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Comprehensive regional modeling for long-range planning: linking integrated urban models and geographic information systems

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Abstract

This study demonstrates the sequential linking of two types of models to permit the comprehensive evaluation of regional transportation and land use policies. First, we operate an integrated urban model (TRANUS), which represents both land and travel markets with zones and networks. The travel and land use projections from TRANUS are outlined, to demonstrate the general reasonableness of the results, as this is the first application of a market-based urban model in the US. Second, the land use projections for each of the 58 zones in the urban model were fed into a Geographic Information System (GIS)-based land allocation model, which spatially allocates the several land uses within each zone according to simple accessibility rules. While neither model is new, this is one of the first attempts to link these two types of models for regional policy assessments. Other integrated urban models may be linked to other GIS land allocation models in this fashion. Pairing these two types of models allows the user to gain the advantages of the urban models, which represent spatial competition across a region and produce measures of user welfare (traveler and locator surplus), and the advantages of the GIS land allocation models, which produce detailed land use maps that can then be used for environmental impact assessment. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In the US, the Federal Clean Air Act requires all urban regions to meet national ambient air quality standards by certain dates. Regions currently not meeting the standards must demonstrate that their transportation plans will result in mobile emissions reductions, according to certain timetables. Furthermore, the planning regulations that implement the Clean Air Act now require

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regions with relatively poor air quality to model transportation plans using land use projections that are “consistent” with the facilities in each plan (i.e., new freeways or transit lines). This is a strong departure from past practice, where one set of land use projections was used for all facility plans, including the Do Nothing case. The Surface Transportation Act now also requires the modeling of “consistent” land use and transportation plans and so over a dozen regions have now implemented the residential and employment location model, DRAM/EMPAL. A few other regions use other locally developed urban models.

The Transportation Research Board Conference on Transportation, Urban Form, and the Environment recommended urban models capable of representing the interactions among land use and travel behaviors (Transportation, 1991). The US Department of Transportation Travel Model Improvement Program’s Land Use Modeling Conference recommended modular urban modeling systems that include GIS capabilities and that can interact with environmental models [Travel Model Improvement Program (TMIP), 1995].

We are trying to develop improved urban models that are theoretically sound and that utilize the capabilities of GIS, as suggested by Klosterman (1994) and the two national panels cited above. Our methods concept is that one or the other of the widely used comprehensive, market-based urban models (TRANUS, MEPLAN), or any other zone-based urban model, can feed its zonal land use projections into any GIS-based land allocation model and this sequence will produce spatially detailed land use projections in GIS, which can then be used to drive a variety of environmental impact assessment models.

Our practical objective is to evaluate regional transportation and land use policies for impacts on user welfare, mobile emissions, energy use in buildings and vehicles, greenhouse gases, important habitats, prime agricultural lands, and water pollution. We also wish to evaluate urban patterns for their expected costs from flooding, wildfires, and other hazards. It is hoped that these models can then be used to design regional plans that do better than the trend scenario, on most or all of the region’s criteria. For example, a plan with improved urban transit, radial commuter rail lines near to some of the radial freeways, with large protected habitats in remote areas, keeping development off of hazardous lands, and which includes road tolls, parking charges, and raw land development charges, might be expected to be economically efficient and reduce negative environmental impacts.

The development of integrated urban (land use/transportation) models is reviewed and the selection of one for our study is outlined. The application of TRANUS, the more tractable of the two widely used comprehensive, market-based urban models, on the Sacramento, CA region is discussed and the results described. Then, the application of a modified version of the California Urban Futures Model (CUFM) GIS software as a second-stage land allocation model is discussed and the results described. Finally, we assess this project. This was an academic modeling exercise performed with substantial help from the TRANUS team. Funding came from the University of California Transportation Center and the California Energy Commission.

2. The integrated urban model: TRANUS

Wegener (1994) reviewed many of the integrated urban models. A review of several integrated models is also found in Webster et al. (1988), Webster and Paulley (1990), and Paulley and

Webster (1991). There are only two comprehensive, market-based urban models that have been widely applied, MEPLAN by Echenique and TRANUS by de la Barra. Both are dynamic spatial allocation models, based in random utility theory and bid-rent theory. Hunt and Simmonds (1993) describe the evolution of theory and methods leading to this class of models. Simmonds (1994) describes and critiques these two models, as well as others. There has been some post hoc validation of the MEPLAN model (Echenique, 1983). We chose TRANUS because it runs in Windows, handles interregional as well as regional flows, and has multidimensional multipath logit route choice. Most importantly for our demonstration project, TRANUS is easier to calibrate than is MEPLAN.

Modeling is normally driven by changes in exogenous economic demand (for basic goods and services), which then create endogenous demand within an input-output table or social account. Exogenous (basic) employment is spatially allocated first, followed by residents (workers) and then endogenous (nonbasic) employment is allocated, followed by residents (workers), in a series of iterations until the land markets equilibrate, across all zones. Travel is generated from the land uses and flows of goods, workers, and shoppers among them and equilibrates and then the land market re-equilibrates, etc., until the land and travel markets are both solved.

An important feature in the TRANUS system is the inclusion of a logit-based ‘substitution’ model. In this scheme, activities choose locations and, at the same time, choose the type of land and/or floorspace they wish to consume. Each activity has an associated ‘choice set’. For example, industrial activities may allocate only on industrial land, while residential activities may allocate on low- and high-density residential land, as well as mixed land, competing against retail activities. A set of preference parameters is used to adjust the consumption of land of different types by consuming sector. This feature was used extensively in the Sacramento application to represent the existing real estate sub-markets, subject to land use regulations.

