METROSCOPE:
SIMULATING FUTURE URBAN LANDSCAPES AT THE PARCEL LEVEL

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Abstract

Over the last decade National and State requirements have stimulated a vast increase in the sophistication and complexity of integrated land use and transportation models. Along with the increasing economic and computational sophistication of models has been a growth of demands on GIS to simultaneously produce aggregate data while storing and displaying highly disaggregate data. Metro has developed a GIS based tool called Metroscope that works with Metro's real estate and transportation models. Metroscope aggregates parcel based data to a model compatible form, receives aggregated output from the models and converts the modeled output back into parcel format constituting in effect a synthetic future landscape.

Introduction

In response to the policy and forecast demands of managing regional growth, Metro has developed a set of econometric, real estate and transportation models to realistically simulate how markets respond to government growth management and transportation policies. For computational reasons highly iterated transportation and real estate models are presently restricted to a limited number of zones. However, policy and transportation analyses have come to require very detailed data at block level spatial scales. Concomitant with the increasing need for ever finer spatial detail has been a combinatorial explosion in data output. When once we were content with population and employment estimates, we now have hundred's of demographic, employment, real estate, and transportation variables. Given the enormous requirements for data handling, preparation, visualization and accounting, we have used GIS to integrate the various model data flows and locate model zone level output to far more detailed levels of geography. The resultant GIS based system we refer to as Metroscope.

Background of Metro's Modeling Effort

Metro's interest in integrating transportation and land use modeling began initially in 1992 and was and continues to be stimulated by a growing number of Federal, State and local information and compliance requirements. Beginning in the 1990's with Federal legislation such as ISTEA & TEA-21 along with EPA air quality conformity requirements put an increased emphasis on the land use and associated air quality effects

of transportation investment. Significantly, at this time there were successful court challenges of MPO transportation plans in California, New York and Illinois based on failure to account for the land use impacts of planned transportation improvements. This litigation further stressed the need to explicitly represent the relationship between land use and transportation within the framework of a consistent, formal simulation model.

Likewise at the State or Oregon and local level new planning requirements demanded information that ultimately must be determined by integrated transportation – land use models; for instance, the maturation of the Urban Growth Boundary (UGB) requirements particularly in the Metro Region. Throughout the 1980's the UGB amounted to a set of oversized new clothes relative to the growth needs of the region. Only in the early 1990's did the Metro Region finally began to grow into the boundary. Finally, by the mid to late 1990's Metro began to grow out of the UGB. State requirements to expand the boundary to maintain a 20 year residential land supply have now precipitated an additional set of questions regarding the interrelationships between housing prices/rents, urban densities, redevelopment and infill rates, travel distances and the share of the economic region's[1] growth we expect within the UGB. Attempting to verbally unravel such a complex fabric remains completely hopeless. However, integrated transportation – land use models properly formulated are capable of providing estimates of all the above factors for any combination of UGB expansion, zoning capacity and transportation/infrastructure investment policy that might be proposed.

GIS Requirements

Growing model sophistication has placed increasing demands and reliance on the GIS system. Present transportation model development underway at Los Alamos National Laboratories and Portland Metro (TRANSIMS) requires detailed block by block land use and demographic data. In response to these demands Metro has developed a suite of four models embedded in a GIS based system we call Metroscope. As we elaborate below, Metroscope operates as far more than an output visualization tool. Metroscope actually extends the spatial resolution level of the models and incorporates additional spatial information that the models do not use.
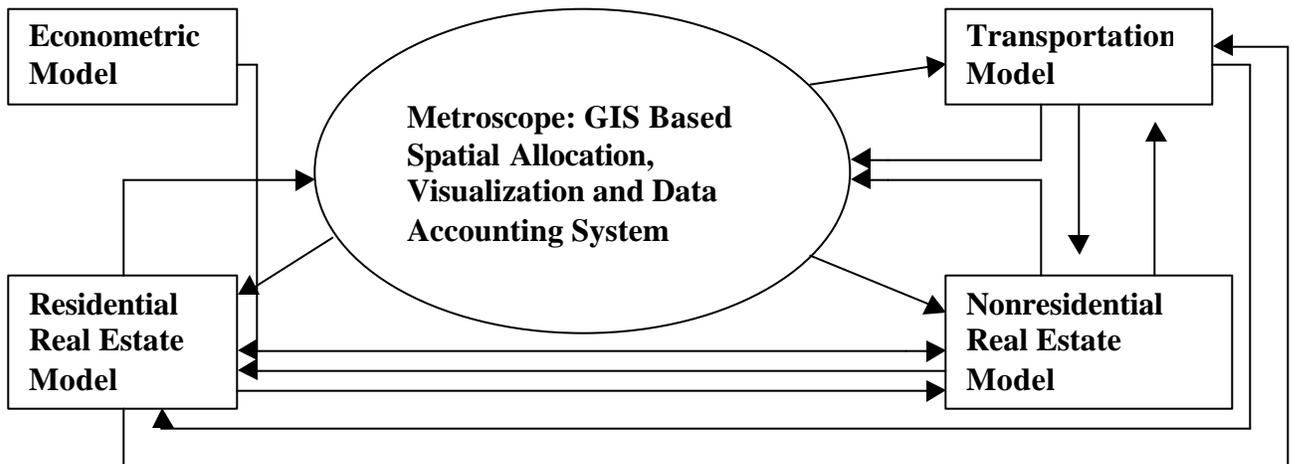
The following schematic shows the flow of information between the various Metroscope modules.

