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An Integrated Computer Modeling Environment for Regional Land Use, Air Quality, and Transportation Planning

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AN INTEGRATED COMPUTER MODELING ENVIRONMENT FOR REGIONAL LAND USE, AIR QUALITY, AND TRANSPORTATION PLANNING

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ABSTRACT

The Land Use, Air Quality, and Transportation Integrated Modeling Environment (LATIME) represents an integrated approach to computer modeling and simulation of land use allocation, travel demand, and mobile source emissions for the Albuquerque, New Mexico, area. This environment provides predictive capability combined with a graphical and geographical interface. The graphical interface shows the causal relationships between data and policy scenarios and supports alternative model formulations. Scenarios are launched from within a Geographic Information System (GIS), and data produced by each model component at each time step within a simulation is stored in the GIS. A menu-driven query system is utilized to review link-based results and regional and area-wide results. These results can also be compared across time or between alternative land use scenarios. Using this environment, policies can be developed and implemented based on comparative analysis, rather than on single-step future projections.

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NOMENCLATURE

CAAA	Clean Air Act Amendments
ISTEA	Intermodal Surface Transportation Efficiency Act
GIS	Geographical Information System
GUI	Graphical User Interface
LEV	Low Emission Vehicle
LATIME	Land Use, Air Quality, and Transportation Integrated Modeling Environment
MRGCOG	Middle Rio Grande Council of Governments
TAZ	Traffic Analysis Zone
TCM	Traffic Control Measure

INTRODUCTION

Patterns of urban growth in the United States in recent decades have led to increased concern over the impacts of these patterns on levels of urban pollution. Vehicle travel has grown much faster than has either population or highway capacity. Traffic congestion has become a major problem in most urban areas. Land use development serving the motoring public has consumed large amounts of land and reinforced society's dependence on the automobile. As a result, traffic growth has been a major contributor to urban air quality problems (Downs, 1992).

A general consensus has emerged among urban planners that transportation planning needs to be integrated with land use and air quality planning (Hartgen et al, 1993; Hanley, 1993). This consensus has been institutionalized through the Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). The laws specify increased levels of responsibility for municipalities to reduce air pollution, while also encouraging the development of alternate travel schemes. New tools are needed to meet these increased responsibilities. Historically, separate disciplines have evolved with their own perspectives, activities, and models. Each discipline uses computer-based tools, but these tools do not always work well together. In general, data be must requested and transferred between different planning and policy departments, and then translated to fit the needs of a different model. It is generally agreed among planners that this process is well-entrenched, and that it presents significant obstacles to integrated analysis. Significant need also exists for the development of behavioral models to assess the impacts of new transportation and air quality policies on selected indicators of urban quality of life. An integrated computer modeling environment can reduce or eliminate these barriers and address the needs for new tools. If different planning constituencies all developed a sense of ownership in the integrated modeling environment, coordination would improve.

Advances in computer hardware and software have increased the potential of integrated models. More powerful desktop computers permit higher levels of model detail and more complex calculations. Graphical User Interfaces (GUIs) support visual access to model assumptions and model data. Geographical Information Systems (GIS) allow improved access to and analysis of geographic data, and provide the user with more useful model outputs.

This paper describes the Land Use, Air Quality, and Transportation Integrated Modeling Environment (LATIME), a prototype integrated modeling environment developed at Sandia National Laboratories for the Albuquerque, New Mexico, metropolitan area. The system was developed using real Albuquerque models and data, and performs simulated time studies of the impacts of various land use policies on such indicators as urban congestion and pollution.

In the following section, an overview of the LATIME modeling environment is presented and the simulation process is discussed. The following section provides further detail regarding the land use policy component of the system, which was developed specifically for this project. Conclusions are then presented, followed by recommendations for further developments.

