1. In essence, what we will attempt here is a brief elaboration of this list with respect to the sources, scales and availability of data associated with each category.

The best source for demographic data is the Census whose data is largely available down to block level (with approximately 4 million blocks in the US). All the categories in Table 1 under Demography, with the exception of taxation, leisure and energy use, are available (with considerable elaboration of some of these) from third party vendors. For example, income, life-style, and expenditure data is available down to census tract from other sources; a variety of health data from non-census sources relating to medical practice and diagnosis is available to block group level; and various life-style segmentations are also available at this level. These types of data are indicated in the appendix which reproduces the summary table of third party vendors who provide their data in ArcInfo format. Most of these vendors provide data for a range of software systems.

Migration data is more problematic although from the PUMS, it is possible to construct detailed classifications which yield migration tables. In fact, the PUMS is a source of much data on individual households, quite useful for micro-simulation, but does suffer from the fact that the data is only available for Public Use Micro Sample Areas (PUMAs) which are areas with at least 100,000 population. This means that PUMS data is effectively micro data but at a coarse, spatially aggregative scale, often equivalent to the county. There is very little by way of temporal dynamics of micro-behavioral process to be inferred from census data and although there are some intercensal estimates as reported in the county and city yearbooks, for example,

Table 1: A Classification of Data Items

SOCIOECONOMIC DATA

Demography

- *Stock Data: population and households*
    - Life cycle - age, sex...
    - Financial - income.....
    - Taxation and subsidies
    - Educational
    - Health
    - Occupational
    - Leisure use
    - Energy use
    - Housing
- *Flow Data: movements*
    - Migration
    - Changes in status

Economy

- *Stock Data*
    - Employment SIC...
    - Unemployment
    - Production by sector
    - Income to firms
    - Taxation and subsidies
    - Energy use
- *Flow Data*
    - Input-output linkages
    - Commodity flows

Demography-Economy Interactions

- Movements between sectors by mode
- Financial transactions
- Wages
- Expenditures

PHYSICAL DATA

Natural Cover

- Land use types
- Vegetation
- Climate
- Special coverages

Man-Made Cover

- *Building-development*
    - Size, Age, Condition .... by land use type
- *Transport infrastructure*
    - Size, Age, Condition .... by mode and type
- *Zoning use*

Natural-Man-Made Interactions

- *Constraints on development*

PHYSICAL-SOCIOECONOMIC INTERACTIONS

Markets

- *Prices of land, buildings*
    - by land use type
- *Transport pricing systems*
    - by mode

Tenure

- *Ownership/rental of land/buildings*

CARTOGRAPHIC DATA

- *TIGER/Line Files etc........*

these data sources only provide a picture of location at one point in time and any comparisons between time simply measure net change.

Data on the economy is even more problematic. Small area employment data is largely not available, and the best single source appears to be the data in the Census Transportation Planning Package, which is taken from the long form questionnaire of the Census and disaggregated to traffic zone, perhaps even to the block level, and is available in various cross classifications for all places over 2,500. The ES202 data which is the other main source from state departments of labor is normally only available at county level although the level depends upon the local rules for nondisclosure which vary from state to state. When it comes to financial and production data associated with the economy, this is rarely available at anything less than the county level. Data associated with linkages between firms is also estimated to county level and available from agencies like IMPLAN, but these data sets are usually formed by techniques for scaling national and regional data to local. In fact, some of the best advances in allocating aggregate data to a disaggregate level are to be found in this area, as well as techniques for estimating missing data which are based on similar logics.

Quite a lot of data on individual sectors and establishments, sometimes by Zip(+4) are now being offered by third party vendors. However much of this data is only available to county or 5 digit Zip; yet it does contain essential employment data at this level as well as data concerning the size, sales, etc. of various businesses. For example, Dun and Bradstreet's Business Line data contains detailed records on up to 10 million businesses which can be identified, in principle, to any spatial scale. Lastly, interactions between the economic and demographic sectors in terms of physical and financial transactions are difficult to measure. The CTTP is the best comprehensive source for trip making data, but it is subject to all the problems of household reporting of this kind of activity, and it misses what actually happens in terms of actual movement recorded *in situ*. Household expenditures are available from several third party sources down to block level, although data based on expenditures from origins to destinations in terms of firms, households and other economic linkages is almost entirely absent other than on an *ad hoc* basis. Once again, these data sets are essentially static in time although in the case of private data sources, there is considerable updating of data which in itself adds value. It is even possible that better time series data at finer spatial scale might emerge if there was a sustained demand for it from agencies such as MPOs.

The most comprehensive data which is both spatial and temporally disaggregate is the least interesting with no behavioral content. This is data which pertains to natural land cover. There are several data sets available at scales of from 1:24000 up available from agencies such as USES. For example, land use maps are available digitally at 1:100000, while DEMs, DLG and other feature map data provide a wealth of information in the public domain, relevant to many physical problems of land use planning. Much of this data is available over the net and its availability is indicated in the USES homepage at *http://www.usgs.gov/*. Man-made cover in the form of data concerning physical structures such as buildings and transport routes is available from state DOTs, and from offices dealing with Tax and Assessment. The latter data, however, is often incomplete, for it is not designed for land use forecasting although it does provide a useful base for parcel level and land value data. Normally, this data is available in point coverages with parcel boundaries rarely available in digital form as yet. This type of data is available on a more frequent basis than the census data, and there is some prospect here that good spatially disaggregate time series will emerge in due course. The major problem, however, is still one of linking this physically based data to socioeconomic characteristics of the population. Howe price data is available from Multiple Listing Services which operate in most cities but as yet, their accuracy is unassured although the data provides extremely good time series which are spatially disaggregate to the level of the street segment. The existing data concerning transport costs and pricing is more problematic and is not in a ready source.

The last set of data relates to positional and cartographic data which is widely available. The TIGER/Line files which represent a joint product of the US Bureau of the Census and USES remain the major source of digital features which can be used to construct everything from street segments to administrative boundaries. This data is widely available and virtually in the public domain for many types of users. Its quality is variable, especially for transportation modeling, but it does provide a comprehensive source for display rather than analysis. We will illustrate its use in the next section. Readers interested in exploring its applicability are referred to http://www.tiger.census.gov/. There are several lists of data sources, the best of which are associated with the GIS industry. Each of the software vendors, as well as the data vendors themselves, have comprehensive lists of available data which they are able to repackage in customized form. For example, the list of data by type and source within the ArcData catalog is reproduced in the appendix to give readers some sense of the variety of data available in digital form which can be processed by GISs such as ArcInfo.

Before we provide some brief examples of new sources of digital data which have relevance to land use forecasting, it is worth summarizing so far. There is little doubt that despite the fact that most data of any relevance at all now exists in digital form, there are still important holes in the data terrain from the perspective of land use modeling. First, hardly any dynamic - that is time series - data exists for small area forecasting apart from that available from comparisons between temporal cross-sections usually over ten years. Second, data below the block level is generally physical rather than socioeconomic in nature as well as being partial, that is, not comprehensive in its coverage. It is also exceptionally difficult to relate to the spatial attributes of socioeconomic data. Third, there is very little comprehensive data with respect to individuals within the population at a fine spatial scale. What data which does exist is from the PUMS, which is spatially aggregative or from one-off panel studies of households or businesses whose sources are far too specific to be able to develop general models from. Fourth, employment data remains the singly biggest problem in terms of sectoral coverage although data pertaining to the behavior of households and the local economy measured in terms of any kind of flow, be it physical or monetary, continue to pose problems. Finally, there is little micro behavioral data pertaining to any spatial-locational processes, although *ad hoc* surveys of developer decision processes are perhaps the exception.

An Example: The Quality of Diverse Digital Data Sources

Before we conclude this brief discussion, it is worthwhile inquiring a little more deeply into our ability to relate unlike digital data sets, and the kind of errors associated with such data. Our emphasis here is mainly on the physical properties of linking data and the positional errors that might occur. Of course, perhaps the most substantial problems pertain to stitching together data sets in terms of their common attributes, but there is not much experience which has been readily documented in this domain, and thus we will simply deal with physical data here. Moreover, one of the biggest changes in data availability has been in terms of physical and locational data, and as our focus here is mainly spatial, given the dearth of dynamic data, then our example is appropriate.

Our example is also of interest in that 30 years ago, Lathrop and Hamburg (1965) designed one of the first land use models for Western New York State - the Buffalo-Niagara Falls metropolitan region - and thus we have a direct comparison. Their model was based on allocating urban activity to small areas - census tracts we presume - using gravitational concepts. The model was dynamic, but only in the sense that a comparative static structure was operated at ten yearly intervals. An example of their predictions is given in Figure 2. Today, the range of data available is very much more extensive although its quality is probably no better, it is not dynamic in the temporal sense, nor does it emphasize micro-behavior. We are in the process of exploring the evolution of the Buffalo region in terms of its macro dynamics from micro data and to this end, we have assembled several sources, all of which are available digitally and all of which can be related directly in the positional cartographic sense. The data sets in question are:

1. The USES Digital Elevation Model for this area which provides detail of terrain from ortho-photos, at a scale of 1:100000. The relevant sheets for the Niagara region are available digitally over the net and are thus in the public domain. The data provides excellent details of topography and water.

2. Data on all taxable parcels in Erie County is available from the State Board of Equalization and Assessment for each year. There are nearly 350,000 parcels in Erie County and each site's coordinates are given with attributes covering land use type, area, land/property values, and age of construction. This data was purchased in ArcInfo coverages from the State Data Center for around $1,000.

3. Processed data from the 1991 Population Census at block group, tract and Zip code level has been purchased from Claritas and also includes forecasts for the next ten years. The data includes significant variables such as income, household size, age, sex, and other similar household characteristics. This data was purchased for around $500.

4. Raw TIGER/Line file data which can be used to extract the street pattern associated with this area. This data was available from the US Depository Library at the University at Buffalo.

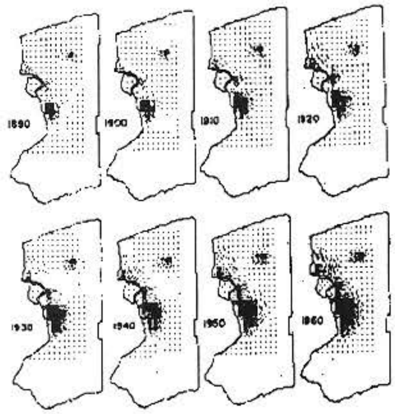

Figure 2:
Lathrop and Hamburg's Simulation
of the Niagara Frontier in 1965

Our ability to relate these data sets is entirely due to the availability of GIS and related software which enables us to overlay the various coverages in a consistent manner. We have transformed all the data to the same coordinate system (UTM-NAD23), and this may have introduced some error or at least proliferated error already in the positional data. We have used ArcInfo for much of the work, but the best overlay display capability for our purposes is within the image processing software ERDAS which has many GIS-like functions. Note also that the Claritas census data was originally prepared for MapInfo. Our ability to move this data across diverse platforms is not in question in that although the major processing and visualization have been using Suns, the data has at various times been in DOS, Mac and Vax environments for this particular project, where making the best use of whatever software exists on whatever platform has been essential.

In Figures 3 and 4, we show the natural cover which forms the physical backcloth on which the various man-made features and socioeconomic attributes of the population can be located. The biggest single problem with this type of data is the "joining" together of different sheets. The line running across Figure 3 which marks the division between the "US" and "Canadian" sheets is clear. We "think" that up to five lines of pixels are missing here but in the vicinity of the US-Canadian border, the Niagara River is completely at error in the area of Grand Island which does not exist. There are procedures for correcting these types of errors systematically, but in this case these errors are so severe that it has been necessary to touch up and import the "correct" detail by hand. In Figure 4, an enlargement of the new image is shown which has been touched up using Adobe Photoshop. These types of problems characterize this kind of physical data which is taken from remote sensors in the first instance or from ortho-photos and is generalized prior to its use in these types of applications.

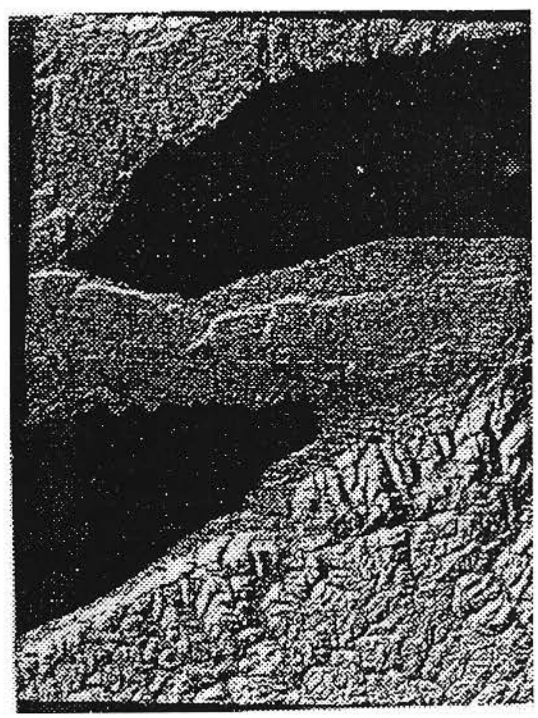

Figure 3: The DTM Coverage with Major Errors in Joining Data

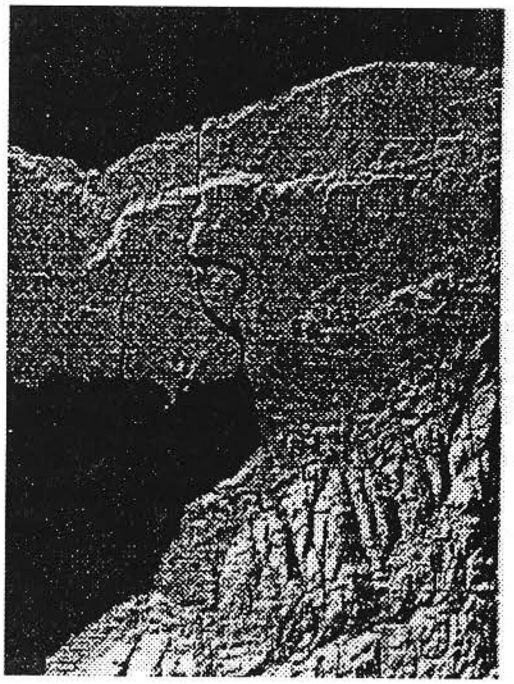

Figure 4: The "Touched-Up" Sheet

The physical backcloth provides the anchor to which all other locational data is fixed. In Figure 5, we show a plot of the parcel data which has been coded by age of construction, thus giving an impression of the historical growth of Buffalo. This data is for Erie County only and had we purchased data for Niagara County, then we may well have been involved in the same problems of stitching sheets as we were for the terrain data. Two immediate problems are revealed by the display; indeed visualization is probably the only way to reveal the nature of these problems. First, a large area of land in the division of Cheektowaga has not been coded with respect to year of construction and this stands out as a geometrical region. It is possible that the data has been coded but has not been input to the file we received, but we have not investigated this further. It does illustrate, however, the problems faced with very large data sets. Second, when we zoom in on the area of Buffalo City itself as we do in Figure 6, there are several locations/parcels located in Lake Erie. We consider these to be miscoded as the rectification error of the two images is not as great as the displacements of these parcels. Errors of this kind clearly abound in this data set. In our project, we are interested in error and we are developing techniques for replacing the missing data. However, in practical problems of land use forecasting, such errors would be unacceptable, and it is entirely likely that some data sets, perhaps this one, might be judged unacceptable at an early stage.

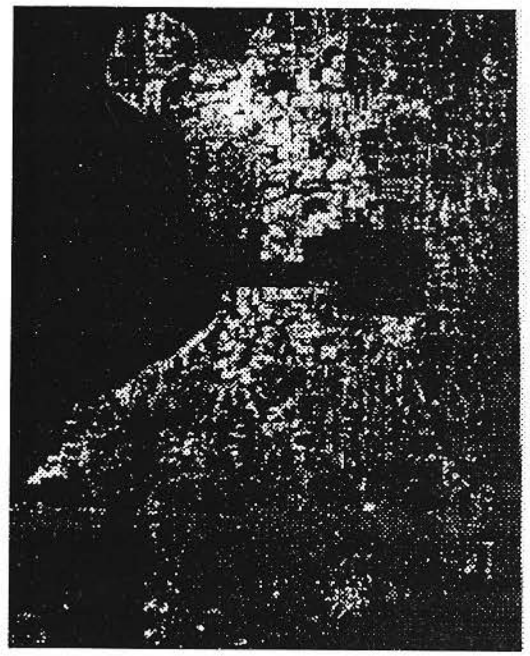

Figure 5: The Parcel Data for Erie County with Mission Region

In Figures 5 and 6, we show the outer boundary of Erie and Niagara Counties which we have generalized from the Claritas data and imported into ERDAS. The rectification of this boundary with respect to the two other data sets is good, and although we do not show various Census divisions associated with this coverage, it is clear to us that these are acceptable too. However, we can also overlay the raw TIGER data onto these images so that we can judge this correspondence between street and parcel data more accurately.

Figure 6:
Locational Errors in the Parcel Data Detectable by Overlay on the DTM

In Figure 7, we show the line features from TIGER which mainly mark out streets on the parcel level data which, in turn, is on the terrain data. Note that in this image, as in Figures 5 and 6, the terrain data is in its uncorrected form and several water bodies are incorrect at the base of the Canadian sheet. These are seen in Figure 7 too. The area which is shown is the North Campus area of SUNY-Buffalo. As we know this area well in terms of street patterns, we can see clear errors in TIGER where parking lots are represented as streets and where street segments have been coded inaccurately. However, amazingly, we are able to point to particular parcels at this level of resolution, query their attribute data, and judge their accuracy. As a general test of the parcel data year of construction attribute and the relative location of these parcels in terms of street segments, the correspondence in Figure 7 is good, much better than we expected.