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[1] The UGB and the Metro jurisdiction cover approximately 1.2 million of the economic region's 1.8 million population. Metro and the UGB are surrounded by "refuge" areas that can provide housing to those willing to trade off travel time in exchange for desired housing at the appropriate price.

WHAT IS MetroScope?

MetroScope Integrates, Displays and Stores Information For Metro's Technical Models

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┌──────────────┐                                    ┌──────────────┐
│ Econometric  │         ╭─────────────────╮        │Transportation│
│ Model        │        ╱ Metroscope: GIS   ╲       │ Model        │
└──────────────┘       │  Based             │       └──────────────┘
                       │  Spatial Allocation,│
                       │  Visualization and  │
                       │  Data               │
┌──────────────┐       │  Accounting System  │      ┌──────────────┐
│ Residential  │        ╲                   ╱       │Nonresidential│
│ Real Estate  │         ╰─────────────────╯        │ Real Estate  │
│ Model        │                                    │ Model        │
└──────────────┘                                    └──────────────┘
```

Metroscope Input:

Metro's GIS (RLIS) provides initial condition data to the residential and nonresidential real estate models and the transportation model. These data are aggregated from the parcel level to the appropriate zone or block face system according to the requirements of a particular model. For instance the residential real estate model operates with 400 zones (Census Tracts). The GIS system operating from the parcel level provides the following data to the residential, nonresidential real estate models and the transportation model.

- Amount of vintage housing stock by tenure and by value and rent category
- Vacant buildable residential land by parcel size category and by zoning category
- Vacant buildable nonresidential land by F.A.R. category by zoning category
- An estimate of the infill and redevelopment stock
- Employment by employment zone for 14 SIC categories.
- Nonresidential real estate by square footage for 6 nonresidential real estate categories.
- Distribution of lot sizes of developed land by land use category
- Conversion of parcel data to block face or traffic analysis zone for the transportation model including households divided into 64 classes of household size, income and age by tenure and 14 classes of employment.

In aggregating parcel level data into zone system data we lose substantial amounts of spatial information such as the distribution of housing by value and urban amenities within the zone. Keep in mind that the modeling system need recover much of that information after the real estate and transportation models have produced their outputs.
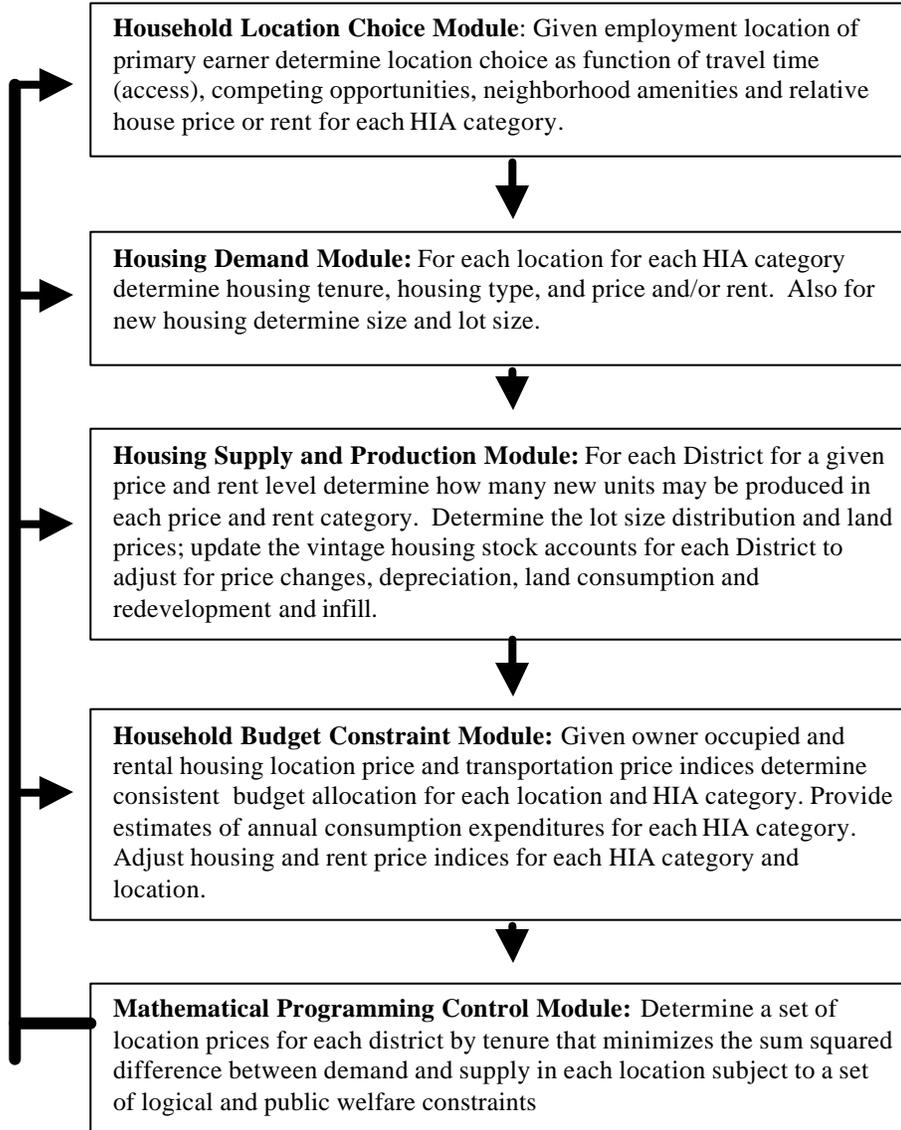
Description of Metroscope Components

The following schematics illustrate the information processing and outputs generated within the two real estate models and the transportation model.

Operation of the Nonresidential Real Estate Model

Demand Calculations

For each of 14 industry types start with an estimate of regional employment in a future forecast year.

Supply Calculations

Compare demand with supply for each real estate type in each employment zone.