OVERVIEW OF LATIME

The Land Use, Air Quality, and Transportation Integrated Modeling Environment (LATIME) is a planning and decision support tool that seamlessly integrates several commonly used planning components into a dynamic computer modeling environment. It has been developed in a modular fashion and includes several commonly used urban modeling packages, allowing the future incorporation of updates to these packages and new components of the policy model that was specifically developed for LATIME.

LATIME 's system features were chosen after discussions with officials in the transportation and air quality planning communities (Hanley, 1993). In addition, the collaboration of the Middle Rio Grande Council of Governments (MRGCOG) has allowed the use of Albuquerque area models and data within the system. The MRGCOG trip generation model calculates daily trip productions and attractions based on 1990 Census data. The MRGCOG travel demand model utilizes several custom macros within the EMME/2 commercial transportation modeling package to assign vehicle trips to links on the road network. The Mobile5a emissions model is incorporated to determine vehicle emissions on each road link, based on model-determined speeds. The land use allocation model incorporated in the system was developed specifically for LATIME using the **ithink** system dynamics modeling package, and allows the simulation of different land use policies within the modeling environment. Program control, data storage and display, and all user interface activities are conducted through macros written for the ARC/INFO Geographic Information System (GIS). The system was developed and operates on a Sun workstation.

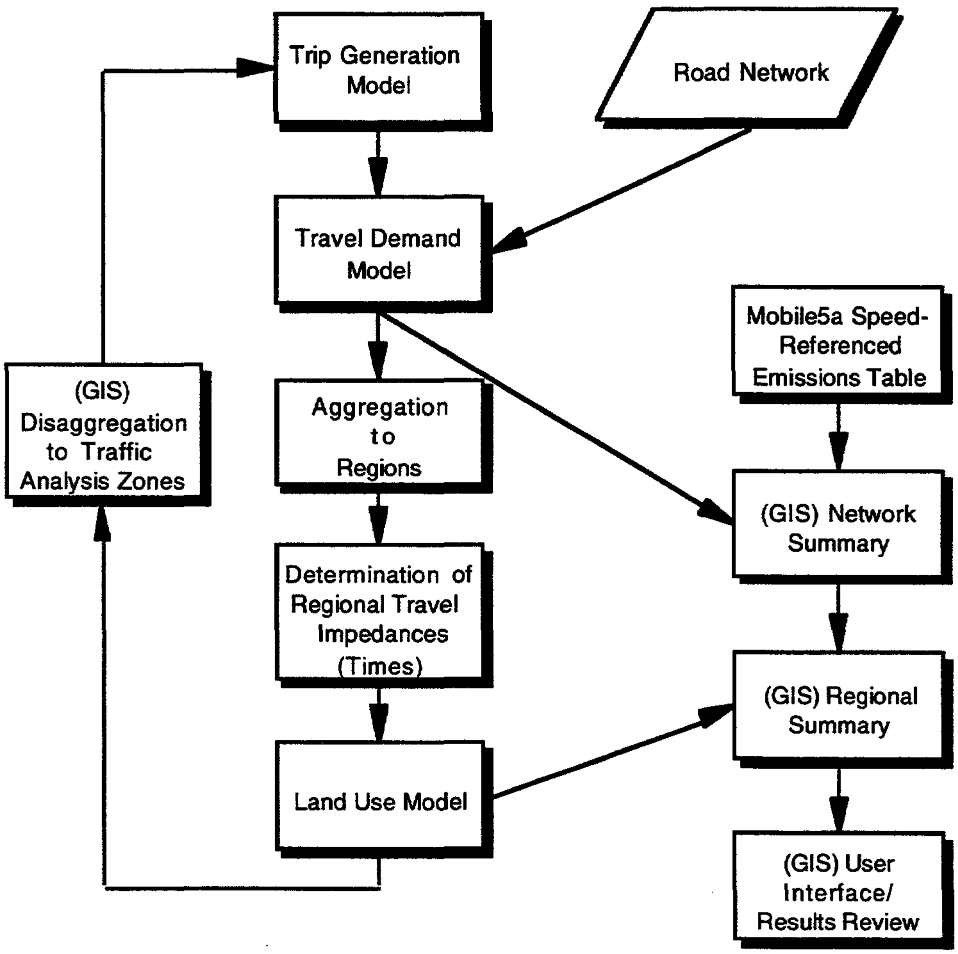

Figure 1: The LATIME Modeling Environment

The modeling components utilized during a simulation are shown in Figure 1. Initialization and control of a simulation is conducted through the GIS. Using menus, the user selects the start year, end year, number of years between each iteration, an existing road network and zoning policy file, and provides a name for the simulation.

Each time step during a simulation begins with a run of the trip generation model, which uses the socioeconomic data updated from the previous iteration and files that describe special and external generators to produce a matrix of daily trip productions and attractions for several trip types. Example trip types include home-to-work, home-to-shopping, etc. In the case of the first iteration, the trip generation model uses base year socioeconomic data that is provided as input to the system. This model is run at the Traffic Analysis Zone (TAZ) level. The MRGCOG trip generation model utilizes 468 TAZs, meaning that the model produces two 468x468 matrices for each type of trip, one each for productions and attractions. Table 1 provides a summary of the data utilized by the trip generation model and all other components of the system, and the results obtained from each step of the process.

Model Component	Inputs	Outputs
Trip Generation	TAZ Socioeconomics: - Population - Dwelling units - Vehicles available - Employed residents - Total employment - Retail employment Special Generators - Productions and attractions input by the user that supersede the model structure External Attractors - Attractions that exist outside the zonal structure	Daily trip productions and attractions, based on zone structure and types of trips