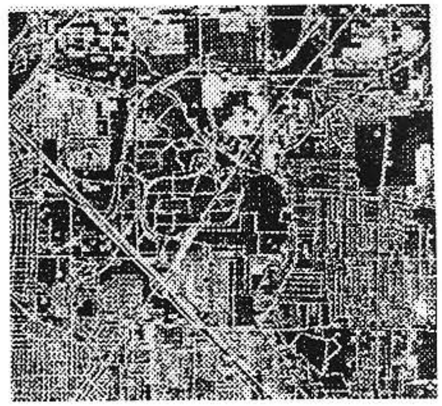

Figure 7:
Matching TIGER to Parcel Data

However, we should conclude by illustrating other problems with TIGER which are based on human error or rather differences in the way the coding instructions have been interpreted at different places. In Figure 8, we have laid a 100 meter grid across the raw Tiger data for Erie and Niagara Counties, and we have coded the data according to whether or not a residential street exists in each grid cell. The resultant image is a map of "residential area" at the 100 meter level which we can use as a proxy for examining the form of urban areas. What is striking about this image is the fact that residential streets have been coded somewhat differently in the northeast of Niagara County where the density of residential streets/cells changes substantially. This may be the Indian reservation, but an examination of other maps suggests human error. In examining the same patterns for six cities in the Northeast, there is a real sense in which these patterns differ in their densities, which are attributable in part to differences in their coding.

Figure 8: Possible Differences in Coding TIGER Data

We have not examined the errors or the problems involved in stitching different socioeconomic attributes together from different data sets. These types of problems, however, are conceptually more difficult. For example, because we have detailed parcel data within each census block group, we can begin to think about the association of the population at these levels with this data. It might be entirely possible to examine distributions of households across various indicators, such as from the PUMS data; examine the distribution of property parcels in terms of land values, etc. across the tax data; and then using correlations between the two sets of distributions, begin to assign population characteristics to parcels with each block group. The methods for doing this kind of data allocation have been slowly developed conceptually over the last 30 years, but there is very little practical experience in doing this. Moreover, we have no sense of how good such procedures might be. Finally, we caution that the development of these types of techniques could be time-consuming, and there is a real danger that a new generation of land use forecasting would become bogged down in problems of rectifying, correcting, and estimating errors in very large data sets unless strict guidelines for practice are laid out in advance.

Next Steps

This has not been a very satisfactory paper to write because an overview of data sources and their errors is so difficult to assemble. We face the problem that unless one is working with data, it is very hard to know details of what the data implies or what is actually available. Our discussion is clearly limited by these points, although we do have some sense of the data terrain which now needs to be elaborated upon in some detail if a clear picture is to be achieved. There are several issues on which we can conclude, and we will list these as items for further research and discussion.

It is clear that there is no general source of micro spatial data on entire populations within the demography and economic sectors below the block level. This is due to both confidentiality/ nondisclosure and the fact that there has been no clear imperative for such data collection. The singly best source is the Census. Data being collected by third party vendors is invariably partial in that it concentrates upon specific sectors pr characteristics or is spatially noncomprehensive. Data on interactions of various kinds other than physical transportation is generally lacking. Data on nonphysical flows such as telecommunications might be available, but there is little sense of the way such data might inform questions of urban location and change even if it were available. We have not addressed such data within this paper, for there is an obvious theoretical vacuum in this domain. The substitution, as well as augmentation, of telecommunications for physical movement is something we have not addressed at all here, and it has profound repercussions for the collection of new data. Better theory is required before we can make much sense of this.

There is little data dealing with longitudinal change which reflects decision processes and patterns. In short, most data does not deal with the decision processes of firms and the various activity patterns of households. It may be possible to generalize from limited sets of such data to more complete populations using various techniques from micro-simulation and although such techniques are promising, there is little empirical evidence that such techniques lead to robust projection. Micro-data at the level of the firm or household is generally lacking and even if it is available, it is often construed and measured in physical terms, and therefore difficult to link to other socioeconomic data.

It would appear that there is much that might be done with constructing synthetic data sets which might meet some of the challenges posed by a new generation of urban location and land use models but again, such ideas have hardly been widely tested. In this paper we have avoided the long-standing link between transport and land use in terms of data, but many of the problems of linking large unlike data sets which we have posed here exist for this interface as well. All in all, the prospect for a new generation of land use modeling based on more micro dynamic urban decision processes looks problematic. In terms of existing data, it would seem that in the short term, an emphasis on simple, well tried techniques should be impressed with the limitations and robustness of the methods involved well charted. Some simple demonstration projects are required here. In terms of the longer term, some major funding of more speculative but more relevant land use urban activity modeling is required. This will require much new data and more innovative use of what already exists.

Acknowledgments

We sent e-mail to the following listservers asking about sources of information for small area data on employment, house prices, and land values:

- gis-l@ubvm.cc.buffalo.edu
- regsc-l@wvnvm.wvnet.edu
- planet@fau-vax.bitnet

We received 25 responses which were very useful and we thank those who communicated with us. This paper is based on research being carried out at the National Center for Geographic Information and Analysis, supported by a grant from the National Science Foundation (SBR-88-10917).

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Appendix: Third Party Data Suppliers from the ArcData Catalog

This is an extract from the Overview Table

Business Establishment Data

	Business Information	Specialized Business Information	Shopping Center Information
America.dbf	The Ultimate Map & Data Set (PB)		
Claritas	Business Data Point Files (GR)		Shopping Center Data
Equifax National Decision Systems	ArcCity™ (PB) Business-Facts® Summary & Employment Business-Facts Location Point Coverages	ArcCity™ Industry-Specific Data Sets (PB)	ArcCity™ (PB) Shopping Centers
Market Statistics	Business-to-Business Database Commercial Database		
National Research Bureau (BMSI)			Shopping Center Database
SMI	BusinessLine™ Business Locations BusinessLine™ Business Stats	Progressive Grocer Trade Dimensions RE-COUNT Restaurant Database SMI Industry Packages (PB)	Shopping Center Profile
Urban Decision Systems (BMSI)	Business Database		Shopping Center Database

Cross-Reference Key: GR = General Reference Data; PB - Packaged Business Data

Packaged Business Data

	General Purpose Packages	Business	Financial Services	Health Care	Retail, Real Estate, & Advertising	Telecommu-niciations & Utilities
America.dbf	The Ultimate Map and Data Set					
Equifax National Decision Systems	ArcCity™	ArcCity/ Automotive	ArcCity/CRA ArcCity/ Financial Services		ArcCity/CRA ArcCity/Retail ArcCity/Real Estate	ArcCity/ Telecommu-nications ArcCity/ Utilities
SMI		Business-to-Business Package	Financial Services Package	Health Care Package	Retail Package Real Estate Package Advertising & Media Package	Utilities and Telecommu-nications Package

Health Care Data

	Consumer Demand and Diagnosis Data	Hospital and Facility Data	Physician Data
Claritas	DRG Demand & ICD-9 Demand Senior Life	HMO Database Hospital Database Nursing Home Database	Physicians Data
Equifax National Decision Systems	Health-Facts™		
SMI	Ambulatory Demand Services Diagnosis Related Groups (DRG) Major Diagnositc Categories (MDC) SMI Industry Packages (PB)	Health Care Provider of Services Point Locations Hospital Utilitzation File SMI Industry Packages (PB)	Physician Speciality Counts Physician Point Locations SMI Industry Packages (PB)

Cross-Reference Key: PB = Packaged Business Data

Financial Services Data

	Financial Services
Claritas	FDIC/FSUC Information
Equifax National Decision Systems	ArcCity™ (PB) ArcCity™ Industry-Specific Data Sets (PB) Financial Facts®
SMI	Financial Institution Deposit Data Financial Registry: Financial Institution Locations SMI Industry Packages (PB)

Cross-Reference Key: PB = Packaged Business Data

Census/Demographic Data

	Five-Year Projections	Current-Year Estimates	1990 Census Data	1980 Census Data
America.dbf			Postmaster™ Brand High-Precision Zipcode Boundaries (GB) The Ultimate Map & Data Set (PB)	
Claritas	Trendline-GIS UPDATE	REZIDE-GIS Trendline-GIS UPDATE	Census Demographics STF-3 InfoPak-GIS REZIDE-GIS Trendline-GIS UPDATE	Census Demographics Trendline-GIS (in 1990 geography)
Data Map		Postal Carrier Route Demographics File ZIP Demographics File		
ESR1				ArcUSA™ 1:2M (GR) ArcUSA™ 1:25M (GR)
Equifax National Decision Systems	ArcCity™ (PB) Pop-Facts® Demographic Database	ArcCity™ (PB) Pop-Facts® Demographic Database	ArcCity™ (PB) Pop-Facts® Demographic Database	
EQUINOX			PopBlocks™ PopBlock/Points™	
Market Statistics	Population Basics Database Demographics U.S.A. Database on Diskette		Demographics U.S.A. Database on Diskette	
SMI	AmericanProfile™	AmericanProfile™	AmericanProfile™	AmericanProfile™ (1970 data also avail.)
Urban Decision Systems (BMSI)	Demographic Database	Demographic Database	Demographic Database	Demographic Database (1970 data also avail.)
Wessex			Wessex Pro/Filer™	

Cross-Reference Key: GB = Geographic Boundaries; GR = General Reference Data; PB = Packaged Business Data

Consumer Data

	Net Worth & Income	Lifestyle Segments	Retail Sales Estimates & Product Preferences	Variety Databases
Claritas		PRIZM® Lifestyle Clusters	Consumer CLOUT™	
Equifax National Decision Systems		ArcCity™ (PB) MicroVision™ Lifestyle Segments	ArcCity™ (PB) Consumer Expenditure Potential	ArcCity™ Industry-Specific Data Sets (PB)
Market Statistics	Income Basics Database		Consumer Expenditure Survey (CEX) Retail Sales Database	Consumer Basics Database
SMI	Affluence/Model Net Worth Categories Affluence/Net Worth	ClusterPLUS® 2000 Lifestyle Segmentation Data Hispanic Portraits WealthWISE™ Financial Clusters	Market Potential™ Retail Sales Expenditures Syndicated Product Potential WealthWISE™ Financial Clusters	SMI Industry Packages
Urban Decision Systems (BMSI)			Consumer Expenditure Database Retail Potential Database	

Cross-Reference Key: PB = Packaged Business Data

Understanding the Decision Makers: Policy Requirements for Land Use Modeling

Robert T. Dunphy, Senior Research Director, Urban Land Institute

Current Trends in Real Estate

In examining the needs of real estate decision makers, it is useful to have a feel for the current markets and product trends - what's hot and what's not. While planners and modelers often need to deal with long-term trends of 20 years or more, private real estate decisions are much more focused on the here and now. Understanding today's real estate market also offers a window on longer term trends. The latest "ULI on the Future: Reinventing Real Estate" offers some key trends from 64 local market experts.

Real Estate Markets

The good news is that the improving economy is having a positive influence on virtually all real estate markets and regions. Of the 64 market experts surveyed, 55 reported increases in net effective rents or sales prices, three reported flat rents or prices, and only 6 reported declines. For the coming year, 62 out of 64 expected increases. The most bullish were those from Atlanta, Austin, Colorado Springs, Fort Lauderdale, Greenville/Spartanburg, Indianapolis, Nashville, Portland (Oregon), Salt Lake City, and San Francisco. Least bullish were those in Buffalo, Fresno, Honolulu, Houston, Los Angeles/Long Beach, Milwaukee, Hartford, Omaha, Las Vegas, and Riverside/San Bernardino. Of course, growth is cyclical and a region out of favor now could rebound later, just as a hot market can blow cool.

Most analysts agree with the trend toward strong growth in smaller, low-cost communities. Low-cost global competition and life-style preferences are important influences in the growth of places like Albuquerque, for example. Christopher Leinberger of Robert Charles Lesser & Company favors the Middle South and Mountain states, places with a mild four season climate as opposed to two season (Sunbelt) and harsh four season areas. In addition, he believes regions with strong growth controls, such as the Northwest and mountain states offer good opportunities for investors because there is less likelihood of overbuilding.[1]

Individual Product trends include:

For Sale housing, which is in the front of the curve in the real estate cycle, recovered first, and seems to be lagging now.

Apartments are a favored product in today's market, largely because of a decline in construction, which has increased occupancies and rental rates.

Suburban office is improving the best, while the CBD office market is sluggish, except for Portland, and Salt Lake City. A positive factor is that space per worker appears to be increasing. An important location factor is that the build-to-suit clients are moving to the urban fringe. Industrial continues to be slow as a result of corporate downsizing. Retail is still over built, but the growth areas are in big box super stores and entertainment retail. Examples include

Wal-Mart and K-mart, which are concentrating on super stores of 100,000 square feet, which combine general merchandise and groceries. In the retail music business, MusicLand's Media Play stores, which offer movies, music, software, books, and magazines in a 50,000 square foot super store, is challenging Blockbuster, with an expected growth from 13 stores in 93 to 180 in 1998.

Who Owns America's Real Estate?

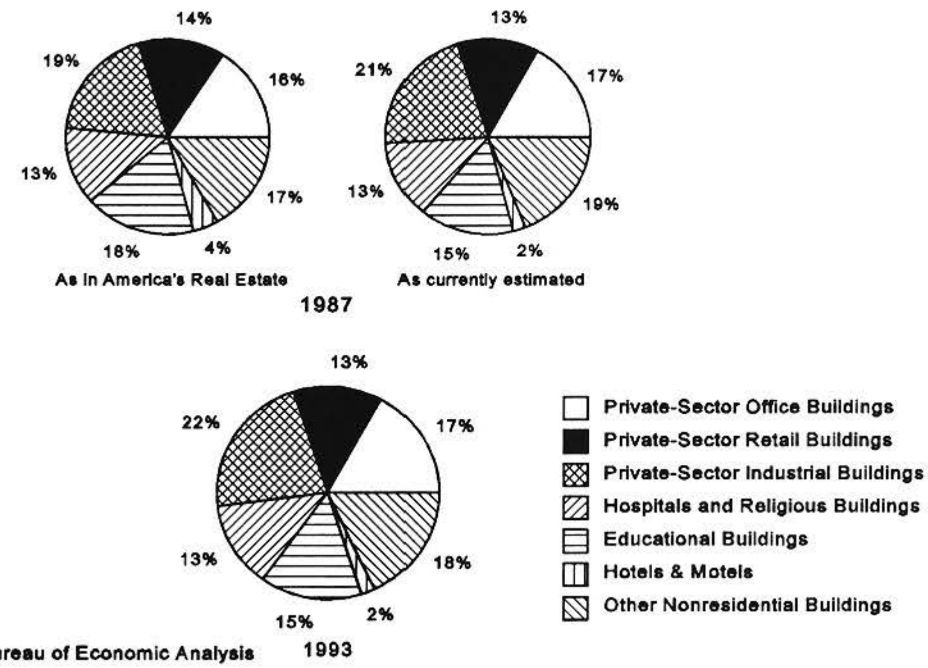
Understanding key land use decision makers begins with an understanding of who owns real estate. While the conventional wisdom sees most development decisions as the responsibility of real estate developers, there is much more diversity in the ownership of America's real estate. Half the value of real estate assets in 1993 was in the hands of households. While the vast majority of these homes were originally built by builders and developers, it is estimated that one in four new homes are built by individuals on their own lot. Business ownership, which includes both commercially owned and leased property, represented about 25% of assets by 1993, a sharp decline from earlier estimates because of falling property values, while most of the rest is in the hands of government. Focusing specifically on non-residential buildings, Figure 1 shows that private sector office and retail buildings combined, the heart of commercial real estate, account for less than 1/3 of asset values, with the largest category being private sector industrial buildings (22%), followed by educational buildings (18%), hospital buildings (13%), hotels and motels (2%), and others. The data shows that many people have a hand in real estate besides full-time professionals.

Real estate firms have a much more important stake in the ownership of office buildings. Figure 2 shows that they were estimated to own 29% in 1993, second only to financial institutions, who controlled 36% of America's office buildings. Almost one out of seven office buildings were owned by services firms, apparently for their own use, who obviously opt for owning rather than renting. Retailers and manufacturing firms own 8% and 7% of buildings, respectively. In the category of retail buildings themselves, Figure 3 indicates that real estate firms currently own 27% of the assets, more than half that owned by the retailers themselves. Another 7% of retail building assets are owned by financial institutions.[2]

This review demonstrates that the ownership of real estate is very diverse, and that for most owners it is a secondary interest rather than a major emphasis. That is an important message in determining the needs of land use decision makers.