For zones and real estate types with excess demand, increase prices to increase supply and reduce demand by location and real estate type.

For zones and real estate types with excess supply, decrease prices to increase demand and reduce supply by location and real estate type.

For each price level calculate land price, calculate land required, capital required and new floor to area ratios.

Distribute employment into as many as six types of real estate depending upon industry type and relative price of different real estate types

Calculate square footage required by each industry type for each real estate type by multiplying employment by industry type by square feet per employee assigned to each real estate type after adjusting for relative price of different real estate types

Test to see if for each real estate type in each employment zone the difference between demand and supply is minimized.

For each industry chose employment zone based on price of real estate type and access (travel time) to all employment, employment in similar industries and access to households.

Operation of the Residential Real Estate Model

Household Location Choice Module: Given employment location of primary earner determine location choice as function of travel time (access), competing opportunities, neighborhood amenities and relative house price or rent for each HIA category.

Housing Demand Module: For each location for each HIA category determine housing tenure, housing type, and price and/or rent. Also for new housing determine size and lot size.

Housing Supply and Production Module: For each District for a given price and rent level determine how many new units may be produced in each price and rent category. Determine the lot size distribution and land prices; update the vintage housing stock accounts for each District to adjust for price changes, depreciation, land consumption and redevelopment and infill.

Household Budget Constraint Module: Given owner occupied and rental housing location price and transportation price indices determine consistent budget allocation for each location and HIA category. Provide estimates of annual consumption expenditures for each HIA category. Adjust housing and rent price indices for each HIA category and location.

Mathematical Programming Control Module: Determine a set of location prices for each district by tenure that minimizes the sum squared difference between demand and supply in each location subject to a set of logical and public welfare constraints

Operation of the Transportation Model

```
┌─────────────────────┐      ┌─────────────────────┐
│ Households by        │      │ Employment by        │
│ household size,      │      │ SIC from             │
│ income and age from  │      │ Nonresidential       │
│ Residential Model    │      │ Model                │
└─────────────────────┘      └─────────────────────┘
          │                             │
          ▼                             ▼
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Trip Generation: Compute (1) workers per household, (2) autos per household and (3) children per household as function of 64 classes of household size, income and age. Compute jobs within 30 minutes of employment as function of employment by SIC class. Calculate trips per household (trip productions) for 6 trip purposes using household classes, no. of workers, no. of autos and no. of children. Calculate trips per jobs (trip attractions) using employment classes for 6 trip purposes.