Travel Demand (EMME/2)	Productions and attractions Road network Traffic Analysis Zones Regions	Link-Based: - Daily vehicle volume - Average speeds Regional: - Number of trips - Average trip times - Average trip distances
Air Quality (Mobile 5a)	Fleet mix Vehicle speed range Year of study	Emission rates in grams per mile, based on speed and study year (HC, CO, NOx)
GIS-Based Emissions Calculations	Emissions rates From travel demand model: - Link speed - Link volume From road network: - Link length	Daily link-based emissions for each study year Daily regional emissions for each study year
Land Use Allocation	Limits to regional growth Area growth rate From previous iteration: - Socioeconomic data - Regional travel impedances	Updated socioeconomic parameters

Table 1: Summary of Input and Output Data Requirements for the Modeling Components of LATIME.

After the results are obtained from the trip generation model, the EMME/2 travel demand model is then run to produce several link-based, zonal and regional results. On a link level, outputs from the model include travel times, volumes, and average speeds. Several intra- and inter-zonal summaries are provided by the model, including number of trips, average trip times, and average trip distances. These zonal results are also aggregated from the 468 zone TAZ structure to the 38 land use regions for use in the land use model. Although the land use model could be run at the TAZ level, reduction to 38 regions reduces calculational complexity and facilitates analysis of the results. All results produced by the travel demand model are stored in the GIS for later review and analysis.

The land use model is then run to update and distribute the socioeconomic variables for the next time step. Inputs include a travel impedance trip table from the travel demand model, regional growth control totals, and regional development limits. Three of the six socioeconomic variables are updated with the land use model. These are population, retail employment, and non-retail employment.

The regional outputs of the land use model are then stored in the GIS and disaggregated to the zonal level for input to the trip generation model. The GIS is also used to generate updates on the three socioeconomic variables that are not included in the land use model: dwelling units, employed residents, and number of vehicles owned. Both the disaggregation and the update of the non-land use variables are conducted using base-year distributions.

Link-based and regional daily emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen are calculated for each year of a simulation study. Emission rates are determined a priori, using the Mobile5a model and a variety of preset variables, such as the MRGCOG-provided Albuquerque fleet mix, vehicle speed range, and the year of the study. Tables of emissions rates, in grams per mile, are then stored in the GIS, based on vehicle speed and study year. Combination of these tables with the link-based speeds and traffic volumes, as determined by the travel demand model, allow calculation of the daily link-based emissions for each study year. This is done for each of the 6,789 links in the Albuquerque area model. The GIS is then utilized to map link-based emissions to regions for overall regional daily totals.