1: U.S. Nonresidential Buildings

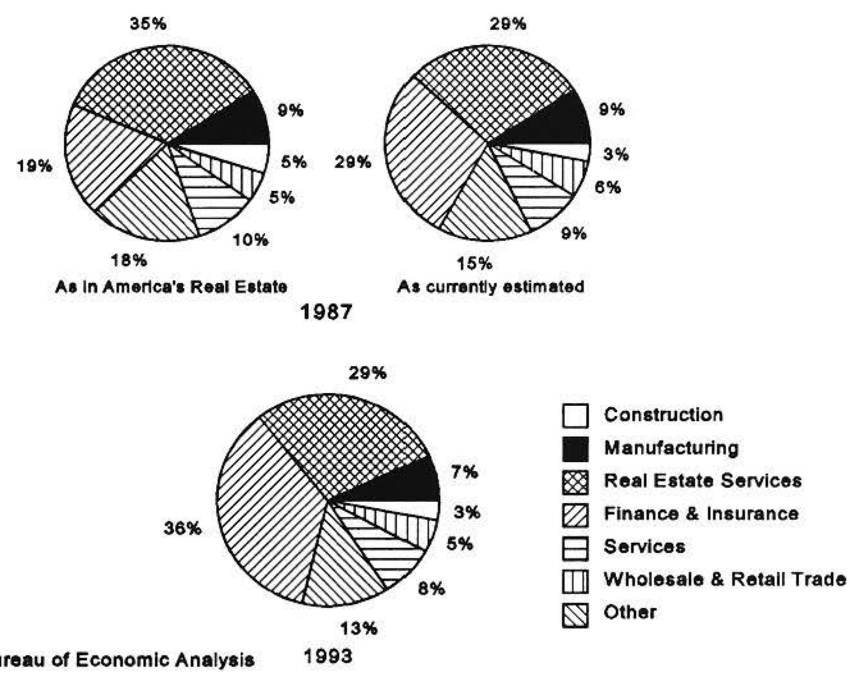
(Valued at 1987 Replacement Cost)



Source: Bureau of Economic Analysis

2: Ownership of America's Office Buildings

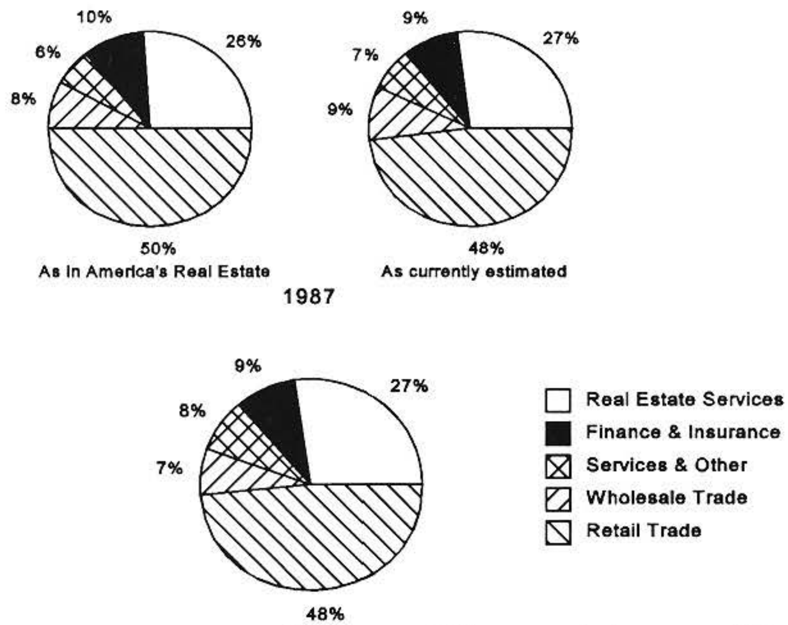
(Valued at 1987 Replacement Cost)



Source: Bureau of Economic Analysis

3: Ownership of America's Retail Buildings*

(Valued at 1987 Replacement Cost)



Source: Bureau of Economic Analysis

*BEA category: "other commercial buildings"

A Diversity of Decision Makers on Land Use

The data on ownership of America's real estate clearly shows that many of the key decision makers are in it as an avocation, rather than as a full-time job. In fact, this overview may understate the level of professionalism in land use decisions, because many organizations outside the real estate field may employ real estate managers. Large corporations have real estate executives, major retailers usually have their own real estate departments, and even universities have someone who manages real estate -- usually with an unsexy title like "physical plant." The point is that for such institutions, land use decisions are secondary to their primary mission. The decision process is not rocket science. At the highest level of professionalism is investment real estate, that which was built as income-producing property, often to be held as part of the developer's own portfolio. This market is estimated at $3 trillion in an annual report by the Real Estate Research Corporation and Equitable Real Estate. About one-third of these assets were held by institutions, generally in the form of mortgage debt of commercial banks, life insurance companies, thrifts and foreign investors. The remaining 61% is spread across real estate partnerships, individuals, governments, corporations, and non-profits.[3]

While there are no solid data on how many development decisions are made by the different parties, it is clear that the principals go well beyond the simplistic view of developers, and include many other interests--businesses large and small, institutions, corporations, governments, contractors, and individuals. As a national example, despite the federal government's interest in reducing spending, of which the

U.S. DOT is expected to absorb a $6.7 billion cut, there is funding proposed for a new office building, because the government's current lease is expiring.

In addition to all the different parties with an ownership interest in land use development decisions, there are many different players working on the same project. The private side includes market analysts, architects, engineers, lawyers, and lenders, while the public side includes planners and planning officials as well as their share of lawyers, analysts and consultants. Another important stake holder is the land owner.

The level of sophistication involved in deciding when and where to build a building varies widely across the scale from real estate dilettantes to professional developers - and in fact, even in the ranks of developers there are many different degrees of sophistication.

Corporate America in the Real Estate Business

While real estate represents an important share of the means of production, it is often taken for granted. The real estate function has not traditionally been seen as central to the business or a career path to the top. This is beginning to change, as competitive pressures have caused an examination of all cost centers, and a redirection of real estate needs as part of a corporate strategy.

Corporate decisions on real estate have often been seen as part hunch and part ego. While build-to-suit projects for individual companies represent an important part of many developers' business in weak markets, the companies have sometimes been criticized for building in soft markets where it would have been cheaper to buy existing space. Decisions on new corporate locations, especially regional and national headquarters, have also seemed to lack a sharp analytical edge. It is widely recognized among commercial real estate brokers that the single most important factor in identifying a new business location is the home of the CEO, or the principal making the decision. Understanding these decision factors will be an essential part of predicting future job location. As indicated above, things are getting more sophisticated, so those who follow growth trends will need to track decision trends.

A recent survey of executives in eleven large corporations found that things were not quite that bad. This survey of corporate real estate leaders, admittedly biased toward managers who would be expected to be good at real estate, found that out of seventeen situations, six were rated as doing a good job in linking real property operations to corporate strategy. Of interest to understanding corporate decisions on expansion and development, only five out of eleven firms studied monitor real property to determine if buildings should be owned or leased. The study suggests that firms that lease rather than own tend to link property decisions to strategic needs more regularly. In addition, although most gave lip service to "occupancy cost minimization", only half of those truly pursue the low cost deal rather than the lowest cost for a particular quality and location. [4]

Figure 4: The Eight -Stage Model of Real Estate Development

ONE: Inception of an Idea Not Feasible Feasible	Developer with background knowledge of the market looks for needs to fill, sees possibilities, has a dozen ideas, does quick feasibility tests in his head (legal, physical, financial).
TWO: Refinement of the Idea Not Feasible Feasible	Developer finds a specific site for the idea; looks for physical feasibility, talks with prospective tenants, lenders, partners, professionals; settles on a tentative design; options the land if the idea looks good.
THREE: Feasibility Not Feasible Feasible	Developer commissions formal market study to estimate market absorption and capture rates, commissions feasibility study comparing estimated value of project to cost, processes plans through government agencies.
FOUR: Contract Negotiation Cannot reach binding contracts Can reach binding contracts	Developer decides on final design based on what market study says users want and will pay for. Contracts are negotiated. Developer gets loan commitment in writing, decides on general contractor, decides general rent requirements, gathers permits from local government.
FIVE: Formal Commitment	Contracts, often contingent on each other, are signed. Developer may have all signed at once: joint venture agreement, constructio loan agreement and permanent loan commitment, construction contract, exercise of land purchase option, purchase of insurance, and prelease agreements.
SIX: Construction	Developer switches to formal accounting system, seeking to keep all costs within budget. Developer approves any changes suggested by marketing people, resolves construction disputes, signs checks, keeps work on schedule, brings in operating people as needed.
SEVEN: Completion and Formal Opening	Developer brings in full-time operating people, increases advertising. City approves occupancy, utilities are connected, tenants move in. Construction lender is taken out, and permanent loan is closed.
EIGHT: Asset and Property Management	Owners oversee property management, including re-leasing; longer-term owners oversee reconfiguring, remodeling, remarketing space as necessary to extend economic life and enhance performance of asset; corporate management of fixed assets and considerations regarding investors' portfolios come into play.

Miles, Mike E. et al, Real Estate Development Principles and Process. Washington, D.C.: ULI-the Urban L Institute, 1991, pp. 152-153.

The Timing of Market Information in the Development Process

Let's look at the process from the developer's point of view. There are eight steps common to the private real estate development process shown in Figure 4. It is a creative, iterative process in which ideas are successively refined, discarded, fine tuned, tested, and finally acted upon. Information is crucial in the development process, beginning from data sufficient for "back of the envelope" decisions to extensive market studies in later phases. In the beginning stages, printed U.S. Census Bureau reports may be completely adequate. As significant commitments are made, extensive computer manipulation of detailed census data may be needed during detailed studies.

A project begins with an idea, often the most difficult stage in real estate development, and one which can occupy 20 to 30 percent of the time spent on a project. Ideas are generated in many different ways. Developers often come upon a site looking for a use. For one reason or another, the owners of a particular parcel want the parcel to be developed. Alternatively, developers might find a use looking for a site, frequently the case when corporations want to expand. Finally, there may be investors interested in committing part of their portfolio to real estate projects.

The first screening the developer does is a "back of the envelope pro-forma." Developers typically use their concept of the tenant to project the tenant's willingness to pay for a particular type of space with appropriate services in a particular location. The income per square foot is then reduced by operating costs per square foot, projected over the project's leasable square feet, and this cash flow is capitalized to estimate a building value. The resulting net value is then compared to estimates of cost, including land plus site development, plus costs per square foot of building. If value exceeds cost, the idea lives to the next stage. If not, back to the drawing board. This is clearly a data intensive process to the developer, one in which information is as often picked up "on the fly" or even "guesstimated" in the early phases. While deeply immersed in technical data, however, it is clearly not rocket science.[5]

Importance of the Market Study in the Development Process

Market research is a critical part of the development process, one which could be improved by better land use forecasts. As indicated above, by the time a project has some standing, it has already been through several rough cuts at market, costs, and revenues, generally with data which no self-respecting planner would accept. In fact, in the past there were many instances where the market study never went any further. There are recognized technical procedures, although market studies have sometimes failed to follow them. Greater importance is often placed on the supply side, and rightly so. The most brilliant estimates of demand are no good if a developer builds a project at the same time everybody in town is developing in an area (developers tend to be like lemmings), and with no distinguishing characteristics. It is at this stage, comparing to competing projects, that the developer decides the final project details, and the target market.

However, the developer's needs for market information and the planner's interest in generating market-driven forecasts are one and the same. The conflicts often occur in situations where local plans are not based on market demand, but they determine the supporting infrastructure investment, which then limits the development options to those areas with services, rather than those with markets. Byron Koste, a Florida developer, calls this comprehensive plan a process that is "planning, zoning, and permitting driven, rather than market driven," in part due to the state concurrency requirements. Examples of demand estimates for three types of developments illustrate the convergence between the needs of developers and planners.

Residential

There is probably better information on the home purchase than any other real estate decision. In addition to extensive census data, several private sources track home buying trends nationally, and major home builders and developers monitor trends in specific markets. A good market survey will inform the builders about the likely markets--young families, empty nesters, etc., and appropriate price levels for the community. While proximity to major employment centers, shopping, and recreation is recognized as important, the diversity of regional commuting patterns makes this a difficult variable to pin down with any precision. Moreover, surveys of buyers show consistently that commuting ranks below the price, size, style and investment potential of the house in importance. In an annual survey of home buyers conducted by *Professional Builder and Remodeler* magazine, proximity to work only surpassed school quality in 1991, reflecting the declining share of home buyers with school-age children.

Demonstrating how insensitive most home buyers are to transportation factors in buying homes, a question in 1980 - at the height of the last gas crisis - about whether the energy crisis and sharply higher prices would cause buyers to look for homes closer to work, more than half said no. While there was a sharp run-up in gas prices from 1977 to 1980, the percentage of home buyers reporting proximity to work was important actually declined. In response to a 1985 question on compromises necessary for an ideal home, 30% were willing to buy farther from work, and drive longer, while only 8% would compromise on a smaller lot or an attached home.[6] Reported commuting data illustrates why. An annual survey of new home buyers conducted by the National Association of Home Builders shows workers commuting almost twice as far as the average commuter --16-17 miles for buyers of detached homes--compared to Nationwide Personal Transportation Survey 1990 estimates of 10 miles for all commuters.[7] Average travel times for commuters buying detached homes were about 25-27 minutes, and those in attached homes were closer to 30, compared to a U.S. average of 18 minutes. A derived estimate for speeds shows that buyers of new homes commute to work at 38 miles per hour, compared to a U.S. average of 33, partially making up for these longer distances. It should be noted that despite a general assumption that people trade longer commutes for a cheaper house, this pattern is not shown in many of the national data sets. Both those of the NAHB and the DOT NPTS show that as commute distance increases, so does housing value.

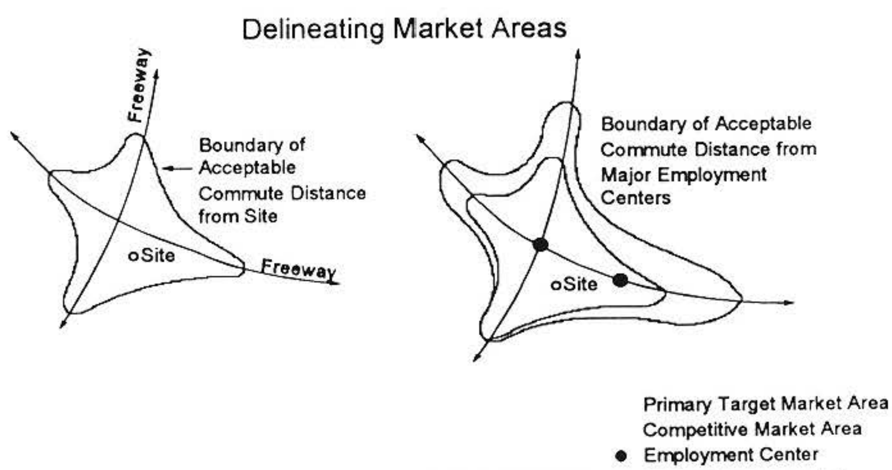
A housing market analysis begins with an estimate of households in the area of interest. ULI's *Residential Development Handbook* suggests a primary market area of 5-10 miles around a potential site.[8] This competitive market area is the toughest to compute. The total demand is a function of demographics (age structure and household formation) and migration. This needs to be split between owners and renters based on demographic trends, household income, housing prices, and interest rates. It is then necessary to examine the market, as measured by sales of different products. By a careful examination of absorption, it is possible to estimate a market share for a new project. While the sales data is often commercially available, local planning estimates for housing demand often are used to start. Better model outputs could make a significant improvement in the data used to begin.

Office Developments

A good understanding of the underlying economy is fundamental to projecting office space. For example, while the Houston economy had been growing overall between 1991 and 1993, a growth of secondary jobs masked a loss of primary jobs, for a net gain. Such trends cannot continue, however, without a recovery in primary employment. In addition to watching regional trends, it is essential to track the changing market shares of downtown and various competitive suburban centers. Don Williams, a market consultant from Houston, points out the need to track underlying demand of office jobs, rather than simply the amount of office space absorption, since it may take a while for job cuts to show up in the space absorption figures. As with residential projects, the demand is only half of the battle. It is critical for the developer to understand the level and nature of competing office projects.[9]

Retail

Demand for retail projects is a direct function of sales, distance, and competition



Note: The primary target market area is determined largely by the amount of time it takes to travel from the site to places of employment. As shown, the area is expanded through its access to transportation corridors. Other considerations affecting the size and shape of the primary target market area include urban growth patterns and infrastructure, socioeconomic conditions, physical barriers, and political boundaries (regulations). The competitive market area encompasses additional areas that are within acceptable commuting distance from major employment centers - areas that would be expected to compete with a given site. What constitutes an acceptable commuting distance varies between regions from under one-half hour to, in some cities, over one hour.

-just the way most traffic models go. In fact, one of the early techniques used in estimating retail demand was "Reilly's Law of Retail Gravitation," one of the forerunners of the gravity model used in travel forecasts. Transportation planners should find much in common with retail market analysts, because many of the techniques are the same, although the application in the private sector is not nearly as technologically advanced.

Needs of the Regulators

The challenge to those on the public side of development decisions is to develop regulatory conditions that complement market pressures, rather than compete with them. The alternative is a prescription for gridlock in the planning office, disruption in the land markets, and never ending conflict and possibly litigation. Even in cases where it is desirable to redirect market pressures, it is important for the planners to understand them. There should be a strong market component behind every comprehensive plan. Just as there are often private market studies which are lacking in technical rigor, it can be assumed that there may be similar problems with the underlying market analysis of public planning. Once it is clear that there are inconsistences, however, it is much more important for the regulators to develop a better picture, since the plan will outlive many projects. Forcing developers to forego profitable opportunities in favor of bad ones does neither side any good, and encourages cynicism about the planning process. Bringing in the planners to understand, and improve the land use models, is a good means of improving both. To the extent that it is possible for such models to measure market demand, better informed planners can negotiate some of the inherent conflicts between the public good and private wishes. For example, in Portland, those concerned about the ability of the market to respond to desires for higher density development around transit encouraged a market study to see if there was such a demand.

Implications for Land Use Forecasting and Analysis Methods

As indicated above, the needs of small area market analysis are highly supportive of better predictions of small-area land use data. So far, however, it appears that there has been very little overlap. Knowledge of such information in the private development community is limited. This may indicate lack of understanding or lack of confidence. On the other hand, given the nature of some of what passes for market data, especially in the early stages, there would seem to be a grateful market for improved data. In some cases, the specification of the variables will be different. Most assuredly, there will be a premium on the short-range predictions. However, there appear to be wide areas of shared need and shared interest.