Trip Distribution: Match trip productions (origin zone) to trip attractions (destination zones) using equations that relate travel time to the probability of making a trip between two zones by trip purpose.

Revised Travel Times

Trip Mode and Time of Day Choice: Compute mode choice for up to 5 modes a function of transport system level of service, land use, household characteristics and trip purpose. Compute time of day choice by trip purpose and mode as function of trip purpose and average daily time distribution adjusted for peak hour level of service.

Revised Travel Times

Check for network equilibrium; if no, iterate again.

Network Assignment and Travel Time Calculation: Determine time of day by trip purpose by travel mode; load network for each origin and destination pair. Compute network travel times.

All three of the above models can be considered equilibrium models in the sense that a set of prices or travel times is computed that insure that the various model components are consistent with one another. In turn the individual models share information so that consistency is assured between models. For instance, the residential real estate model uses employment data from the nonresidential model and travel times from the transportation model. By the same token, the nonresidential model uses households from the residential model and travel times from the transportation model. Finally, the transportation model uses household and employment data from both real estate models.

Metroscope in Detail

As noted above the GIS serves several roles in regard to Metroscope operation. These are data accounting, data visualization and mapping model control zone output down to the parcel level. The following schematic illustrates how the GIS moves data back and forth between the parcel based accounting system and the level of geography native to the models and the data visualization system.

The Metroscope Data Flow Cycle

Year T + 0

> **The Native Landscape:** Parcel based data on residential and nonresidential real estate includes real measured data on number and type of dwelling units, size of building, lot size, land use and zoning. Includes estimated/ synthesized data by parcel on amount and type of employment, household size, household income, age and real estate price/rent and land price. Data include vacant land by zoning and parcel size and estimate of stock of infill lots and redevelopment lots.

Year T + 0

> **Model Level of Detail:** Aggregate residential data to 400 zones and nonresidential data to 70 zones. Obtain Year T + 5 regional employment and household totals from econometric model. Obtain Year T + 0 travel time data from transportation model.

> **Operate Residential and Nonresidential Models:** Use models to compute T + 5 distribution of dwelling units, buildings, households and employment as well as other relevant data.

Year T + 5

> **Model Level of Detail at T + 5:** Present modeled residential and nonresidential data at the 400 and 70 zone level of detail. Modeled data include real estate prices/rents, tenure choice, total allocation of households by HIA, employment by SIC, lots sizes, household spending, densities, etc.

Year T + 5

> **Populate the Synthetic Landscape:** Using the 400 and 70 zone modeled data as controls return the new data to the **native landscape** using a set of "expert rules" algorithms that make use of parcel level spatial information not available to the aggregated data.

Year T + 5

> **Revised Native Landscape at T + 5:** Store "revised native landscape" at the parcel base with updated parcel file for changed parcels. Transfer updated parcel data to transportation model for conversion to block-face estimates to be used in TRANSIMS.

As can be noted from the above schematic, the Metroscope approach is to cycle a composite of actual and estimated parcel level data into and out of a modeling process over time. The result is that parcel level data evolve over time as vacant land is developed, areas are redeveloped and populations come and go. Vital to this process is the use of algorithms that allow consistent communication between the parcel level data and the economically powerful but spatially limited operations occurring in the real estate and transportation models. The following Figures and Tables provide a graphic example of how this process works.