Utilizing several menus that have been developed in the GIS, the results of simulations can be viewed in several manners. A user can select a particular time slice from a specific simulation and review all link, zonal, and regional traffic volumes or emissions. Using the mouse to select a region, the regional densities of all socioeconomic variables can be viewed, as well as total trips to and from that region and the average travel time and distance of these trips. Selecting two regions allows the user to view all inter-regional results. The user also has the ability to conduct comparisons of several variables between different simulations, or between different time steps within a single simulation. In this manner, differences between population, employment, and emissions densities are observable. Also available are comparisons of total trips, average times and distances, total emissions, and all socioeconomic variables.

Since the Albuquerque travel demand model only considers one mode of vehicle traffic, and has no provisions for modes such as transit, bicycling, or walking, LATIME does not presently have the capacity to model the impacts of policies related to these modes on future land use and travel patterns. However, a variety of policy scenarios can be utilized within LATIME to predict impacts on regional land use, congestion, and emissions. Different roadway construction schemes can be analyzed through the development and input of different road network models. The effects of land use policies designed to encourage changing allocations can also be modeled, such as those that promote higher densities in central regions and discourage low density growth in outlying areas. By adjusting regional limits to growth within LATIME, the predicted effects of a wide variety of policy options can be compared.

THE LAND USE ALLOCATION MODEL

The purpose of the land use allocation module is to calculate land use scenarios that are realistic, internally consistent, and can be easily updated. These future transportation/land use scenarios must also be realistically influenced by transportation measures including transit improvements and land use policy decisions.

Operational land use allocation models were first developed by Lowry in the 1960s (Lowry 1964). Putman linked land use models to transportation network models in the 1970s (Putman 1983). Marshall and Lawe have updated the Lowry/Putman model structure to better represent suburban growth areas in the 1990s. This model has been applied to the Tampa Bay Region, the New Hampshire Maine Seacoast Region, and the Burlington Vermont Region (Marshall and Lawe 1993, Marshall and Lawe 1995). A simple version of this model has been incorporated into LATIME. An overview of the land use allocation model is shown in Figure 2.