Where to Start: Meshing Technical Capacity and Political Reality

Recognizing the similarity in the needs of private market analysts and land use modelers, it would make sense to open up a dialogue between them. This could be as frightening to the modelers as to their private counterparts. It is hard to find anyone from the development community with a good understanding of the technical procedures and outputs, except that they sometimes come back to bite them. Those at the front end must learn to listen to the needs of these users, with the promise that their message will be well received. The developers and private market analysts are neither dense nor technically unsophisticated, just not aware that there is something out there that can help them. Those on the regulatory side also need to buy in, even though they may be uncomfortable with both of the other two parties.

For openers, it is recommended that a forum be set up, preferably in a community where there are academic researchers (widely trusted by all sides), who have dealt with the real estate community as well as the public. Case studies of major projects in which there are suitable land use models could be evaluated. While it would be preferable to do this is a retrospective mode, this never seems to work out. At any rate, developers are only interested in the next project, not the last one. Off-the-shelf models could be evaluated in the context of the private sector information. The regional transportation agency could act as a convener and set the agenda, with the prospect that there could be a public/private initiative to improve the quality of forecasts of demand, as well as better short-term supply trends.

Public Policy Options for Land Use Forecasts

In addition to being able to identify the key factors expected to influence future development patterns, a major consideration will be the range of realistic public policy scenarios available. Certainly, one option is that of business as usual - a market driven development policy, accompanied by transportation policies of cheap driving and free parking, and jurisdiction neutral geography, distinguished only by proximity and prior preferences rather than planning policies. This probably represents the most likely scenario in most regions, given the lack of effective regional institutions, the strength of market pressures, and the inherent jealousy of local governments. There is a growing list of communities which are considering alternative futures, but most are still in the talking stage. A ULI survey of North American communities, which appeared to have presented credible alternatives to a decentralization scenario, identified only three major regions which were felt to qualify. However, interest is flourishing in more aggressive actions to manage growth. A number of these growth management policies have been catalogued by the Municipal and Research Services Center of Washington, to assist Washington local governments comply with provisions of the Washington Growth Management Act of 1990. The survey, which points out that most legislation is similar, at least at the state level, identifies.[10]

- Growth boundaries - Washington adopted this idea from Portland
- Protection of certain lands from development
- Paying for growth - Which could involve either increasing the cost to build in certain areas or sharing the revenues from growth to avoid "fiscal zoning"
- Minimum service levels - such as Florida's concurrency regulations

Other Initiatives in California include:[11]

- Growth caps - permits
- Down zoning

- Provision of low-moderate income housing, which could affect transportation

In Portland, Oregon, state transportation initiatives which could influence location are:[12]

- Reductions in regional parking ratios
- Caps on VMT per person

Finally, successful programs of downtown revitalization, such as those in San Diego and Portland, can have such a significant influence on regional growth that they need to be incorporated into the output from a land use forecast.

Enhanced Roles for Key Participants

Enhancing the effectiveness and use of land use models will require broader participation than that of the gurus responsible for their care and feeding. They include:

States play a key role in infrastructure investment, as well as in granting legal authority for growth management to localities. They need to become a more significant player, with strong participation from the Departments of Transportation, such as in Oregon and New Jersey.

Local Governments have eventual responsibility for dealing with the impacts of forecasts, controlling land markets through zoning and other planning policies, and providing many of the public services, especially water, sewer, local transportation improvements, and public schools. Local planners have probably been more likely to deal with land use forecasts as a matter of jurisdictional equity, negotiating what appear to be their governments' reasonable shares of regional growth, than of playing a meaningful role in constructing technical alternatives. Only through greater understanding and participation of local staff and officials can land use models gain public credibility.

MPOs have usually had lead responsibility in developing and using land use models. In addition to the monumental technical, administrative, and political endeavor of operating models, and producing consistent results, they will need to assist in the training of local governments to give them a greater ownership in the process.

Developers and the Private Sector
Just as local governments have primary responsibility for implementing growth policy for the public sector, developers play a similar role for the private sector. Despite having a typically shorter time horizon focused on near term market conditions, developers have a critical interest in land values and changes in supply. A more immediate concern is with better data on the traffic impacts of development, a badly needed component of impact assessment. Developers may also have a different view of the market than the public sector, a conflict which should be addressed. Pike Oliver, a developer and development advisor from Southern California, points out that "planners tend to overestimate residential density, and underestimate employment density." Since the goals of developers and the goals of local governments are both to identify and serve future market demand - although the public sector may have a greater interest in influencing it - developers are likely to be a willing participant in a broader dialogue on forecasting the location of growth. In addition, major landowners and corporate users, for whom developers often act as

intermediaries, would be valuable allies in an expanded modeling effort.

Real estate researchers include both academic researchers as well as real estate consultants, market data firms, and research arms of lenders. They bring a strong economic focus to issues of land markets, housing and job location, as well as data which might not be readily available through the public sector.

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Summary of Workshop One

Keith Lawton, Portland METRO

Review of Existing Land Use Models

The group believed that the most widely known and used land use models in the U.S., Dram-Empal, Empiric, POLIS, and PLUM, are heavily based on transport as the most important explanation of location. A problem that was obvious to this group is that, in general, little is known about models used by others and, within the group, nothing was known of foreign models.

With regard to the use and understanding of existing models, the group identified several important shortcomings. First, the models do not have sufficient policy variables to deal with many policies of interest as noted in Wegener's comparative matrices. It is hard for real estate planners/developers to accept the output of these models because many more variables are incorporated in the practice of planning for developments. There is a sense by the group that transport measures are about the fifth most important element in location decisions.

Currently, none of the models incorporate a land development step linked to consumer choice step. Most of the models are too abstract. Those experienced in use of the models agreed there is a need to use more aggregate zone systems to get better statistical fit measures. This same need was also identified with early aggregate transport models.

The models need a clear and describable basis of theory, not just a mathematical or statistical mechanism. The users also need to understand and to believe the underlying theory used to develop the models. A theoretical behavioral basis would make credibility easier to achieve. Long term credibility will only come with time series validation.

Research Recommendations For Improving Existing Models

From the discussion of current models and practice, four recommendations for existing model research were identified by the workshop group.

Recommendation 1

First, and most important, there is little information readily available to practitioners and would-be practitioners concerning the full range of experience with existing land use models. The only comparative study (ISGLUTI) is about ten years old, is dense, and a discouraging information source. There is a need for an investment in a comparative description of available models, perhaps an extension of Michael Wegener's comparison. This comparative study should include more dimensions of evaluation such as policy responsiveness, data needs, structure classification, environmental measures, and level of integration. This would enable prospective applications to make a more informed decision on modeling strategy. For this research, access is not equated with "availability of package", but rather a clear exposition of theory, relationships, variables and parameter estimation. If ease of use and user friendliness are the prime criteria, we would be using the Sim City black box approach.

Recommendation 2
Whatever methods are used, strong efforts must be made to get time-series validation either by back-casting or by building in a strategy to track forecasts and test in the future. MPOs with strong GIS capabilities should be able to provide this information more easily in the future. Thus, the second recommendation for research is the exploration of methods and processes for time-series validation. Particular attention should be given to back-casting in the first few applications. Guidance on what is reasonable is important.

Recommendation 3
In terms of a qualitative evaluation of the land use effects of transportation proposals (policy or infrastructure), the transportation models can be used as a measure to estimate direction and a crude estimate of amount of change. (Travel and land use are in a way, mirror images of each other). An example would be to use the summed utility of nested models in the destination choice model to run unconstrained estimates of destination choice (with and without the change) to gauge the activity effects of the accessibility changes. This would give a policy or strategic view of the direction of change with suggested system changes without waiting for the complete land use model.

Guidance on the use of existing transportation models for sketch evaluation of land use effects of transportation actions should be prepared. A clear delineation of the appropriate use of such an approach, including limitations, is needed.

Recommendation 4
There was a plea from this group for the research work to be put out for competitive proposals from a wide range of researchers and consultants. Many dimensions of numerous disciplines are needed. Too narrow an approach is less likely to be successful. It is important that the research teams be multidisciplinary with a diverse membership.

Developing New Models

The group discussed several areas of improvements needed in any new land models.

Behavior:
The models must be behavioral based. The behaviors of all the actors in the decision process must be included, not just the final location decision of the household or firm.

Short- and Long-Term:
The group began with the assumption that there would be a "quick-fix" approach using current modeling techniques followed by new model development. The consensus was that while none of the existing model suites dealt comprehensively with all the responses

desired, responsiveness to all the issues was included in one or other of the models. The development of a "new" comprehensive modeling approach is thus going to be based on current known techniques, and it is unlikely that a two track approach to developing new models will be needed.

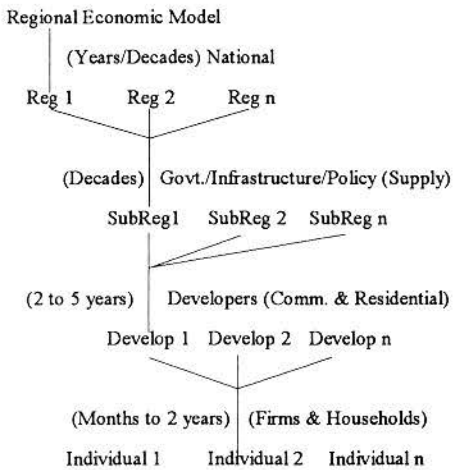
Levels of Spatial Aggregation/ Disaggregation:
Different influences on the location of development or activities work at different levels of granularity or aggregation. This seems to be at the heart of the research problem. Household location decisions and firm location decisions occur at the point and lot level.

Developer and Government location decisions occur at various subregional levels of aggregation and affect the developed land inventory used in household and firm location decisions. They are also decisions that are informed by the market effects of the individual preferences in household and firm location decision structure. This decision process includes transportation infrastructure.

Larger aggregation is required for modeling the economic interaction among regions/cities. These decisions are based on economic regions and their competitive advantages, but are also affected by the local environment detail that flows from the higher levels of disaggregation in the household, firm, developer, and government decision models. Currently, there is no single system for multiple levels of aggregation. Meaningful modeling with aggregate models alone does not seem to be possible. This leads to the question of how to integrate models running on different spatial aggregation levels and different time or duration scales. Historically the approach has been to cascade the models (top down), usually going to lower levels of spatial aggregation with each step, starting with a regional forecast model. It needs to be bidirectional, however, in that lower levels affect higher levels as well. For example, transport and land supply affect location decisions for housing and businesses, but also affect regional economic interaction in that the decision of a business to locate in another economic region may be a joint decision concerning location within the economic region.

Research Recommendations For New Model Development

Recommendation 5
Research into coupling various levels of model structure, perhaps a nested model structure, needs to be accomplished. Different time scales at different levels and different spatial scales at different levels may be a way of structuring both the question and the model interrelationships. The following "diagram" is just an example of one concept which is to think in the same terms as a traditional nested model. Initially, each level is conditional on the upper levels, but because the lower levels operate on different time scales from the upper levels, the demand implied by the lower levels can be used to consume the supply, thus conditioning the upper levels in a time based feedback loop. This is a way to handle the large-scale impacts of fine scale small behavioral changes over a longer period of time. In other words, the large-scale impacts of small behavioral changes.



Recommendation 6

There is a need to determine the trade-offs between aggregate/sketch models and the detailed behavioral based disaggregate models. There is some level of fine granularity which deals with the great variation in individual behavior. How do we factor up to the aggregate world in this situation? At some fine level of granularity, we are likely to find no regularity or predictability of behavior. Here we will have to rely on ad hoc allocation and intelligence. The behavioral base is important if we are to understand and apply policy solutions (for example, a part of ITS is the manipulation of behavior). The group did not feel that a bottom to top disaggregate microsimulation was likely to prove useful, and that at some level there will have to be an interface between the disaggregate model and the aggregate.

Research is needed to blend aggregate and disaggregate modeling. This research should determine the appropriateness of each technique at various stages in the allocation modeling process and develop a consistent interface or "hand-off" method to link these models consistently. Additionally, the cost-effectiveness of the modeling strategy as a whole should be studied.

Elements in Improvement

The workshop group discussed the fundamental elements of improvement needed in land use models.

Theory:

Improvements should be theory based in order to learn anything and to develop a consistent approach.

Land Prices/Bid Rent:

This element needs to be made endogenous in the modeling process as both a response to the market (behavioral change as a result of price), and as a market response to the demand impact of disaggregate behavioral changes. Is this a natural interface between the aggregate and disaggregate models? Or is it totally within the disaggregate realm?

Demographic/Household Structure Change:

Micro-simulation offers much in the household structure change area, which is likely to be an important element in household moves, dwelling acquisition and disposition. This could be a major basis driving location choice. Demographic change alone can be evaluated using cohort survival, but this is not very useful. Los Alamos is developing good methods for the development of synthetic household data at the micro level. This is an important step that will be necessary for the application of household transition models (as developed by Goulias and Kitamura, for example) in a disaggregate environment. A similar argument could be made for firms, although the data acquisition and model development could be intractable.

Land Use-Transportation Environment Models (LTE):
Should these be freestanding, sequential or integrated? In most American practice, these are currently freestanding and sequential. Wegener's paper at this conference details several models that are integrated to one degree or another. While we all realize that distribution of activity determines transportation, transportation effects on the distribution of activity are less well handled. There are very few examples of an environment to land use link, dealing with air quality. Noise is an environmental issue in countries other than the U.S. There is very weak model usage with regard to the environment's impact on transportation.

Broad Involvement in the Research Process:
The research community, practitioners, environmental groups, policy level individuals - all of these need to be included in the process. Even within the research community, there are many different disciplines and skill levels which need to be included in a complementary way.

Recommendation 7
The above four elements represent areas of "modular research" which are needed in the development of a more complete system. There are probably many more. These issues are ripe for academic stand-alone research; they will be a part of the needed solution.

This group did not spend a lot of time on this issue, as many of the elements needed are included in one or the other existing model packages, often without the empirical data and analysis needed to make them fully operational.

Recommendation 8
We cannot wait for perfect data with which to construct models and predict land use. Research on the use of imperfect data and data synthesis needs to be performed. Research on the best methods for getting disaggregate data from aggregate data is needed. The use and potential misuse of synthetic/ dissaggregated data needs detailed exploration.

Recommendation 9
The technology related to data collection is changing very rapidly. The National Information Infrastructure (NII), related to ITS, may provide the opportunity to improve and speed up data collection. There will be a lot of data monitored as a part of this program, and research into methods of collection, capture and adding of value is important. How can we take advantage of this coming opportunity?

Research is also needed in the use of remote sensing to determine land use and change in land use data capture and the use of GIS to provide data. Research on the use of data on commercial transactions (credit cards etc., already in use by the private sector) to determine more about activity location and density is needed.

Recommendation 10
Employment data is an area that needs a comprehensive research effort in the U.S. All MPOs (and others) are aware of the gaps in current resources, and many have

had difficulty in model calibration (land use allocation and transportation) which appears to be caused by dirty, incorrect employment data. This is also an area where the data is nearly all imputed in some agencies (leading to spurious correlations when building models without an awareness of source). There are problems dealing with multiple job holders and part-time employees, also with the classification of employment data.

Recommendation 11

There has been very little thought about data acquisition in the past, with a heavy dependence on the use of aggregate administrative records. With the need to move into behavioral theory based analysis, it is important to consider data needs in the light of proposed modeling theory. Research into the use of stated response surveys and revealed response panel surveys for decision-making units, including households, businesses and the development community, is needed. This would include the issues of cost-effectiveness of repeated contacts of panel members, as well as the use of stated preference to elicit information on elasticities outside the current experience range and hypothetical situations. Stated preference can be more cost-effective than revealed preference in answering certain questions, enabling the separation of variables that are highly correlated in revealed preference surveys.

Recommendation 12

Given the impossibility of developing research surveys on every issue, both in terms of complexity and cost, it is clear that we will be dependent on multiple sources of data. This is related to the synthetic data generation/imputation discussed earlier. Research and guidance on data integration is needed.

Recommendation 13

There is a need to develop efficient land use consumption tracking. Some agencies do a lot in this area. A research project evaluating effectiveness and cost of methods could be of great value. This is not a huge task.

Recommendation 14

Honesty and accountability are important in the estimation, calibration and validation of models. Modelers (transportation) have a history of over promising which leads to effective misrepresentation on occasion. The state of the practice is much worse than is realized by the lay person, and the blame for this lies in a lack of good validation practices in the profession. Research into and standardization of validation statistical techniques and reporting methods is needed. The following observations are important to this research effort.

1) Temporal validity is the only validity. Models must be validated over time in terms of accuracy of prediction. Base year validation is not very useful or honest.
2) Responsiveness to policies of interest is important. A good model is invalid for use in responding to policies not explicitly modeled.
3) The need for time series data in both model estimation and calibration is obvious. Also, a separate time series for validation is needed. There is a need for research into better model estimation techniques utilizing time series data. What model forms make sense in this context?

4) Validation concerns accuracy in measuring change, not just in the aggregate end state. When is a model good? What is a reasonable level of error? More research and guidance are needed.
5) Standard methods to deal with external factors, such as change in politics, in the evaluation model performance are needed.

Use of Models

Because of the difficulties of forecasting the unknown, the following thoughts about the way in which models are used seemed important to us. There are always too many unknowns, surprises and degrees of freedom for any of us to regard a single forecast with sanguinity. Making multiple forecasts, varying the input assumptions enables us to do a risk analysis of various proposals for action. Multiple scenario analysis approaches the question from a similar but different direction. The multi-method approach combines detailed models with qualitative interviews with decision makers. The evaluation of results obtained from differing levels of analysis should improve understanding and credibility.

Recommendation 15

Very large models, although they are theoretically more comfortable, limit the number of tests that can be performed; this leads to a preference for simpler models or the development of a test strategy minimizing the number of tests while getting needed information. Research is needed to determine what test strategy is cost-effective. What are the parameters? Models must be accessible to all players, hence explainable. They need to encourage the evaluation of other points of view.