Figure One: Year 1999 Actual Parcel Based Data Provide the Metroscope Initial Conditions – Census Tract 12.01 Zoning & Taxlots
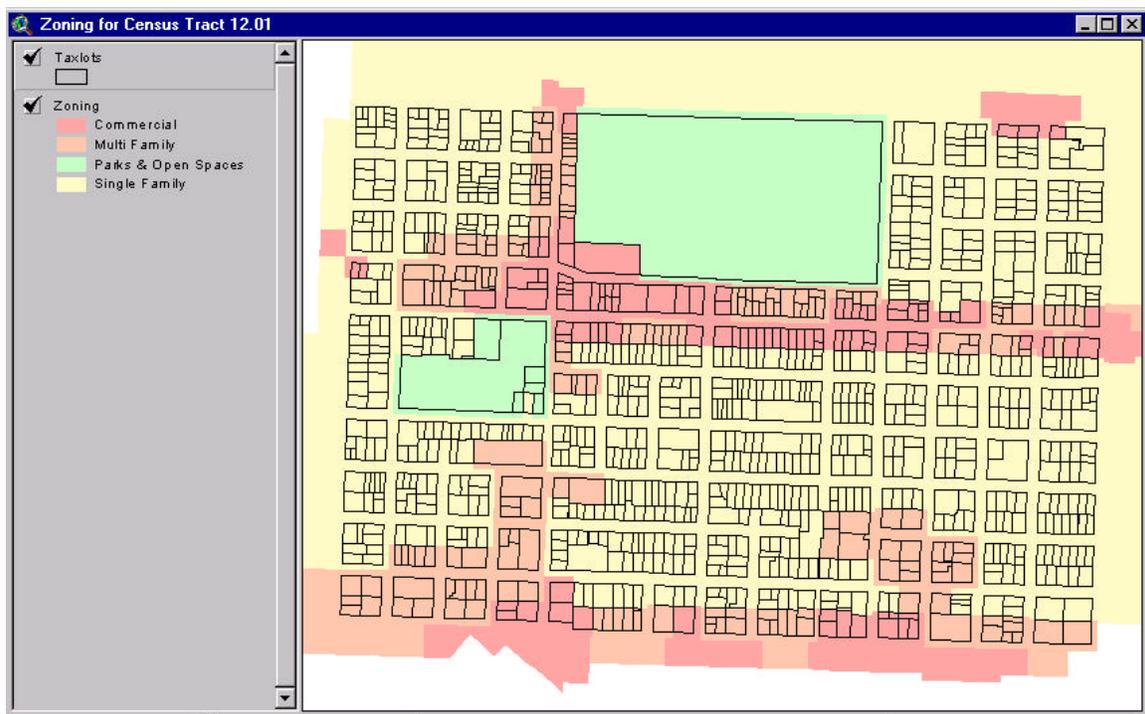
Figure One displays some of the parcel level data that are aggregated to the Census Tract level for use in the real estate models. Table One provides the tabular counterpart to Figure One. In Table One vacant land by parcel size and zoning is aggregated to the Census Tract level. Similarly, housing stock data are extracted from the parcel data and combined with Census data, building permit data and real estate price survey data to yield an estimate of existing housing stock by price/rent category.

Table One: Vacant Land by Parcel Size and Zoning and Housing Stock by Tenure and Price Category Provide Supply Data to the Residential Real Estate Model

Census Tract: 12.01

Model Level 1999 Vacant Land Inventory				Model Level Vintage Housing Inventory		
Parcel Size Category – Acres	SFD	SFA	MFD		1990 Census Dwelling Units	1995 Estimate Dwelling Units
1000 - 2500 Lot Size Cat. Min-Max Sq. Ft.						
< .5	0	0	0.32	Own:0-49.99	117	0
.5 - .99	0	0	0	Own:50-74.99	140	8
1 - 4.99	0	0	0	Own:75-99.99	18	70
5 - 9.99	0	0	0	Own:100-119.99	18	48
10 - 19.99	0	0	0	Own:120-149.99	0	107
20 plus	0	0	0	Own:150-174.99	0	81
2500 - 5000 Lot Size Cat. Min-Max Sq.Ft.				Own:175-199.9	0	23
< .5	0	0.31	0.72	Own:200+	0	25
.5 - .99	0	0	0	Total:	293	362
1 - 4.99	0	0	0			
5 - 9.99	0	0	0	Rent:0-199	176	74
10 - 19.99	0	0	0	Rent:200-299	433	128
20 plus	0	0	0	Rent:300-399	939	361
5000 - 7000 Lot Size Cat. Min-Max Sq. Ft.				Rent:400-499	395	629
< .5	0.23	0	0	Rent:500-599	73	645
.5 - .99	0	0	0	Rent:600-749	39	331
1 - 4.99	0	0	0	Rent:750-999	0	72
5 - 9.99	0	0	0	Rent:1000	0	8
10 - 19.99	0	0	0	Total:	2055	2250
20 plus	0	0	0			

Table One presents the vacant land data displayed spatially in Figure One in tabular form arrayed and aggregated for use in the residential real estate model. Table One also contains data on the existing dwelling units displayed in Figure One. Here too, the data have been converted from their spatial context to the aggregated tabular context necessary for use in the modeling framework.