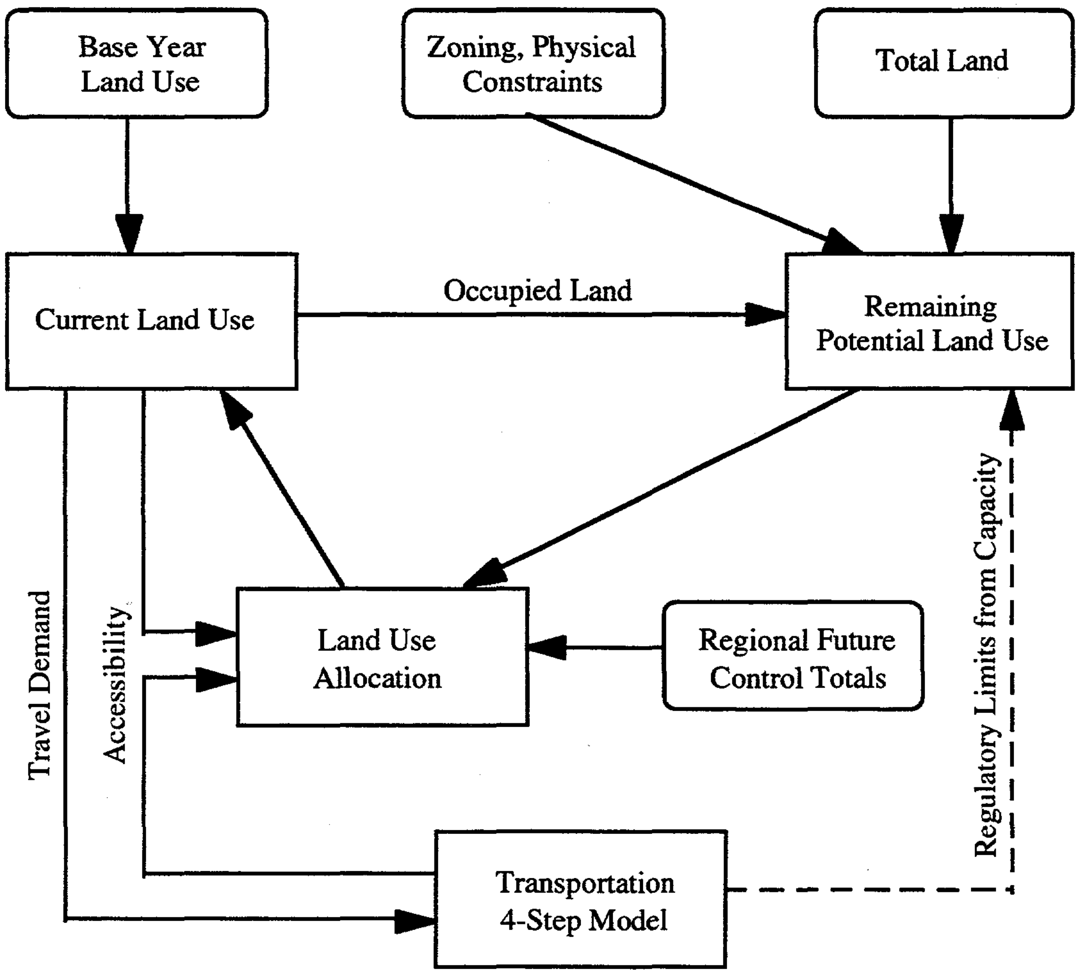

Figure 2: Land Use Allocation Model

The earlier projects integrated land use allocation models with travel demand models. The new focus in this project is providing access to the model structure as an icon-based interface. This structure is much more accessible to planners than a typical "black-box" computer model. This enables planners to experiment with the model in order to better understand its assumptions and sensitivity to changes in these assumptions. Experimentation could achieve several benefits including better models, more educated model users, and more appropriate model use.

A commercial simulation package, **ithink** (High Performance Systems, 1993) was used as the front-end of this interface. The use of **ithink** as a modeling tool facilitates visualization of the interactions between variables within a system. Since it is currently available only for the Windows and Macintosh operating systems, a routine was developed that automatically converts the structure of an **ithink** model into the C Programming Language, allowing it to be utilized on the Sun workstation.