Members of this conference workshop were:
Keith Lawton
Frank Southworth
Jim McLelland
Doug Porter
Dan Brand
Rich Steinmann
Michael Wegener
Bob Griffiths
Raymond Brady
Ken Cervenka
Chuck Metalitz

Summary of Workshop Two

Robert J. Czerniak, New Mexico State University

Question 1: List Land Use Models Used by or Familiar to Participants

The workshop participants identified three classes of land use models with which they were familiar. The first type, commercial modeling software, included MEPLAN and DRAM/EMPAL. Participants also mentioned GAP software developed at Rice University, which was used by Oklahoma City in an adapted form. The second type of software was classified as "locally developed." It was represented by Portland, Oregon, where a spreadsheet model is used. In addition, an experimental software used by Norbert Oppenheim (also spreadsheet based) was also discussed. A third model in this category was the Lafeyette, Indiana MPO land use model developed at Purdue University. Based on environmental constraints, it models land use change in five-year increments. It appears that this model is similar to the LESA model developed by USDA. The final category was a mix of best professional judgment, historic models like EMPIRIC, and Alex Anas' METROSIM.

Of the models discussed, the group reached a consensus that any land use model should be policy sensitive and market based. As mentioned earlier, the model developed by Purdue University is driven by environmental constraints; this type of model was not viewed favorably by the workshop. The overwhelming choice of the group was a model with the following characteristics: discrete choice theory for demand, profit maximization for supply, nonlinear optimization, and ease of use.

In addition to the quantitative models, the group also mentioned the use of the Delphi technique to obtain informed views about regional trends and trend analysis for gross estimates of land use change.

Question 2: Identify Technical and Organizational Issues Which Affect Land Use Models

The group identified a number of shortcomings for existing models. They include lack of access to source code; model insensitivity to network changes; too much time spent in checking accounting (looking for inconsistencies, overages and shortages); and no benchmarks, for example capacity, against which to judge whether or not a land use model is reasonable. There was also a discussion about whether land use model parameters are theoretically based and if there is an acceptable range for parameters. Basically, parameters are allowed to deviate until the model fits a given situation. The workshop recognized this as a major deficiency in the land use models.

There was also a discussion about the approaches needed to model different scenarios. These are best represented by a series of questions.

1. How does one model "big events" or unexpected large developments?

2. How do we include new types of employment and its effects?
3. How to factor a variable like educational quality into a housing choice submodel? And what about the role of changing educational quality over time?
4. How to model an event or new infrastructure in a metro area where there is no trend to provide baseline information? The models also need to respond to new techniques like TDM, LLRT and their associated impacts.

Other topics under technical issues included the difficulty of modeling without zoning and the need to recognize that models are being asked to provide results for questions which they were not originally intended to answer. There was also a concern that transportation was too important an element in the land use modeling process. The statement was made that if we assume transportation is important, of course it will be. One participant noted that it is important to recognize what you can or cannot control through public policy and understand that using the model or not using it will not change this. Modeling is not always the best way to test new policy.

Organizational Issues

There was a variety of organizational issues that need to be addressed by a new modeling program. The most important was the creation of a communication network among the MPOs, researchers and FHWA professionals who are concerned about land use modeling. The MPO staffs feel they need access to the collective wisdom of all agencies. For example, MPOs should be able to diagnose and fix model problems and share these solutions with others. In addition, this knowledge and experience should be documented.

A question for the federal government is, to what degree should software that is developed in the public domain be allowed to shift to the private sector. How many times must taxpayers pay for a model?

The model architecture should be open to MPO staff. The comment about access to source code was raised again. There is also the issue of local staff being required to defend a model and its results when the modeling process and assumptions are held within the model and are unknown to the staff.

There was some variation in the number of staff assigned to land use models. It appeared that most MPOs assign staff part-time to the models or that they are assigned full-time for part of the year. The range of staff was 4 to 1.5. The group felt that one full-time person with another FTE (whether this is one or more people) was required to build and maintain a land use model. There was also discussion about relying more on consultants to run models since they know the intricacies of the system. A strong recommendation was made that should a consultant run the model, the consultant should defend the results as well.

Question 3: What Model Improvements Are Needed

The improvements to the land use models were identified under three general headings: outreach, technical improvements and data. The participants indicated a need to provide the public with information about land use modeling through an outreach effort. The central question is how to translate model results into information that can be understood and used by elected officials, other decision makers, and those members of the public who are concerned about the land use topic. One way to address this issue is to develop visualization tools, e.g., ARCVIEW2, a computer program which combines the display of graphics, maps, pictures and data. There is also a need to better integrate existing transportation and land use models, similar to the arrangement being developed between the TRANPLAN and ARCINFO programs or the transparency that exists in TRANSCAD.

The emphasis for any technical improvement to the land use models should be integrating transportation and land use. The models should be based on a market approach that reflects the demand/supply characteristics of the land market. It should include discrete choice theory for demand, profit maximization for supply and a price mechanism. The model developers should document the principles which guide model use and application. If possible, eliminate artificial feedback loops (where this is required because of an inherent weakness in the model algorithm rather than in the land use process itself). There was a strong feeling within the group that the models should remain in the public domain.

There were a few comments during the first day's session on data. There is a need to identify a better approach to mid decade census numbers. Accurate employment data is difficult to obtain. There should be some effort to encourage state employment departments to release employee addresses for address matching. Techniques to better predict employment and income change should be developed. Researchers and modelers need to obtain more input from the development community.

Finally, there was strong feeling that the land use modeling effort should be contracted in an open competitive environment. Keep the research process open.

Question 4: What Are New Directions for Land Use Models?

The models should be done in a modular approach. The metaphor of a toolbox was suggested. The following equivalent to the four-step process was suggested:

- household demand,
  - households by life cycle, occupation (have to divide by white/blue collar, income, multiple wage-earners, etc.)

- household supply,
  - existing stock, developers, individual lots/owner/landlord

- non-residential demand,
  - non-residential by types, the shorter the time frame, the more the categories
  - need to be able to link the firms by type and the occupations by type

- non-residential supply,
  - government is a supplier in the sense of providing amenities and infrastructure, but regulation and fiscal policy is part of interaction module
  - a demographic module for change (income, aging, household change, etc.)
  - a pricing module

One positive characteristic of a modular approach is that a module can be improved without affecting the other modules. Module capabilities would also expand as the database expanded. Start with existing conditions, account for changes in existing conditions, determine land suitability analysis, project baseline and future land use. Database management is an important starting point for the model. The modules would bring together the supply and demand sides of the total model. The unique part of land use modeling is the supply side analysis. Transportation supply is controlled by the public; land is not.

Within the modules, the actors in the land development process such as homeowners, renters, developers, retail businesses, etc., should be recognizable elements. For example, what is the role of the developer-does it need to be modeled separately or is it only a pass-through? Each actor interacts with the database and changes it. This introduces behavior which may make the models more dynamic. Some questions that may be addressed by such an approach include: what are the locational constraints of various uses, e.g., industrial land may need to be separated from residential areas. What are the government policy implications?

MEPLAN Example

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. Access is measured by the logsum of travel times from zone to all destination zones. Sometimes a government action, like building a transit station, will have an impact beyond the model's estimate of attractiveness. This kind of market model can be sensitive to equity issues and address policy questions.

Question 5: Topics for the Research Agenda

The kinds of models we need are out there. The current generation of models has a reasonably sound theoretical basis. We should improve these before we move to another level of sophistication. Some of the ideas listed below could be spun off from the available databases rather than tied to a full model development run. The group liked the idea of using a set of MPOs in combination with universities as research sites and developing a set of standard tests.

We need to:

- learn more about the supply side of land use. Why do developers make the decisions they do?
- test the issues around equilibrium. How chaotic is the land use-transportation system; can we assume any kind of equilibrium?
- research and evaluate the lag time between the implementation of a change in the transportation system or in land use and the impact of each on the other system.
- study the issues of zone size and related data needs and outputs
- undertake more research on the decision making on the demand side of land use.

Question 6: Data

Users Needs

An LUT model needs to reflect the demand/supply characteristics of the land market.

An LUT model needs to test community design issues and how they affect travel demand. For example, economics appear to be pushing specialization of land uses. Cheap travel encourages single-purpose land uses. Stated preference studies may be able to adjust parameters to reflect these characteristics. Auto ownership-land use models do not usually try to predict this variable, but would seem to be related to land pattern. Usually predicted by income (demand side), but may be as related to amount of transit (supply side).

Model Needs

We do not necessarily need more data, but better data about critical model parameters. We do need better assessment of the available research already published.

Summary of Workshop Three

Paul Waddell, Ph.D., The University of Texas at Dallas

Introduction

The Land Use Model Conference was structured as a series of parallel workshops, with one day spent on reviewing the current state of the practice, and a second day dedicated to identifying directions for long-term model development. This report is consequently divided into two sections, along the same lines. Participants in the workshop included a variety of perspectives and experience, ranging from small to large Metropolitan Planning Agencies, to academics, to consultants. Most of the land use modeling activity currently in operation or development in the world was represented in the conference, making it unusually comprehensive. The exchange was brisk and informative. The directions for short- and long-term land use modeling effort were outlined, charting an ambitious agenda for academics, practitioners, and consultants to achieve over the next several years if we are to meet the challenges of the Clean Air Act Amendments and ISTEA, and to address the land use, transportation, environmental, and social policy concerns that MPOs are increasingly asked to contend with.

Improving Existing Models

The range of experience with existing land use forecasting procedures varies considerably. Perhaps the most common among smaller MPOs is some form of consensus-based forecasting process, while many of the larger MPOs now use some form of land use model, the most common of which is the DRAM/EMPAL model set developed in the 1970s by Stephen Putman. There is a broad array of quantitative tools now finding their way into the operations of MPOs in the U.S., ranging from sketch planning tools to assess the impact of transportation on land use patterns, to simplified Lowry models implemented on microcomputers, to sophisticated discrete choice-based models of residential location. Abroad, where the last two decades have produced more innovations in land use modeling than in the U.S., there are several fully operational and mature land use-transportation models, and some modeling efforts pushing the envelope into microsimulation techniques like those at the core of the TMIP TRANSIMS project at the Los Alamos Laboratory. The discussion in this section will focus on only those models perceived as currently operational in the U.S. context. Others are treated in the subsequent section on long-term model improvements. Each specific modeling approach is discussed individually, followed by a set of short-term recommendations.

Consensus-Based Land Use Forecasts

All MPOs use a consensus-based approach in some phase of their development and adoption of land use forecasts. In many organizations, the input to a committee is based on quantitative models, but in most MPOs, the development of land use forecasts remains more an art based on a combination of data, plans, and negotiation. While Delphi is a specific methodology for arriving at consensus, it is unlikely that most MPOs use the Delphi technique to achieve consensus on their land use forecasts. More typically, it is a procedure that begins with a collection of data from member jurisdictions, including building permits, development plans, and zoning. The process then incorporates the long-term expectations of planners and politicians from the jurisdictions, to arrive at a zonal-level forecast of population and employment for input to the travel models. Several shortcomings to the typical practice of consensus-based land use forecasts are apparent:

- There is no systematic and quantitative method to deal with the land use-transportation interactions required by the Clean Air Act and ISTEA. Specific issues such as the likely impact of rail stations on land use densification in adjacent neighborhoods, or of major freeway alternatives on sub-regional shares of future development, would most likely have to be addressed by a combination of assumptions and negotiations.

- Forecasts based on consensus about planned developments and development trends are likely to reflect an emphasis on supply side at the expense of demand side considerations. Planned developments, available land, zoning, and jurisdictional land use policy objectives are all clearly important, but unless balanced by demand side considerations of market behavior in response to supply side initiatives such as redevelopment policy or transit development, the forecasts will be more likely to express a set of assumptions rather than a realistic assessment of the future.

- The impact of public policies on development (e.g., school quality, municipal services, and taxing policies) must be dealt with in an ad hoc fashion, since no systematic way of quantifying their impact is typically used.

- Disagreements over outcomes in the forecast are difficult to resolve because there is no quantified relationship between input assumptions and forecasting outcomes. A model-based approach would typically allow a modification to be introduced, and would automate the reallocation resulting from the change, reducing staff time spent performing such an allocation, and negotiation time.

- Disagreements or changes in the forecast that have distributional consequences across jurisdictions must be addressed by negotiation rather than a quantitative assessment of the likely impact area (e.g., from a new freeway). This not only places a large burden on staff time, but is subject to numerous potential biases.

- The inconsistency of jurisdictional forecast allocation procedures to transportation zones suggests that it would be difficult to test sensitivity of land uses to transportation system alternatives with any degree of consistency and confidence.

In short, it is unlikely that a purely consensus-based land use forecasting approach is apt to be a credible response to the mandates of the CAAA and ISTEA for assessing the interactions between transportation and land use. On the other hand, land use models are not credible enough to produce forecasts that are usable straight from the computer. Nor is it likely that this would ever be the case. Rather, some MPOs have described the role of land use models as a member of the Technical Review Committee - as only one input in a process rather heavily dominated by consensus building. We will always need some level of technical or policy review process to "legitimize" the forecasts and generate confidence in the planning that is done using them. A desirable scenario, however, would be for models to improve to the point that they become, to use the earlier metaphor, the majority vote on such a review committee.

HLFM II+
One of the existing land use models reviewed by the workshop is the Highway Land Use Forecasting Model (HLFM II+) developed by Alan Horowitz. This model is based on the QRS2 (Quick Response System) travel model, coupled with a Lowry Gravity land use model. It is being marketed primarily to small to medium sized MPOs, and there is relatively little experience on which to evaluate the model.

HLFM II+ models total households, and Basic, Retail, and Other Employment. Zonal attractiveness is based on available vacant land in each zone and accessibility. The primary advantages of this model appear to include its low price ($300), adequate documentation, availability for the Windows platform, and ease of use. Several concerns about the model, however, may erode these advantages for some MPOs:

- It only represents highway mode; there is no mode split component and no representation of the transit system.
- There is no disaggregation of households by type (e.g., by income or stage of life cycle).
- The gravity models in the land use component and in the trip distribution models are inconsistent.
- The model has inadequate representation of zonal attractiveness, using only vacant land as the attractiveness variable. Since other factors affect land use patterns besides vacant land and accessibility, such as income, housing prices, crime, and schools, the vacant land variable in practice is modified to approximate a K-factor to adjust for these omitted effects.
- The model is validated to a base year rather than calibrated from historical data and then validated using current data.
- There is little behavioral content to the model, so it does not lend itself to use for a wide variety of policy analyses.

Models such as HLFM II+ are likely to become more common as MPOs previously using consensus-based land use forecasts struggle to comply with the mandates of the CAAA and ISTEA. It is likely that such models will perform satisfactorily for some MPOs, most likely smaller and more homogeneous urban areas. Larger and more complex urban regions may find that the lack of behavioral and policy content in models such as HLFM II+ pose significant constraints on their credibility.

DRAM/EMPAL
The most widely used land use model in the U.S. is the Disaggregated Residential Allocation Model (DRAM), coupled with

the Employment Allocation Model (EMPAL), developed by Stephen Putman. The models have evolved significantly since their introduction in the early 1970s, but still retain their basic original structure. DRAM/EMPAL is still the only model system in widespread use in the U.S. that provides a systematic way to incorporate, and potentially produce an equilibrium between, land use and transportation. DRAM/EMPAL has, therefore, become somewhat of a de facto standard among major MPOs striving to comply with the CAAA and ISTEA mandates to incorporate feedback between land use and transportation in the planning process.

DRAM and EMPAL are singly-constrained spatial interaction models, derived from the Lowry Gravity model, but modified to incorporate a multivariate attractiveness term. DRAM models household location, typically disagreggated into income quartiles. EMPAL models employment location, normally by four to five industry groups. DRAM's zonal attractiveness term includes the income distribution of the zone, vacant developable land, the percent of land already developed, and residential land. EMPAL's attractiveness term includes the lagged employment of the same type in the zone, and total land. In application, K-factors are used to reflect all influences not captured by the model. In addition, users can override the model with constraints on the level of activity in a given zone.

Several concerns about the DRAM/ EMPAL model system have been raised by practitioners applying the models, and by academics examining the underlying theory and structure. Among these concerns are:

- The capacity of the model in evaluating land use-transportation interactions is rarely exploited fully in practical application. The reason for this involves the sequential and iterative application of the DRAM/EMPAL models with the UTPS or other travel demand models. For a valid assessment of the land use-transportation interactions, the models would either have to be completely integrated into a simultaneous procedure, or the models would have to be run iteratively for a horizon forecast year until convergence between land use and transportation systems was achieved. Using DRAM/EMPAL in iteration with existing travel demand models, in most MPOs the time and cost of running the travel demand models multiple times for each horizon forecast year is often excessive, and frequently only one iteration is performed per horizon forecast year.

- The models require a relatively high level of effort and resources. A staff of full-time analysts, at least one with a modeling capability, is likely to be required in addition, to substantial consulting time to assist in the calibration and operation of the models.

- Employment by industry in each zone is converted into households for allocation using a regional employment to household by income matrix, which imposes crude regional generalizations on each zone. This approach seems particularly unrealistic when one reflects on the frequency of multiple-earner households, multiple job workers, and job changes not accompanied by residence changes. In reality, the connection between employment and households is complex, and this key aspect of DRAM is particularly unrealistic.

- Important household/demographic characteristics are missing, such as household structure/children present, stage of life cycle, number of workers, and ethnicity - all of which have been widely documented to affect location choices and travel behavior.

- These is no representation of the land market; land price effects of changes in transportation services or policies cannot be estimated. Households and businesses compete for land, with the successful bidders determining the land use and location patterns that ultimately result from the market clearing process. Without a market representation, it is difficult to capture key aspects of the urban development process.

- Structures are not separately accounted for from the activities that occupy them. Housing and commercial space are not endogenous to the models, making the models less transparent in their behavior than models that account for land, structures, and activities, and the relationships between them, including prices.