From Table One we note that our inner city census tract, 12.01 contains very little vacant land about 1 acre for multi-family and ½ acre for single-family. All of the vacant land occurs on parcels of less than ½ acre. The existing residential real estate data indicates about 300 owner occupied and 2000 renter occupied units exist in the tract as of 1995. Price/rent data indicate that the stock has appreciated in price between 1990 and 95 but was generally still low in value. The residential model automatically adjusts capacity to account for infill and redevelopment. Areas with little vacant land, relatively low values for existing stock and high demand will generate 10 – 20 units of infill and redevelopment for every unit developed on vacant land. Conversely, areas with ample

vacant land and high values for existing stock will experience 1 – 2 units of infill and redevelopment for every 10 – 15 units developed on vacant land.

Figure Two displays at the 400 zone level some of the year 2000 output of the residential real estate model. In this instance we are displaying the tenure choice (percent owner) by census tract of one person households, age 25 - 54 years with an income between $29,000 and $43,000. (Keep in mind we have the option of show 64 combinations of household size, income and age for up to 20 variables.)

Figure Two: Using Initial Condition Land Use Data, Travel Times and Regional Growth Data the Residential Model Allocates Households and Real Estate
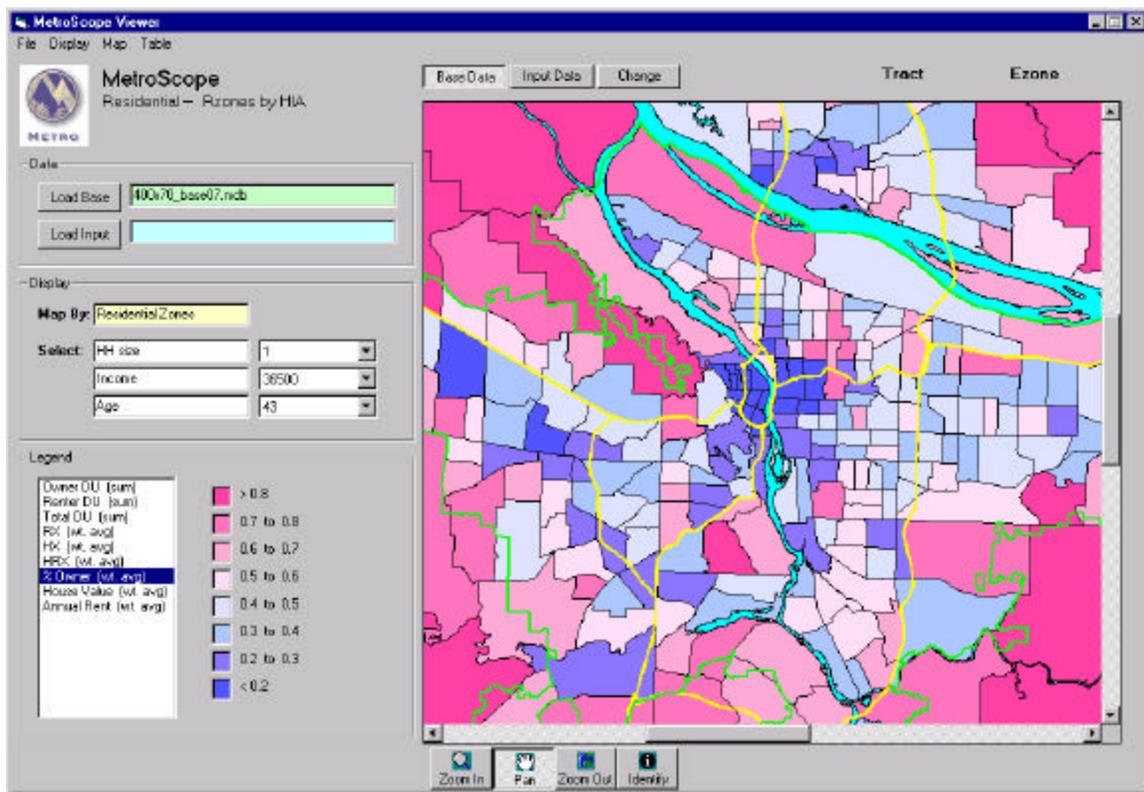
Figure Two shows the pattern for the entire region of where a particular household size, income and age class chooses to locate and whether they are owners or renters. Should we choose, we could show the same data or any of 64 HIA classes or show a summary for all classes.