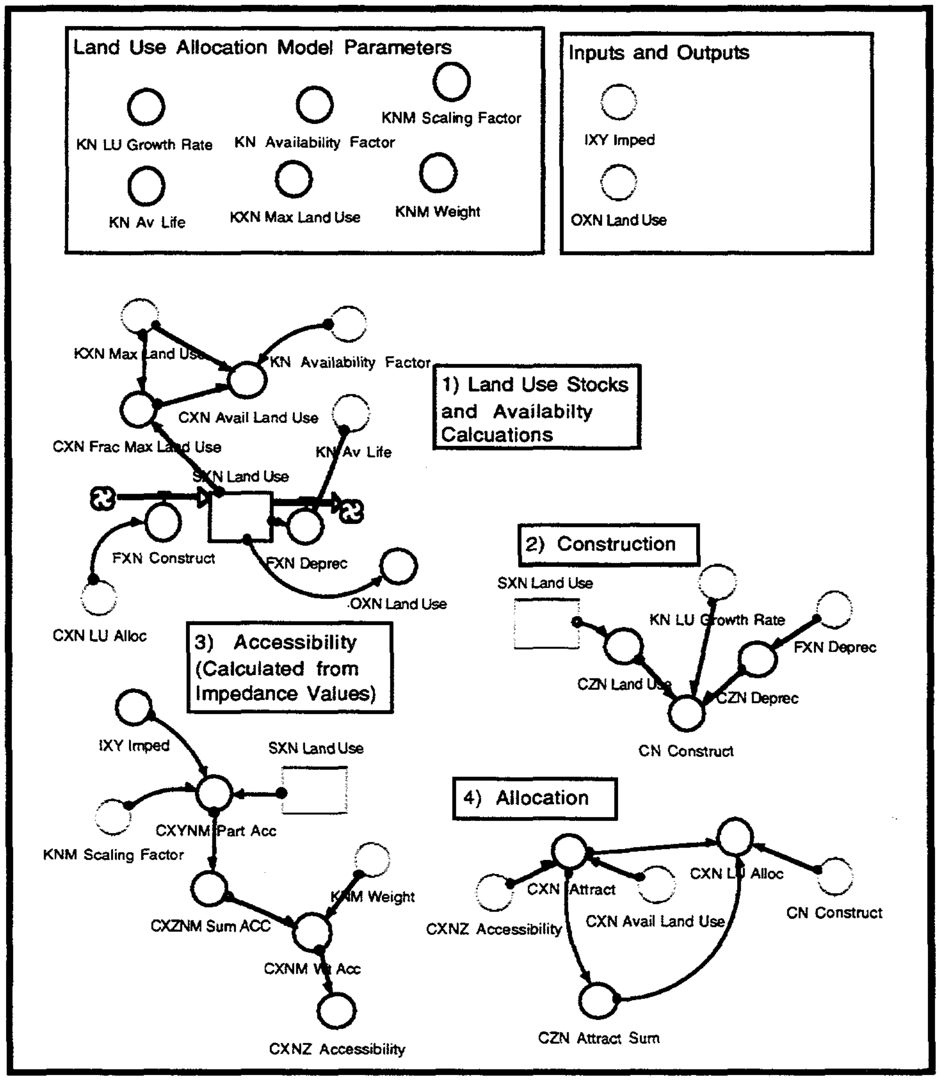

Figure 3: Visual Display of the Land Use Allocation Model, Developed with the ithink modeling package.

The visual display of the land use model is shown in Figure 3. Each icon represents data, parameters, or calculated values from embedded equations. Access to the data, parameter, or equations is gained through double-clicking on an icon. Arrows linking icons indicate causality in the model structure. For example, "CXN Attract" is a function of "CXNZ Accessibility" and

"CXN Avail Land Use." In English, the attractiveness of a transportation analysis zone (TAZ) for development is a function of its accessibility and the availability of land for development.

The letters N, M, X, and Y in the names define a hierarchical structure for data and calculations. N and M are any two land use types, and X and Y are any two TAZs. The attractiveness equation "CXN Attract" is calculated for every TAZ X for every land use type N. The input variables also have distinct values for every TAZ X for every land use type N. One of the inputs, "CXNZ Accessibility" is calculated in the accessibility part of the mode structure which is shown in Figure 2. The "Z" in the name is there because its calculation involves a summation, in this case across all land use types "M."

Duplicate images of individual icons can be used both to break the structure into subcomponents and to group objects together. For example, all model parameters have been grouped in the upper left-hand corner of Figure 2 for easy access for model testing. Although this nomenclature is complex, one can get used to it, and it has an important advantage over the equally complex convention of a linear set of equations with summation symbols. It visually shows the relationships between variables. We believe that further improvement in making the model structure more intuitive is possible and desirable.

In this version of LATIME, development constraints have been estimated very generally based on readily available GIS data. Model parameters are generic. The model does operate and gives reasonable results. If the model were to be used for real planning work, it would be important to better estimate development constraints and to estimate parameters based on actual development patterns over a five- or ten-year period.