- The models have no way to account for adjacency or spillover effects, such as the spillover of residential development from one zone to an adjacent or nearby zone as development opportunities within a zone diminish due to buildout (DRAM), or agglomeration effects across adjacent zones, such as occur in the evolution of an employment center which occupies several zones (EMPAL).

- In normal practice, there is an inconsistency between the zonal system used for DRAM/EMPAL and that used for transportation modeling. This has led to the use of allocation techniques to disaggregate the land use forecasts to traffic zones, and aggregation techniques to squeeze the travel time matrix generated by the travel models for use in the land use models. This inconsistency may cause not only a loss of information in the interaction of the models, but may also affect the accuracy of the forecasts.

- There has been some note made by Putman and others that the models do not perform well with very disaggregate zonal systems, or where there is sparse activity within certain zones, causing pressure to aggregate the zonal system, which runs counter to the need for consistency between the zonal systems used in the land use and transportation models.

- The models are static cross-sectional, and do not realistically reflect the fact that only a fraction of the households and businesses move in any given time period, and that the land and housing markets may never reach equilibrium, but are continually adjusting towards equilibrium. Urban development is an incremental process, in which changes occur at the margin, based on the existing distribution of activity, infrastructure, housing, and nonresidential space.

- There is a possibility that these models may underestimate the sensitivity of land use to transport changes if important attractiveness terms are omitted.

Stephen Putman has indicated that all development has ceased on the DRAM/EMPAL models as of January 1995, and that he is beginning development of a new model system, based on logit formulations. This is consistent with other models already in development or operation, and appears to be a primary direction for future model development.

Employment Data

Before any model can be implemented, accurate input data must be prepared with which to calibrate and apply the models. While household and population data are readily available from the decennial censuses and from special travel surveys, data on employment is much less adequate. Improving the quality and availability of employment data is almost certainly the single highest priority for short-term improvement of land use models. There is no federal data collection effort for small-area employment data comparable to the decennial census of population and housing, and most other sources of employment data are problematic:

- The 1990 Census Transportation Planning Package and the 1980 Journey to Work data suffer from several deficiencies for use as small-area employment estimates. First, they are based on a household, not an establishment survey. Second, they are based on only a 10 percent sample of the household survey, with work place geocoding. They only represent a worker's primary job, truncating all other employment activity. In addition, geocoding of work places may include sufficient errors that expansion of the sample to represent the full population of jobs by work place are rather rough estimates. To be fair, these data were intended for analysis of commuting patterns, not necessarily for providing accurate workplace employment estimates. There is also the possibility that such data will not be collected in upcoming censuses.

- Proprietary establishment data from sources such as Dun & Bradstreet are available as alternatives, but these data are generally very expensive, subject to proprietary constraints that limit their distribution, and extremely labor intensive to geocode and clean satisfactorily to use as the basis for small-area employment estimates. In addition, there are no generally accepted standards for using such data to produce reliable estimates. The quality of such data has never been adequately tested and documented, but practical experience suggests that substantial data problems remain.

- There are significant inconsistencies in the use of employment classification strategies in land use and transportation modeling. Regional employment forecasts are almost invariably provided by Standard Industrial Classification (SIC). Most MPOs then group industries by SIC into larger categories by collapsing one digit SIC groups together. Often these larger groupings are called Basic, Retail and Service, or some slight disaggregation of these groups. The use of the term 'Basic' employment is, however, highly confused in general practice. It is rarely used in the way intended in economic base theory, as export-oriented employment. In fact, it is increasingly difficult to identify export-oriented employment when consulting, financial and other service industries may provide services across town and across the globe. Transportation planners, on the other hand, may often think that Basic employment refers to that employment occupying industrial and warehouse space. This conception is rooted in land use, however, not economic activity. Ultimately, employment by industry must be mapped onto small zones and individual land uses, making this industry vs. land use confusion somewhat inescapable. In order to relate employment to households, or preferably to workers, there is yet another relevant classification of employment: occupation. The grouping of employment by skill level, or occupation, correlates with worker wages, and therefore, with household income. In practice, these distinctions between industrial, land use, and occupational classifications of employment are rarely if ever acknowledged, and the resulting estimates and forecasting of employment has been correspondingly poor.

- One approach to obtaining improved employment data for use in the land use and transportation modeling process is to obtain better access to disaggregated establishment data from the Bureau of Labor Statistics. The County Business Patterns is now being tabulated by Zip Code, and this is a step in the right direction. Arrangements should be made to provide alternative geocoding of these data, to census geography or to traffic zones. In addition, accommodation of needs for local validation of these data would go a long way towards solving this data problem.

- In lieu of increased federal data availability, more innovative use of existing data will be required. Advanced statistical, probabilistic, or iterative procedures can be used to link County Business Patterns at the county and zip code level, and establishment or parcel data, to produce synthetic small-area employment estimates that are robust and cost-effective.

Summary of Short-Term Recommendations

A synthesis of the foregoing discussion elicits the following summary recommendations for short-term land use model improvements:

1. Improve the quality and availability of employment data, preferably through increased access to small-area geocoding of establishment data from the Bureau of Labor Statistics.

2. Where models such as DRAM/EMPAL are used, generate better guidelines on the appropriate procedures for generating convergence between the travel and land use models. Use consistent congested travel times, and as consistent a zonal system as possible between the land use and travel models. Use a full network as opposed to a sketch network in interfacing the models.

3. Use the local review process as a policy review, with a model providing the neutral data to discipline a highly

political process. This will, of course, require that the models produce reasonable results.

4. Move fairly quickly towards random utility-based models consistent with recent development in the travel models.

Developing New Models

The second phase of the Land Use Model Conference was the assessment of the directions new model development needs to take if it is to address the current and anticipated needs of land use, transportation, and environmental planning. Since they were not covered in the existing models because there is no U.S. application experience, models developed abroad in the last two decades are briefly discussed here, before proceeding to considerations for entirely new models.

TRANUS, developed by Tomas de la Barra, and MEPLAN, developed by Marcial Eschenique, offer two similar approaches to land use-transportation modeling. Both incorporate Input-Output models with a zonal disaggregation using discrete choice (logit) models. Both have explicit representation of the demand and supply sides of the development process, including the accounting of activity, structures, and land use, as well as using prices as the market clearing mechanism. These models are mature, and have been implemented in a variety of locations in Europe and Latin America. Both are now being tested in Sacramento, California. It will be valuable to examine how these models fare in application in U.S. metropolitan areas, and whether they might offer short-term application prospects while the next generation of land use models is under development.

A large number of models are now under development and at various stages of application, both in the U.S. and abroad. The range of these models reflects several of the themes echoed in the Conference. These models were reviewed in the paper by Michael Wegener, and need not be discussed further here, except to say that the direction is towards more behavioral and disaggregate models that explicitly model the choices made by specific decision makers in the urban development process. Many of these models are based on random utility, discrete choice formulations, and some of them have begun to implement microsimulation techniques that may ultimately be needed to support microsimulation approaches in the travel models such as the TRANSIMS project, or even activity based travel models that are on the near-term horizon.

Recommendations for New Model Development

1. Do not attempt to build "THE MODEL," meaning a single model that addresses every requirement or consideration. Such efforts, while attractive, are likely to repeat the mistakes that led to Lee's 1973 "Requiem for Large Scale Models," a paper that contributed to the demise of urban models for some time. Balanced against this admonition, however, is the desire for flexibility in addressing planning and policy problems at varying geographic and temporal scales, and across household, employment, and land use types. The need for flexibility is most likely to be

effective if implemented through a consistent and modular design.

2. There is a need to facilitate collaboration between MPOs, academics, federal and state agencies, and consultants in the development and testing of new models and procedures. It is possible this could be accomplished with a program for Land Use Research Centers, comparable to the Transportation Research Centers now in operation. These centers could serve as focal points for the training of MPO staff, the development of new procedures and models, and the dissemination of information.

3. A variety of models are likely to be needed in order to be responsive to different needs and agency circumstances. Such models are likely to vary in complexity, cost, comprehensiveness, and application in small to large MPOs.

4. New land use models should place a greater emphasis on their use for policy analysis, planning, and sensitivity testing within an integrated land use, transportation, and environmental framework. These considerations are substantially different than the historical baseline forecasting activity of MPOs, and require greater attention to the explicit incorporation of policy variables whose impacts need to be analyzed.

5. Models must move towards much greater disaggregation of households, of employment, of land use, and of zones, if they are to support the needs of travel models as they evolve towards activity-based models. As the models become more disaggregate, however, they must pass the test of transparency and reasonableness of the results.

6. Microsimulation techniques are likely to ultimately be needed in land use models, in order to support the behavioral complexity required of activity-based forecasting, and to continue to make the models more transparent in their behavior. Issues such as the linking of workers, households, housing units, jobs, businesses, buildings, and land suggest that microsimulation, while perhaps unavoidable if we require sufficient disaggregation of behavior, will come at a high cost in terms of complexity and resources. It remains to be seen whether these techniques will ultimately produce better forecasts.

7. The use of synthetic data and panel surveys as data sources for calibrating the next generation of land use models needs to be further explored. Panel surveys are becoming more common, and are particularly useful for observing dynamic behavior such as the adjustments household make to travel cost changes, or to housing costs. Behavior such as residential mobility is by definition dynamic, and single period surveys are less effective for analyzing such dynamic behavior.

8. Employment data will continue to remain a major priority for the long-term. Accessibility, cost and quality all remain major concerns.

9. GIS will certainly be a part of most new model development, either in the development of input data, or visualization of outputs from the models, or potentially as a core

technology in which to embed the models and link between land use, transportation, and environmental modules.

10. The next generation of land use models will be more explicit about the decision makers and decisions being modeled: households, businesses, developers, and local governments will be the primary groups of decision makers, and these may become modules in the land use model system.

11. The models will need to be more sophisticated about the varying temporal and geographic scales relevant to different processes in urban development: from almost instantaneous adjustment of travel route, to slower adjustment of residential location, to much slower construction of new infrastructure. These time scales also impact the appropriateness of different model assumptions, such as whether certain aspects are fixed or adaptable (e.g., housing supply).

12. Major shifts in technology, social attitudes and behavior are unlikely to be anticipated by any model, current or future. The limits of models must be acknowledged by their producers and consumers.

13. There is a need to develop consistent evaluation indicators for current and future models, to assess the quality of their predictions. Similarly, data standards need to be developed for inputs to the modeling process.

14. Disaggregation of the models, data, zones, and policies should be balanced appropriately. It makes little sense to disaggregate the zonal system and input data, for example, if the behavioral foundation and model is not sensitive to the scale of the disaggregation. An example of this might be the need to assess land use and transportation impacts of localized urban design alternatives. If the models had no variables representing urban design, disaggregation of the data and zonal system would be wasted.

15. While there is substantial research that documents the presence of neighborhood effects, land use models have not widely attempted to incorporate these effects, other than the income distribution of a zone.

16. Travel costs are becoming less important determinants of household and business location choices as amenities and other factors become more significant. Models should not be structured in such a way as to predetermine the primacy of travel costs as the principal influence on location. The relative weight of travel costs should emerge from the calibration. In addition, more effort should be devoted to articulating the nature and variety of accessibilities relevant to residential and business location choices.

Summary of Workshop Four

George T. Lathrop, Ph.D., City of Charlotte Department of Transportation

The individuals in our workshop have offered a number of recommendations. These recommendations are not in a particular order and some may be repetitious; however, the group feels strongly about them. I would not be faithful to their concerns if I did not mention them again.

First, without exception, the group is very concerned that available resources, whatever they may be, are not utilized for the development of one model. They are unanimous in their opinion that we must find a mechanism to offer an opportunity for the development of alternative possibilities, some of which clearly may fail, with the thought that in diversity and variety there is a greater probability of success.

As one of the members of the group expressed it, there is a severe danger of premature decisions about things which then cannot be reversed. The example of the QWERTYUIOP keyboard on the typewriter was offered. That decision, made a long time ago, was a bad decision, but the investment which has been made subsequently in machines, and the capabilities of the people who use those machines, is such that we will never change it.

That extends into the recommendation that we made earlier about a number of sites and programs. That continues to be a consensual ideal for the group.

There is a strong sense that whatever we do, if it is possible, we need to move toward a simulation capability which can be used in a context which, to communicate the idea without trivializing it, would be almost like Sim City. The idea is that a group of people, of various backgrounds and various interests and concerns, could sit down together and talk about different possibilities and, with some immediacy, see what the effects of those possibilities might be. We could turn this into a real "what if" machine; people could investigate different possibilities. This concept grew out of an observation that we are not using these models to plan, we are using them to test and evaluate, to understand the consequences of actions, because planning, after all, is the moment of inspiration, not the investigation and analysis of consequences..

A surprise concern in the workshop is the need for openness. We must be open, not only to our peers and our policy guidance people, but also to those who are not necessarily directly involved in what we do. This goes beyond being responsive to the Freedom of Information Act and the removal of bureaucratic barriers and foot-dragging, to a positive spirit of cooperation, sharing and knowledge.

Our group sees two different kinds of use for development simulation: (1) a "what if" kind of use, mentioned earlier, not to forecast, but to understand clearly the implications of different actions and policies, the we don't know if this is going to happen or not, but what else would happen if it did? What else would happen if there were changes like this? What would happen if all the neighborhoods in this area were developed with the neo-traditional form? (2) The forecasting or projection model, the market model, which forecasts and is sensitive to market processes and non-market actors.

We spent more time discussing criteria for simulation models and process. We see two kinds.

An example of the first is that the railway gauge in one state in Australia was 6 inches wider than the railway gauge in the next state. When you got to the border, you had to off-load everything and reload to continue your journey. This is an obvious kind of criterion; the need of a tie to census data is one example.

The second kind describes quality, may or may not be achieved and, in fact, may turn out to be a criterion whereby different efforts might be compared to see how well each succeeded: the incorporation of market forces, the inclusion of feedback, and so forth.

The group is still very enthusiastic about the idea of putting seed money into a number of different MPOs and letting them work with various actors and people, including the private sector, developers, forecasters from other fields, academics, consultants, etc., to develop different models and processes.

We came up with a laundry list of things we think are important, both in the short-term and in the long-term.

1. Development of a computer-based tool that would help inform policy makers and elected officials of the long-term consequences of decisions under consideration. This tool would have clear, graphical orientation; would allow policy makers and elected officials to connect policies articulated in documents with the consequences of such policies and alternative policies. The model would also incorporate some indication of confidence intervals associated with estimates of such consequences. It would need to link to a broader set of issues related to police, health care providers, water/sewer, open space, schools, etc.

2. Development of another computer-based suite, in parallel with the one for policy makers, that would be geared towards those with greater interests in models and assumptions. This tool would be broad-based (i.e., LTE), and would allow policy sensitivity analysis, and incorporate models of land markets, zoning, urban growth boundaries, etc. It would allow various approaches to representing market imperfections and corrections thereto. It would allow differential applications of land use codes and zoning approaches across jurisdictions, so as to allow the demonstration of the effects of different land use patterns on transportation. The models need to be "self-healing," in that they should allow tinkering without violating integrity. Models should incorporate

the ability to examine policy impacts like fiscal disparities, and urban services areas. There is a need to facilitate microscale focus, for purposes such as locating a regional airport, regional park, or light rail. Also, ability to examine impacts of pricing.

3. A body of data that can go hand in hand with the modeling tools. The data would include what is on the ground as well as what is in the pipeline, including major changes like base closings, shopping mall developments, etc. Probably these should be in some GIS-based format.

4. A body of forecasts for use in the models, compatible with the data. These might take the form of an inventory of land uses at the traffic zone level for the base case and in five- year increments through Delphi/modified Delphi. Also, a reasonable inventory of approved but not yet built projects at the parcel or traffic zone level, and an inventory of zoning yield (buildout). The forecasts would be believable outputs by employment, by land use type, household, household income.

5. Modeling tools that can help us understand the interactions of city and suburban economies, that is, for example, how conditions in Baltimore affect and are affected by conditions in Baltimore County.

For a moment we considered advocating some sort of wider (certainly not unfunded) mandate to MPOs across the country: the inclusion of certain data handling and GIS oriented capabilities. We realize that this is probably impractical. What it really comes down to, perhaps, is that these sites be places where good practice, in a full range of characteristics of process and substance, is reviewed, used, analyzed, and compared, so that the lessons can be transferred to and used by other MPOs across the country.

Summary of Workshop Five

J.D. Hunt, Ph.D., University of Calgary

The participants were asked to indicate the land use model they used or with which they were reasonably familiar. The term model in this sense was seen to represent a rather broad range of forecasting techniques, from formal sets of equations embodied in software systems to ad hoc extrapolation processes. The following land use models were indicated:

- Shift-share results interpreted and adjusted by expert panel for Philadelphia
- Ad hoc extrapolation together with form of Delphi Method for Ithica
- Custom-built software model of unknown form (possibly DRAM/EMPAL) for Denver
- DRAM/EMPAL model for Los Angeles Region (SCAG)
- Software model based on mathematical programming formulation with various sub-models based on other approaches for Stockholm
- DRAM/EMPAL model for Sacramento
- TRANUS model for Sacramento
- MEPLAN model for Sacramento
- Disaggregate behavioral model with sample enumeration for Calgary
- MEPLAN model for Edmonton
- MEPLAN models for a wide range of cities outside North America, including London, Naples, Dortmund, Bilbao, Cambridgeshire and Edinburgh.

Members of the workshop were asked to identify the issues that they were concerned about, that had led them to come to the conference and be participants. Five categories of issues were identified including model form/model design; modeling method/model use; data; knowledge of techniques; and, exogenous "background" inputs.