Table Two summarizes the census tract aggregate data showing the updated year 2000 housing stock by price/rent category. Notable is that despite almost no vacant land the housing stock has increased over 100 units due mainly to infill and redevelopment. Significantly, owner occupied has increased, renter occupied has decreased and overall prices and rents have continued to increase.

Table 2: Year 2000 Housing Stock Increases Over the 95 Level in Number and Value but Renter Decreases Slightly

Census Tract: 12.01

Model Level Housing Output

	2000 Estimate Dwelling Units
Own:0-49.99	0
Own:50-74.99	5
Own:75-99.99	100
Own:100-119.99	117
Own:120-149.99	98
Own:150-174.99	48
Own:175-199.9	100
Own:200+	21
Total:	489
Rent:0-199	0
Rent:200-299	0
Rent:300-399	559
Rent:400-499	633
Rent:500-599	333
Rent:600-749	414
Rent:750-999	286
Rent:1000	0
Total:	2225

In Figure Two census tract 12.01 is simply a blue patch on the map display. Likewise, in Table Two the data are highly aggregated and totally bereft on any spatial context below the census tract boundaries.

Figure Three presents the aggregate data in Figure Two after it has been processed back to the parcel level. In this case we have retained owner/renter choice and 4 income classes. Conceptually, it is possible to allocate owner/renter choice over all 64 classes of household size, income and age for a total of 128 different variations. However, such an extremely busy display would muddle far more than it would clarify. Rather, we have chosen to limit the display to 8 classes.

Figure Three: Residential Model Ouput for Census Tract 12.01 is Allocated Back to the Parcel Level Using Parcel Based Spatial Information
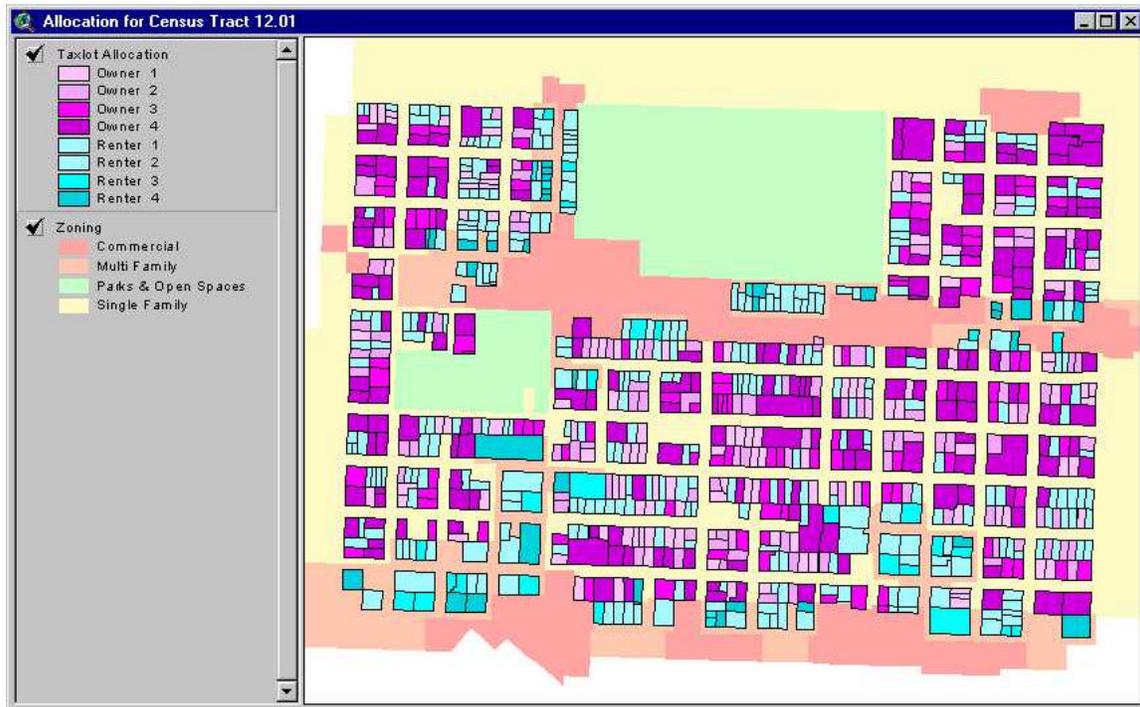
Figure Three provides far more spatial and socio-economic detail than was available in the regional level data. In Figure three we note that roughly half the area is taken by owner occupied dwellings though they comprise less than 20% of the households. This underscores the much higher densities of renter occupied structures. Similarly, owners are predominately from the middle and high income groups while renters represent low and moderate income groups. All of the modeled data though produced on an aggregated basis, has now been disaggregated back to the parcel level to create a synthetic landscape.