CONCLUSIONS

The types of summaries that are available from LATIME in the GIS are shown in Table 2. These outputs can be studied for any time step within a simulation. Comparisons of this information can also be made between different steps within a simulation and across simulations.

Link-Based:	**Regional:**
• Daily vehicle volumes • Average vehicle speeds • Daily emissions - HC, CO, NOx	• All socioeconomic parameters • Daily emissions - HC, CO, NOx • Total vehicle trips • Average travel times • Average travel distances

Table 2: Simulation Summaries Provided by the LATIME Geographic Information System.

LATIME is designed to benefit decision makers involved with issues related to urban growth and development, such as transportation, land use, and air quality, at the local, regional, and state levels. Users will be better able to assess options related to constraints of the CAAA or programs under ISTEA, and to compare different possible courses of action involving near and long term growth of urban areas. For example, different development and zoning schemes can be tested in regard to air quality conformity issues. Also, since ISTEA allows considerable flexibility in the implementation of such programs as congestion mitigation and air quality improvement, this system can be used to compare the potential benefits of different scenarios.

Through development of LATIME, the functionality of an integrated modeling environment has been demonstrated. This environment provides predictive capabilities of the dynamic interactions between human behavior, traffic patterns, and related air quality. The seamless transfer of data between the several modeling components reduces the need for human interaction and therefore the risk of data entry errors. The use of the GIS as a storage, summarization, analysis and display tool greatly facilitates the assessment of the results from studies. With this system, users can predict gradual and subtle changes through multiple time steps. Direct comparisons can also be made between different simulation runs. These capabilities combine to provide decision makers with an analysis tool that allows the assessment of the relative merits of many different policy options.

A graphical icon-based model interface has also been demonstrated through the example of the land use allocation model. This approach offers considerable promise but needs additional work, both to make the interface more user friendly and to include more policy options and socioeconomic variables. However, the merits of automatically expanding a relatively simple, graphically-based interface to a region-wide model have been illustrated with LATIME.

The benefits of an integrated modeling environment include the use of a graphical and geographical user interface, user access to model relationships and data, and internal consistency among model elements. These benefits will ultimately translate into more model simulations and sensitivity analyses, more up-to-date and accurate models, better model understanding by planners, and thus more useful and used models.

RECOMMENDATIONS FOR FURTHER DEVELOPMENTS

Both the graphical user interface and the geographical information system aspects of LATIME have proven to be useful in supporting the types of transportation, land use, and air quality analyses required today. These directions should be pursued both in research projects and in operational urban models. The ultimate vision would be of a suite of modules that operate together in a "Plug and Play" environment. The quest for this environment is currently frustrated by inconsistencies between file formats and operating environments, but these obstacles can be overcome and are gradually diminishing with advances in computer software.

Utilizing the same basic structure that LATIME possesses, valuable improvements could expand in several directions. Additional modular units could be developed to offer increased policy modeling capabilities, such as the inclusion of Traffic Control Measures (TCMs) as specified in ISTEA. TCMs range from construction of new roadways and traffic signals to low emission vehicle (LEV) programs and innovative taxation schemes. New modules could also include possible municipal programs, such as park and ride schemes. The inclusion of other travel modes, such as transit, walking, bicycling, and even telecommuting, would allow a system such as LATIME to remain abreast of continuing changes in the urban environment.

Improvements to the system dynamics would dramatically improve the capabilities of LATIME. Greater resolution would be achieved if the land use model were expanded from the 38 regions to the 468 TAZs. In addition, several special trip generator files are presently not updated during a simulation run. For example, for reasons of simplification, the impact of Kirtland Air Force Base on local transportation is assumed to remain constant throughout the years of a simulation run. For a more accurate set of results, these factors should be updated according to local parameters. Another present limitation to the dynamics of the system involves the fact that the road network does not change during a simulation. Simulations with LATIME would much more accurately reflect real world conditions if changes in the road network were entered at each step in the simulation. These improvements would help to match the processes and outputs of LATIME more closely with real world conditions.

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