Specific issues under each of these categories are as follows:

Model Form/Model Design
- Consistency of land use and transport forecasts
- Representing impacts of land use on non-motorized modes
- Representing impacts of new transport technologies on land use and environmental quality
- Representing changes in personal attitudes over time
- Representing impacts of land use on air quality via transport
- Representing impacts of land development policies in older cities
- Policy sensitivity
- Problems with boundary effects and external effects
- Behavioral basis of location choice
- Accuracy concerning long-term economic and demographic changes
- Representing impacts of urban-design-level conditions on transport behavior

Modeling Method/Model Use
- Consideration of range of scenarios
- Presenting model results in a way that helps citizens accept trade-offs
- Cost-effective and transferable models for small MPOs
- Models useful for both normative and predictive purposes

- Models used both for forecasting and policy development
- Models as part of a larger economic evaluation involving welfare measures

Data
- Consistency of data from different sources
- Accuracy of employment data
- GIS platforms for full LTE models and data
- Freight data
- Knowledge of techniques
- Available data sources
- Stated preference surveys for parameter estimation
- Measurements of attitudes
- Education programs for practitioners
- Education for students
- Exogenous "Background" Inputs
- Predicting exogenous inputs
- Inter-regional projections

There was a wide-ranging discussion regarding the most needed improvements for existing land use models. The very wide variety of existing models and the wide range of techniques with which participants were familiar made it difficult for the group to focus on very specific improvements. There was a general recognition that different models and techniques address different issues and have different problems that should be addressed. In the end, a set of the three most important improvements was developed for land use modeling in general, as follows:

- Develop separate analysis procedures for neighborhood-level and regional-level considerations.

- Bolster treatment of freight movements by including forecasting of industrial location, drawing on logistics research, and exploiting the new data on freight movements that is becoming available.

- Use the following criteria to judge potential improvements to land use models and techniques:

  - Existence and strength of theoretical linkages with higher-level and lower-level models
  - Transparent model design for users and for public
  - Modularity allowing calculation checks and sub-model substitution
  - Policy sensitivity, including regulatory and environmental constraints
  - User-friendly output
  - Internal consistency concerning data and variable values
  - Behavioral completeness
  - Ease of use, “openness” and documentation
  - Cost-effectiveness, standard package for small regions
  - Quality of economic evaluation measures, including equity
  - Quality of environmental evaluation measures
  - Level of disaggregation of outputs regarding socioeconomic and demographic categories
  - Provision of inputs to activity-based travel models
  - Sensitivity to non-auto treatments at neighborhood level

Developing New Models

The participants were asked to develop a list of desirable attributes for a new system for land use modeling. The resulting list of desirable attributes that developed from the group discussions is as follows:

- The system should provide representations that are behaviorally accurate and complete, which is admittedly a "motherhood" statement, but still should be made. The role of rationality, concerning both dispersion in behavior and imperfect information, and the role of equilibrium, concerning the dis-equilibrium in reality and both lead and lag responses, should be considered and should be reflected in explicit representation within the system.

- The system should be sensitive to relevant policy, which is another motherhood statement but still should be made. The system should be able to address a wider range of issues than just transport. That is, it should seek to do more than just treat the impacts of transport accessibility on land use distributions and the impacts of land use distributions on transport demand. It should also consider such things as housing needs, financial impacts of policy, environmental impacts of spatially-distributed activities.

- The system should be able to take into account and appropriately represent the actions of individuals, households, governments, firms, as both employers and producers, developers and investors, including both the "pioneers" and the "followers", environmentalists, and large public/private institutions.

- The system should include consistent linkages between the analysis at different levels of spatial resolution, from the regional level, to the district level, to the small area (urban-design) level, to the traffic zone level.

- The system should include full representation of temporal dynamics, including both "lag" responses and the cases where some actors anticipate future conditions and respond to these anticipated future conditions (e.g., where developers make decisions based on future situation) - not a "lag" response, rather a "lead" response.

- The system should be fully responsive and sensitive to environmental constraints arising because of concern about environmental impacts.

- The system should include representation of the "flexibility" that exists regarding various constraints, that is, where in the real-world it sometimes happens that pressure on a constraint leads to the relaxation of the constraint in order to relieve the pressure.

- The system should include internal checks on the consistency of inputs. An example would be where there is a check that projected income growth input to a given system is consistent with projected economic growth input to the system.

- The system should be able to interact with the microsimulation transportation model being developed in TRANSIMS project.

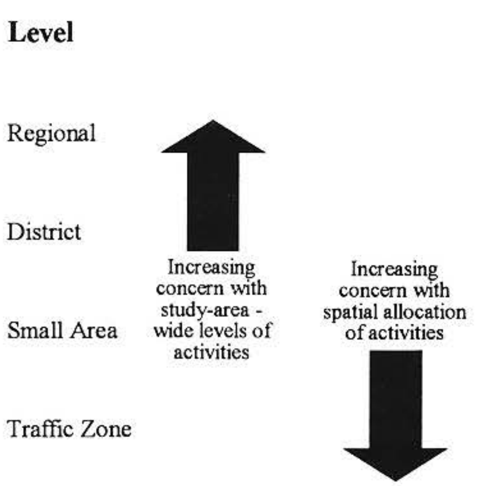
- The system should be fully compatible with GIS systems.

- The system should be modular in configuration, which would allow: interventions to adjust data/information flows, staged development of sub-models, separate testing of specific sub-models.

- The system should be able to provide results reasonably quickly, that is, it should have a quick "turn-around" time.

The participants were also asked to develop a plan of action for where we go from here concerning both existing models and new modeling systems. The plan of action that evolved from discussions is as follows:

- Do not try to develop a single model that does all these tasks at all these levels; rather, adopt a "horses-for-courses" approach where various purpose-built processes are developed for certain categories of tasks. This is based on the recognition that there are a number of different forecasting tasks that must be done concerning a variety of different levels of spatial resolution, as shown in the following figure:



- The task to be performed, where the model is a tool, may include policy development, forecasting single-point values, or more appropriately, ranges of values, or identification of normative solutions where a given criterion measure is optimized. The various purpose-built processes can be based on a single, overriding theoretical framework, but this framework should be general enough that specific tasks with varying levels of spatial resolution and available data and specific issue can be accommodated.

- The acknowledged purpose of land use modeling activity should be to consider a wider range of issues than just those related to transport demand modeling, that is, more than just the effect of transport on land use distribution and the transport demand arising from land use distribution.

- More effort should be made working towards establishing better data generally. This is recognized to be a "motherhood" statement, but it still should be mentioned. Notwithstanding any effort that is made in this regard, work should not be suspended in any other areas on the basis of the expectation of better data; rather, work in all other areas should continue on the basis of data already available. Modeling systems and processes that can only work with kinds of data that are not already available should not be pursued. Systems and processes that have relatively more flexibility in terms of the kinds of data that are required should be emphasized, merely as a matter of prudence in that reliance should not be placed on specific future developments that are not certain.

- Both a short-term plan of action and a long-term plan of action should be developed and pursued, each with its own objectives and stream of funding.

- For the short term, there should be a plan to draw on existing models and encourage their use in a number of situations, possibly making some slight improvements and adjustments to increase applicability in a United States context. Some demonstration projects should be sponsored to try out several different modeling systems that have been developed elsewhere. A considerable amount of work has been done and much has been learned regarding land use modeling outside of the United States. There should be a concerted effort made to draw on this experience.

- For the short term, a technology transfer program should be developed to impart to United States practitioners the benefits of the experience gained elsewhere. This program should include some short courses and a comprehensive written synthesis of current practice concerning operational models. A broker should be identified for this function. Much more than a World Wide Web site on the Internet is required. There should be some national centers for education and research established to act in the same way as what is intended for the national transportation centers.

- For the long term, new modeling systems should be developed. To the extent possible, these new systems should have the attributes outlined in Section 4 above. A reasonable time-frame for this work would be a minimum of five years. A major and very significant part of this effort would be research into the nature of the behaviors of the actors involved.

- For the long term, several alternative new modeling forms should be considered/pursued - not just one. Several types of model and modeling systems should be considered in several streams of activity; all the available effort and resources should not be directed at one single stream of activity working towards just one modeling system. This is seen as consistent with the "horses-for-course" approach advocated in point A above, and it is seen as a prudent course that avoids risking all of the scarce resources available on a single approach. It would appear, at this point in time, that the microsimulation approach has much to offer in terms of the desirable attributes outlined in Section 4 above. However, there are some concerns about the practicality of such an approach regarding both computing power and data requirements. Accordingly, this approach should be one of those considered as the basis for a new modeling system, but most definitely it should <u>not</u> be the only approach considered.

- For the development of new modeling systems in the long term, too much reliance should not be placed on transport modelers. That is, they should not be the only ones working on the development of these new systems and should not be the only ones used as sources of general approach and inspiration. Economists, geographers, logistics managers, computer scientists, statisticians and planners should also be involved. In fact, given the very long time that transport modelers have spent in the area, it might be a good idea to keep transport modelers out of the thinking in some streams of activity at some stages - in order to allow some different ideas to germinate and develop before having to withstand the "momentum" in the standard thinking that has developed in transport modeling.

Summary of Workshop Six

Bruce Douglas, Parsons, Brinckerhoff, Quade & Douglas

The purpose of the workshop was to deliberate a series of questions about the state of the practice, its problems, key issues and suggested research. The following sections of this report include a discussion of land use models, deficiencies and suggested research topics.

Workshop Profile

The composition of a workshop group tends to establish the group's bias based on the member's attitudes and experience with respect to land use and transportation models. Workshop Six was composed of a cross-section of representatives from metropolitan planning organizations (MPOs), transportation and land use model experts, public interest and citizen groups, model developers and academicians. Forty percent of the members came from large and small councils of government. Interestingly enough, all of the MPO representatives were responsible for demographic forecasts rather than for transportation model operation. Roughly half the group had experience in either developing or intensely using land use models.

Most of the workshop members had advanced degrees; nearly half had obtained doctorates in subjects related to land use or transportation planning. One-third of the workshop members had a strong interest in the environmental and community impacts of transportation and land use decisions and translated this interest into needs for improving the communication of results to citizens and decision makers regardless of the models or estimating techniques used.

Experience with rigorous land use models was essentially limited to U.S. practice. Only one member of the workshop had significant hands-on European experience although other members of the group had a reading knowledge of European practice.

Virtually all of the workshop members are involved in evaluating the results of land use and transportation models and assessing their ability to produce credible results in the present climate of political and citizen concerns found in most metropolitan areas. Thus, the workshop members recognized the critical importance of results which:

1) pass the test of reason among citizen groups and political decision makers, and
2) respond sensitively to the relationships observed by the transportation and land use planners. These twin requirements pose a significant challenge to the developers of the next generation of land use and transportation models.

Existing Methods, Models and U.S. Experience

For most metropolitan areas, land use modeling involves a process of forecasting development and demographic changes at the regional level with a secondary process to allocate development to the zones used for transportation analysis. In many cases, the amount of future development is determined by national demographic forecasts published by the Department of Commerce, Bureau of Economic Analysis (BEA). Thus, the land use "model" in many cases is a method for allocating development among the difference jurisdictions in the region. The most commonly used land use "models" are:

- Trend analysis - This is perhaps the most static of all methods as it presumes continuation of current policies and choice mechanisms. It is also, in many cases, politically defensible and represents a cooperative distribution of growth. The process is frequently driven by availability of vacant land and infrastructure such as sewerage. Transportation facilities generally play a minor role in the allocation of development.

- Delphi and Quasi-Delphi Methods - A true Delphic methodology is rarely used since it ordinarily involves negotiations among jurisdictional representatives who often allocate growth totals to each jurisdiction. The final allocation to transportation zones is then frequently done by local planners using trend analyses or a vision approach.

- Over Zoning - A de facto allocation process where all parcels of land are zoned for a future or existing use. The development envelope created by the zoning system usually, if not always, exceeds the development forecast for the entire jurisdiction over the next 20 years or so.

- DRAM/EMPAL - The most frequently used computerized land use allocation model implemented in the U.S. today, it includes sensitivity to accessibility as defined by the transportation network, as well as to a small number of policy inputs.

- Other Land Use/Transportation Models - The group had only limited experience with MEPLAN, Metrosim, and other econometric models of urban development whose applications have been restricted mostly to countries outside the United States. Modules from these models hold promise for implementation in the transportation model improvement program, but more information is needed about their capabilities and data requirements.

The results of the various processes used vary from the visionary to the cynical depending on the philosophies and political power of the group controlling the land use allocation process. An examination of the results of these so called "cooperative" forecasts clearly indicates why planners and analysts are attracted to methods which appear to be more rigorous and which can be replicated.

Deficiencies in the Current Land Use Models and Forecasting Process

There are serious deficiencies in the land use forecasting methods and models used in the U.S. today. These deficiencies fall into three major categories:

- The results of the process are not politically acceptable;
- The cost of collecting the required data and maintaining the model are, in most cases, prohibitively expensive;
- The methods and models seem incapable of reflecting the behavior of

the principal actors in the development and land use markets.

The land use and transportation models are part of a process which includes local and regional planners and officials. The regional and local leaders will frequently agree on general policies and assumptions about the future, but then disagree vehemently about the forecasts themselves. Frequently, this is the result of forecasts which do not follow current trends or which result in unacceptable forecasts for particular subregional areas. Local officials often believe they "know what's going to happen". These local visions frequently lead to over zoning - forecast development far exceeds what the market can support. The level of developer interest may frequently be overestimated leading to long-range plans which never get built.

Actual experience with models and negotiated long-range plans in the U.S. include cases in which the negotiated forecasts did not match the model results, because the negotiated forecasts represent wishes that do not support the policies included in the model. Traditional transportation planning has presumed a single regional land use plan resulting from a "coordinated, collaborative" process which results in a single land use plan for corridor or project analysis. A few recent projects such as Lutraq (Portland, Oregon), MSM Transportation and Land Use Study (Princeton, New Jersey) are examples of changes from this single land use practice. But even in these cases, the question was one of where development would take place within a narrowly confined part of the region, not how much change would occur in the region in its competition with land markets elsewhere in the country.

The current transportation and land use models are not adequately linked to address both transportation and land use issues together, including their interaction. It is still rare to find land use and transportation planners sitting together to deliberate the future. The group recognizes that in most regions there are a number of demographic and land use forecasts used as control totals by states, public utilities and regional MPOs. There is always some question as to which total to use and for what purpose. The purpose of the analysis generally drives the decision on which forecast to use. Even within the control totals produced by public agencies, a high percentage of the development process is in the hands of private sector market including developers, landowners, and financial institutions which are outside the control of the governing body. While some of the workshop members believe we have sufficient understanding of the private market, getting that understanding incorporated into the land use models is a major concern and a current defect in the models that are used today.

The modeling of human behavior is a central deficiency in today's models. In particular, how do we model changes in human behavior over time? Our perception of human behavior will create the land use plan. Attempts to include other variables which would help to explain differences in behavior such as ethnicity have been rejected by public agencies that fear a possible citizen backlash from such practice. The point is that human behavior and attitudes can change over time and the land use models do not reflect this possibility.

Current models and methods in use in the U.S. lack appropriate mechanisms for disaggregating large area land use forecasts to small zone transportation analysis zones. The consequences of mis-allocation are much more serious than mis-specification of transportation service levels. For example, a planned unit development covering a thousand acres could be forecast based on a developer's plan, prepared by a firm which subsequently goes bankrupt or loses interest because of property assemblage problems. In general, the land use models don't take into account the land use market. While the MPO, with the land use models, may have a better concept of development potential in their region as a whole, they will easily find themselves at a disadvantage with respect to details relating to a specific site. Nonprofit environmental organizations and developers frequently will have better data about near-term plans on a particular site. Each level of disaggregation makes local knowledge more important. Such information is difficult to put into a formal model.

Data collection and maintenance presents a daunting challenge to most MPOs. The principal problems revolve around the accuracy of employment data, the rapid inflation in the number of descriptive variables desired, and in the future, almost certainly, questions about the confidentiality of household and work place information which, while easy to collect, is also easy to abuse. As a second concern, the data may be current, but virtually impossible to forecast unless one understands the changes in human behavior which will take place over the next decade or two.

While land use models tend to focus on the impact of transportation and other infrastructure changes on development patterns, they do not produce information about the development patterns necessary for improved transportation analysis regarding the use of pedestrian and bicycle facilities. For example, a given traffic zone may contain a known number of retail employees or square feet of commercial space. What may not be known is whether the employment is concentrated in one mall or WalMart or dispersed among the residential areas which also occupy the zone. The transportation implications of these two alternative forms of development are significant. The use of smaller transportation zones will improve transportation analysis, but this has implications on the land use modeling: a disaggregation process must be used which can be supported.

The workshop conclusion was that the land use forecast methods and models in use in the U.S. are inadequate to answer the questions asked by public officials and citizens concerning development in the future. They are definitely incapable of responding to the questions likely to be raised in the near and long-term future as citizens and public officials become more interested and concerned about development patterns.

The Land Development Process

The long-range planning process and land use development process live in a dynamic tension. The workshop group was concerned that the modeling and understanding of the planning process is superior to our understanding of the development process. Master plans tend to be the legal right to develop and therefore form a basis for development. MPOs have the power to prioritize public sector investments but may not be able to factor the reality of individual private development projects into their plans. At some point in the process, the citizens and the community have to establish what they want in their future since alternative development patterns can have a substantial impact on the transportation infrastructure. This may require analysis and comparison of the trend with a development pattern which is more appropriate for each community. The regional planners must then go to individual jurisdictions to get the local plans revised and change the regulatory framework to make sure that they happen.

There is much concern that the current models and methods look at vacant land and sewerage as the driving forces in development forecasts. There is much less attention paid to parcels in developed areas which are candidates for rehabilitation and revitalization. This is a particular problem given the decline in our central cities coupled with model systems which do not incorporate all of the dynamics of the urban development process. To put it bluntly, the current modeling and analytical processes appear suitable for predicting sprawl but unable to assess controlled growth.