Figure Four displays the final step in creating a synthetic future landscape compatible with the latest transportation models (TRANSIMS). These maps are produced after the parcel level data displayed in Figure Three are passed over to the transportation model. The parcel level density information implicit in Figure Three in then converted to "block face" household densities to be used for generating trip making patterns in the transportation model.

**Figure Four: Parcel Level Household Allocation is Converted to Block Face
Household Density for Use in TRANSIMS Modeling**
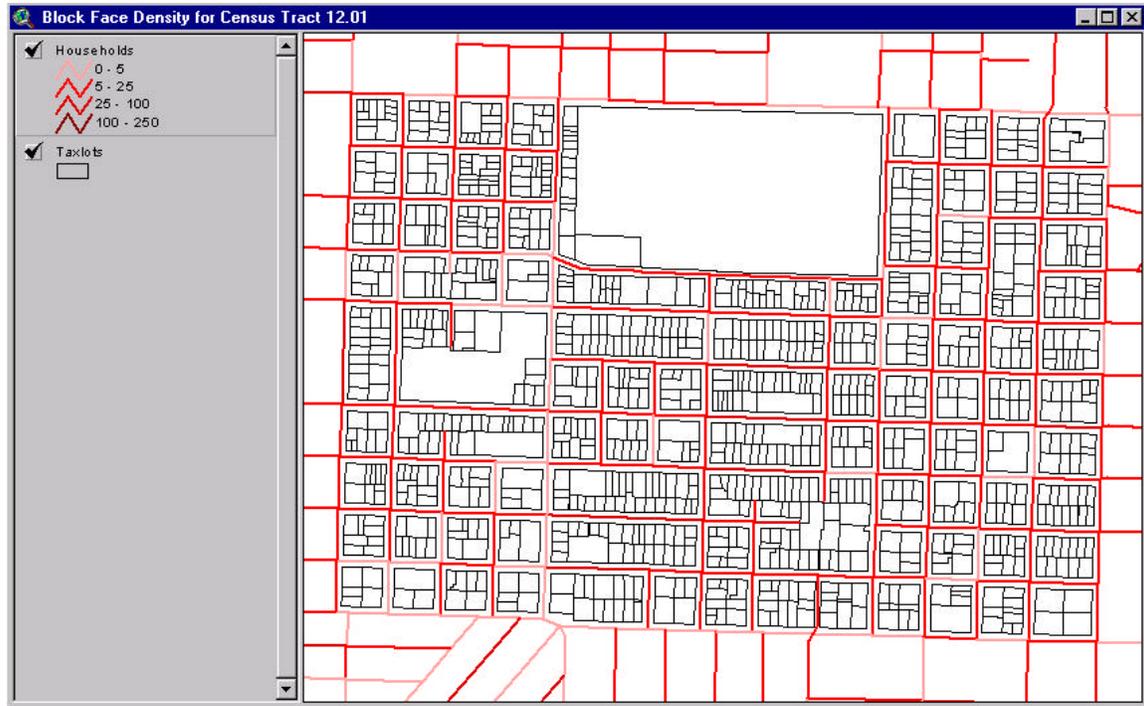
Conclusion

Over the past several years both National and State requirements have placed ever
greater demands on the technical aspects of modeling land use and transportation. At one
end the increasing requirements for integration of land use and transportation in an
economically realistic and consistent framework has lead to highly iterative systems of
hundreds of simultaneous equations. Necessarily for computational and theoretical
reasons these requirements have lead to use of aggregated data in fairly large zones. At
the other end are the requirements to make the maximum use of the detailed spatial and
nonspatial information that GIS has made available to us. In this paper we have
demonstrated a system whereby streams of parcel level data are aggregated and converted
to a model useable format. In turn once the data are processed in the models we reverse
the process so that the spatial and other omitted data are returned to the system on an
estimated or "synthesized" basis. In addition the data streams generated by the models
may be visualized using GIS at several levels of aggregation depending on the type of

data and the interests of the user. Model data output consistently returned to the parcel level also provides the initial conditions for use in the next modeling period.

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