Developers and households represent two market clearing mechanisms, but the relative weight of their decisions is substantial. Each individual household makes decisions about residence, place of work, and place of other activities. A developer, on the other hand, makes major decisions about assembling property and developing hundreds, if not thousands, of units. Misunderstanding and mistakenly predicting developer behavior is much more serious than mistaking individual household behavior. This difficulty in predicting developer behavior increases the uncertainty about development in a particular spot. Consequently, the estimates are really probabilities rather than certain estimates. The results, of course, are that land use plans can vary dramatically from the visionary to the cynical. At the same time, it is rare to find land use plans which forecast abandonment and decline of what are today healthy developments. It is difficult to envision a public official who wants to preside over the demise of his inner city.

Issues in Land Use and Transportation Modeling

The consideration of issues around land use and transportation modeling starts with a definition of the role of land use models as seen by the workshop. The fundamental challenge is whether or not land use models can combine the realities of growth and development processes with local plans and the legal regulatory framework to produce a realistic forecast. Suggested roles for land use models include 1) displaying the implications of local land use plans when summarized for the region, 2) displaying the probable build-out rate according to what is realistic, 3) casting forth alternative scenarios of development and their implications, and 4) providing land use scenarios to compare and evaluate alternative transportation scenarios.

The challenge of displaying both regional and local (even to the individual site) development patterns suggests that one model will not fit all requirements. This leads to the idea of subarea models and modular development to allow for analysis at both the micro and macro level. It is possible that different levels of modeling sophistication would be appropriate for different sized MPOs. There is a consensus that land use models must not only reflect the macro impacts of infrastructure on development patterns, but also the urban design attributes of new development as it affects transportation decisions. The results of the land use modeling and transportation analysis process must assist local officials into deciding upon an appropriate mix of land use; otherwise the land use and transportation models will have no value to the political process. For example, a city council wants to know where affordable housing is going to be placed and what will happen to the shopping area retail development with the coming of a new WalMart.

Perhaps the most significant challenge to the next generation of land use models will be to produce land use plans which stand the test of reasonableness or "reality" when viewed by local officials and citizens. Different jurisdictions and communities have different concerns and certain community perspectives may lead to questions of equity. Models will have to be able to handle trade-off and impact assessments. Community groups, generally, are not sitting at the table as part of the discussions about modeling. Thus, evaluation processes normally do not embody multiple viewpoints when evaluating scenarios.

Developing and testing different land use scenarios is an important element in land use modeling. This will place a significant demand on the planning process as well as on the modeling process. Continuation of policies is just one scenario and more input is needed to develop alternative scenarios. The days of working with a single land use forecast must be over. It still appears to be an issue whether are not MPOs will be required to use multiple scenarios. It will be important to be able to show the impacts of different approaches by testing alternative scenarios. Thus, the model can be used as a tool to help the general public and public officials to understand the process and what future decisions produce.

There is a price to be paid for scenario development however. The number of land use plans and development patterns can grow quickly and present a daunting task to the transportation/land use planners to develop land use transportation alternatives within a manageable framework. We will need to develop an evaluation methodology which can screen land use/transportation alternatives efficiently and still provide locally needed information.

There are cutting edge models which will accommodate life-style and life-cycle factors, but any improvement in the transportation analysis models will require concurrent increase in the level of sophistication of the land use models. More esoteric land use models, in turn, require more data which presents two dilemmas:

1) More detailed land use models and demographic forecast require increasingly expensive data collection.

2) Perhaps a more threatening challenge is the question of confidentiality. The sample of households willing to provide extensive personal data may also bias the results.

A particular assault on the planning process in some areas is being mounted by sophisticated community groups which analyze projected land development patterns at the parcel level. Communities tend to focus on individual properties, particularly in areas where there is deterioration. One suggestion is to invite the community to become an active agent in the land market process. There must be a caveat, however, about using small zone forecasts. They tend to focus development on individual property owners who may not be anticipating 10, 15 or 20 year time horizons. The consequence may be that the future plans seem unreal. There must be opportunities to better understand the market process, recognizing that it is much different in healthy development areas than in those that are declining.

There was a general consensus that the land market was not well represented in land use models, nor is it particularly well understood by the transportation planning profession. There was agreement that representing the land market in models has merit, but the theory is not well developed and data are hard to get. The level of data needed may be inconsistently available from one area to the next, even within a subregion. In the absence of significant understanding, there is a tendency to try to collect more data, which may or may not provide appreciation for the ways in which the land market operates.

Although it is possible to develop alternative land use scenarios, it is extremely difficult to estimate the probability for achievement of each of these scenarios. In an environment where zoning and long-range master plans are seen as "fixed", the concept of probability of success may seem difficult to accept. The developers of transportation planning models are consequently forced to assess the probability of alternative land use plans and their impact on the transportation model. Since most models concern the probability of a choice or an event, statistical problems arise when we try to deal with an interval around that probability rather than a single point. It would be possible, using elasticities or sensitivity analyses to provide a matrix of how the probabilities would change given changes in selected variables. Introducing probabilities into land use models may add a tremendous increase in the number of transportation alternatives that need to be analyzed, or the number of land use alternatives needed to assess the value of one transportation alternative.

In the short run, there is a need for near term improvements to provide methods to disaggregate regional and subregional data to zone level data. This is particularly vexing, in that travel zones are getting smaller and smaller due to improvements in computing capabilities, which leads to a need for smaller disaggregation of land use data.

Summary of Research Needs

The focus of research in land use modeling must consider the total transportation, land use, and environmental planning process. The decision processes in land development and transportation are highly inter-related. In the same manner, development and environmental concerns are frequently involved in trade-off analyses.

The suggested research topics fall into three broad areas: the behavior of persons and markets; questions of model stability and sensitivity; and, development of techniques and comparisons of capabilities of the existing models. Each of these research areas provide opportunities for numerous research topics.

1. Modeling Land Markets
The consensus of the workshop was that much of our existing knowledge and understanding of land markets and pricing structures is not accounted for in the land use models available for application today. Also, much of the understanding and the

knowledge of the ways in which land markets operate is housed in concepts and jargon known to developers, but is not integrated into the structured understanding in models used by transportation planners. Current models also have no capability to model the uncertainty and variations in the land markets.

2. Developing Guidelines for Local Land Use Plans

This research area is designed to address the difficulty of adjusting land use plans for over zoning or providing "wish-lists" rather than real plans. This is a sensitive area since land use planning and zoning have traditionally resided at the local level of relatively small jurisdictions, and there is a general distrust of planning performed by state and federal agencies. For many jurisdictions, zoning carries with it a set of implicit planning policies which local citizens often find difficult to unravel and understand.

Research is needed to define the appropriate roles for land use models in the local planning process. Should they be used to forecast where a specific development will occur, or should they just allocate growth proportionately everywhere? For example, should the forecast contain the number of retail employees in a transportation zone or should it be specific by parcel in the kind of development expected?

3. Research on Aggregation/ Disaggregation Issues

In current planning of land use and transportation facilities, transportation analyses normally occur using a zone system which is more detailed than the land areas used to forecast development, growth and changes in demographic composition. Thus, the two modeling efforts tend to deal with different geographic scales. Typically, the aggregation of local land use plans into a regional total will result in a different, usually larger estimate of future development than the regional total derived from national gross estimates.

In the short run, it would appear that techniques and methods involving more usage of GIS capability should be developed to allocate from the larger planning districts (aggregation of zones) used for land use forecasts to the zone level needed for transportation planning. This may require hand adjustments and post allocation checking. In the short run, it may be more efficient to use land use models for the regional forecast work with heuristic processes incorporating the models along with other information and judgment to arrive at the zone level estimates.

4. Developing Processes for Generating and Evaluating Scenarios

The most exciting development in transportation planning in the last decade is the recognition that land use scenarios have a powerful influence on future transportation needs. We have finally abandoned the foolish concept of a "level playing field" where multiple transportation alternatives were proposed to fit one fixed land use development plan. Recognizing this leads to a whole new set of challenges.

Significant research is needed in determining the range of possible plans and policies available for a particular region, imposed by the region itself or from the state level. The plans and policies must then be clustered to meet the interests and needs of different interest groups such as local communities, regional agencies and individual citizens. A methodology is required to create policy clusters or combination and aggregation of policies that would work to support each other. A further technique for clustering these policies into alternate land development scenarios is also essential.

Scenario development and testing present intriguing software issues since different models would be needed to handle different policies. Research should be started to evaluate complex versions of the popular urban simulation program SIMCITY or other artificial intelligence and chaos theory models to deal with the complex interactions of policies and plans with individual behavior.

5. Developing New Methods for Understanding Land Use Preferences

Citizens frequently find it difficult to visualize land use characteristics of development as portrayed by planners with their zoning maps and housing density maps. New methods for communicating the different options available and recording citizen preferences are needed. This may also lead to a new generation of evaluation criteria which would improve the land use models.

6. Developing Land Use Models for Nonurban Areas

Traditional land use and transportation models tend to virtually ignore development beyond the regional boundary. This regional boundary tends to be somewhat arbitrary since it rarely, if ever, represents a growth limit. As regions continue to expand, it will be necessary to take into account what happens with development if constraints are placed on locations within the region; some of the development will leak through the region boundary, other development will escape to a competing region. It is important to be able to distinguish the difference.

As regions become more freeway- and auto-oriented, there will be a need to accommodate specialized travel. Other types of specialized trips will result from increased recreation travel and long-distance trips outside the modeled region. These trips will also need to be accommodated and their land use implications must be accounted for.

7. Modeling Location Decision Behavior

This research topic recognizes that household and business location decisions are made by distinct individuals and not by homogenized average families or households. Current models tend to homogenize populations with respect to income and life-style variables. There is a great need to better understand behavior within each critical subset of the total population.

There is basic research needed in methods to integrate this knowledge into the land use and transportation models. The research must address such fundamental issues as whether the business or job location precedes residential location decisions, or the manner in which these two decisions interact. Knowledge is needed on how the process of selecting job and home locations varies with respect to the number of workers in the family, the income of the household and relative income of the workers. Once this information is available and behavior patterns are understood, it will be necessary to develop models that will use this knowledge to predict travel patterns.

8. Comparing of Existing Land Use Models

There are a number of land use models and modules in limited application around the world. A laboratory "bench test" of the models is needed to allow for intelligent choices for applications in the U.S. We suggest a cooperative research project funded by state and local governments if necessary, but through a centralized research program such as NCTRP or NCHRP. Direct funding through FHWA/FTA will also be appropriate. The research would focus on data requirements cost of implementation, particularly the data collection, and the sensitivity of the models to policies and policy clusters.

9. Accommodating Land Use Uncertainty in Transportation Models

It is important to recognize that land development contains high levels of uncertainty. Even if the development scenario accounts for alternate policies and plans, it does not account for developer decisions such as to abandon projects, (which may appear to be irrational). Transportation modeling must have a realistic expectation about land use model contributions to the transportation planning process.

10. Assessing Cost and Confidentiality Issues for TRANSIMS

The travel model improvement program appears to be putting more pressure on land use models to provide detailed information to feed the simulation process. The principal question for local MPOs will be the cost and data collection problems, particularly those of confidentiality required to provide the detailed information about household behavior needed to feed the behavioral decision models. We recognize that such data are available in many cases due to credit card and banking activities. Capturing these data and using them for modeling purposes may present difficulties not accounted for.

11. Modeling Changes in Behavior Over Time

Transportation and land use models operate under the premise that human behavior on a constant set of stimuli will result in a constant set of responses. In other words, an individual's choice will remain the same if the attributes of the choice are identical through time. There is concern that this is not necessarily true in the long run, and research to determine the variation in decisions is necessary.

Needs For The Next Generation of Land Use Models

The group's prescription for the next generation of land use models was derived from its conviction that the land use modeling process has as its primary objective a need to communicate the sensitivity of land development to transportation, and the impact of transportation investments on future land development patterns. The next generation of land use models must be able to address a wider range of policy questions than have been examined in current practice. In particular, it will be important for models to be able to identify sensitivity of development patterns to those actions which are under the control of the political and land market processes.

The results of the land use model must be consistent and defensible. The group suggests that transportation zones be consistent with land use zones for ease of comparison. The results must be reasonably associated with the actions of consumers, developers and the community as represented in the model input stream. There is a growing interest in being able to identify local response to regional policies since the impact on the local homeowner occurs at the jurisdiction level.

The new land use models must make maximum use of geographic information systems (GIS) with the most advanced graphics capabilities obtainable. Graphic output is essential to providing information that is useful at the consumer and planner levels.

It is important that new models be able to aggregate local plans to the regional level to illustrate to planners where zoning has been excessive and inappropriate for the level of total development desired. In this way, planning organizations will be able to test alternative development scenarios and, given adequate sensitivity to policy questions, the models can indicate areas of probable growth. The model results should be built around the information that local officials need for appropriate decision making, and the types of data that are required to satisfy needs of developers, environmental groups, and neighborhood organizers.

The model should be built in a modular structure so that different types of information can be disaggregated at appropriate detail levels to evaluate attributes of interest at a local level. For example, citizens are frequently interested in indicators of pedestrian and bicycle access, availability of sidewalks, traffic levels at a local level. The models must, therefore, address individual location choices, the results of developer actions, the roles of the public sector, private sector, and the land market. Information should also be available about urban design elements which have an impact on transit and non-automobile use. The land use models must also be able to provide the information about individual activities at a level of detail needed to support the simulation process in the TMIP models. This will increase data requirements which are necessary to describe households, sizes, life-styles and cycles, and the socioeconomic dynamics in both the short- and long-term.

To be truly useful, the next generation of land use models will have to involve complicated and intricate relationships, but still be able to provide relatively simple explanations and descriptions of the interaction between land use and transportation. In order to be effective, educators will need better access to information on how and why the new land use models perform as they do. This will require tutorials, provision of internships, and other methods to extend the information base and increase the corps of educators and practitioners in the U.S. who are familiar with the new model systems.

List of Attendees

Alex Anas	SUNY at Buffalo
Larry Anderson	Texas Natural Resource Conservation Commission
Patricia Bass	Texas Transportation Institute
Michael Batty	State University of New York at Buffalo
Terry Bills	Southern California Association of Governments
David Boyd	Ithaca-Tomkins County Transportation Council
Annette Boyer	Pikes Peak Area Council of Governments
Raymond Brady	Association of Bay Area Governments
Daniel Brand	Charles River Associates, Inc.
Dunbar Brooks	Baltimore Metropolitan Council
Kenneth Cervenka	North Central Texas Council of Governments
Donald Chen	Surface Transportation Policy Project
John Coil	Denver Regional Council of Governments
Wilbur Conder	Portland METRO
Bob Czerniak	New Mexico State University
Tomas de la Barra	Modelistica
Betty Deakin	University of California, Berkeley
James deBettencourt	Center for Neighborhood Technology
Bruce Douglas	Parsons, Brinckerhoff, Quade & Douglas, Inc.
Fred Ducca	Federal Highway Administration
Robert Dunphy	The Urban Land Institute
Marcial Echenique	Marcial Echenique and Partners
Kim Fisher	Texas Transportation Institute
Ron Fisher	Federal Transit Administration
Stephen Fitzroy	Puget Sound Regional Council
Jonathan Gifford	George Mason University
Robert Griffiths	Metro Washington Council of Governments
Susan Handy	University of Texas at Austin
Britton Harris	Consultant
Greig Harvey	Deakin, Harvey, Skabardonis, Inc.
James Hoben	Department of Housing and Urban Development
John Holtzclaw	Sierra Club
Madeleine Hormann	Pikes Peak Area Council of Governments
John Hunt	University of Calgary
Lyssa Jenkens	North Central Texas Council of Governments
Robert Johnston	University of California - Davis
Roy Larson	Metropolitan Council of the Twin Cities
George Lathrop	Charlotte Department of Transportation
Keith Lawton	METRO Planning Department, Portland
Franklin Lenk	Mid-America Regional Council
Lars Lundqvist	Royal Institute of Technology
Roger Mackett	University College London

List of Attendees

Hani Mahmassani	University of Texas at Austin
Marilee Martin	Houston-Galveston Area Council
Joseph McLelland	Charlotte Department of Transportation
Charles Metalitz	Northeastern Illinois Planning Commission
Eric Miller	University of Toronto
Mark Miller	University of California at Berkeley / California PATH
Darrell Morgeson	Los Alamos National Laboratory
Larry Mugler	Denver Regional Council of Governments
Robert O'Neal	North Central Texas Council of Governments
Norbert Oppenheim	City University of New York
Noel Paramanantham	Texoma Council of Governments
Rolf Pendall	University of California
Robert Pendergrass	Indian Nations Council of Governments
Douglas Porter	The Growth Management Institute
Stephen Putman	University of Pennsylvania
Amelia Regan	University of Texas at Austin
Michael Replogle	Environmental Defense Fund
Thomas Rossi	Cambridge Systematics, Inc.
Guy Rousseau	Indian Nations Council of Governments
Max Samfield	Houston-Galveston Area Council
Barry Seymour	Delaware Valley Regional Planning Commission
Habib Shamskhou	Farradyne Systems, Inc.
John Sharp	Association of Central Oklahoma Governments
Gordon Shunk	Texas Transportation Institute
David Simmonds	David Simmonds Consultancy
Frank Southworth	Oak Ridge National Laboratory
Richard Steinmann	Federal Transit Administration
Todd Steiss	Baltimore Metropolitan Council
Dexter Stone	Ark-Tex Council of Governments
Jeff Tayman	SANDAG
Paula van Lare	U.S. EPA/OPPE
Paul Waddell	University of Texas at Dallas
Michael Wegener	University of Dortmund
Darrell Westmoreland	Ark-Tex Council of Governments
Chester Wilmot	Louisiana State University
Robert Wood	Texoma Council of Governments
Chen Yang	Association of Central Oklahoma Governments
Ying-Ming Yen	Purdue University