A complex set of economic welfare, travel, emissions, energy use, transit ridership, and other evaluation measures are produced. All of the economic categories, trip purposes and travel modes, and zone and network structure can be defined to fit any region’s geography and available datasets (Hunt and Simmonds, 1993). TRANUS runs typically in 5-year increments, with accessibilities affecting land uses in the next period. This model is efficient at using available information and at synthesizing missing data.

Growth can be represented by increasing exogenous demand, or, if necessary, by increasing population, households, or total employment, if projections for only one of these are available. In addition, one can “force” demographic changes, such as the immigration of low-education households and the model accounts for the changes in incomes, wages, and rents. The out-migration of retired households can also be handled manually, to override the model’s projections.

The route choice equations and algorithms do not overassign to least-cost paths in uncongested parts of the network, a common problem with standard assignment programs. Multimodal path skims are done with all direct and time costs collected, and so few modes are needed. Walk and bike modes may be included, if such travel survey data are available. Goods movement is represented, with terminal costs accounted for (as much as 60% of goods transport costs can be terminal costs). Trip generation and distribution are elastic and so the model represents induced demand.

The model is essentially a large set of nested multinomial logit demand equations embedded in algorithms to accomplish equilibration. Calibration run-time is fast, due to efficient convergence

algorithms and to hierarchical design. Calibration, however, is not simple, due to the large number of calibration variables, which are internal to the model, that is, are inputs to other sub-models. Because of the model's complexity, calibration cannot be judged by a single goodness-of-fit statistic and must be done judgementsally, looking at many fits. Calibration can take weeks of effort.

The evaluation module in TRANUS gives rents, traveler surplus, trips and vehicle-miles of travel (VMT) by mode and operator, internal rate-of-return for operators, energy use in vehicles and buildings, and other evaluation data, all by household income class or employment type.

All data handling is in ASCII format and with Excel tables and so TRANUS links to other models. The model is described in English (de la Barra et al., 1984; de la Barra, 1989; many recent in-house papers), all screens are in English, and up-to-date manuals are available in English.

Simmonds (1994) identifies the advantages of this class of models as: comprehensiveness, flexibility in representing economic activity types and transportation modes, low reliance on observed base period data, and low reliance on future forecast year input data. The disadvantages include time-consuming calibration of the linked submodels and the resultant difficulty in testing alternative model specifications and the difficulty in getting good calibration data for more than one base year. More generally, TRANUS and MEPLAN are cross-sectional models that extrapolate base year behaviors, rely on economic base theory, and place great weight on accessibility in location decisions. Many urban economists and others have criticized these assumptions (TMIP, 1995). When we started this project in 1995, no other market-based urban models were available.

3. Application of TRANUS to the Sacramento, CA, region

3.1. Input and calibration data

We chose the four-county Sacramento Area Council of Governments (SACOG) planning region (Yolo, Sacramento, Placer, and El Dorado counties) for our study (Fig. 1). This makes for a fairly coherent market shed and also is the Federal nonattainment region for ozone. A very high proportion of hydrocarbons (total organic gases: TOG) in this region come from autos. The region is predicted to grow fairly rapidly (about 2.2%/year, to 2015). We estimated a daily model, to capture all weekday travel, emissions, and user economic welfare effects.

First, three household income categories were defined, following the region's datasets, in this case SACOG's household travel survey, done in 1991. Then, we defined the employment categories, according to local data availability and past experience (agriculture/mining, office, medical, retail, education, government). SACOG provided us with employment surveys for 1990, with fewer categories and we supplemented these data with US Census data. Trip purposes were defined somewhat differently from the SACOG categories [Home-Based Work (HBW) high income, HBW medium income, HBW low income, home to services, home to school, exogenous]. Land use categories were defined as agriculture/mining/forestry, industrial, office high density, office low density, residential high density, and residential low density. In this initial application, we did not model freight movements and we did not develop a floorspace demand model.

We adopted SACOG's district structure, to simplify data comparisons with their travel model outputs, and used 58 internal districts. Initially, we used SACOG's networks and attempted to edit them down to the sketch network needed by TRANUS with this district zone structure. This



Fig. 1. Location of study area.

effort produced a network with too many links to relate well to the zones and so the TRANUS team started from scratch and developed new networks. The modal types adopted were: auto single occupant, auto multi-occupant, auto with park-and-ride access, light rail/bus walk access, light rail/bus drive access, and bike/walk.

The transport calibration data included: road counts; public transport route counts; value of walk, wait, and ride time by mode; average parking costs by zone; free-flow speeds by link type; transit fares; operating costs by transit operator and auto user; average occupancy for autos by trip purpose and for transit vehicles; car availability by trip purpose by household income class; number of trips by zone pair; proportion of trips in morning peak by purpose; and cordon volumes.

The land use calibration data included: number of households by income group by zone; average number of people per household by income class; average acres per dwelling by income class by zone; average acres per employee by type by zone; land sales prices by type of land use, land use designation in local plans, and zone; number of employees by employment category by residence zone and workplace zone by income class (difficult to approximate in this region); average income per capita by income class; household expenditures for land, travel, retail, and other; and flows of school children by residence zone and school zone by income class.

The future scenario input data included (by 5-year period): network changes; changes in transit headways and fares; roadway tolls; parking charges; allowable growth of each land use by zone; and projections of total regional employment. Agricultural exclusive zoning in Yolo and Sacramento counties limited the acres available for development in several zones.

The datasets varied greatly in difficulty of acquiring them. Because SACOG was about to implement the DRAM/EMPAL land allocation model, they could provide us with existing land use data (acres) by zone for 1990. These are expensive data to generate. A large part of the other data came from SACOG's household travel survey and travel models. We used the TRW-REDI datasets on real property sales by county (private, nationwide data).

3.2. *The scenarios*

We identified four scenarios for 2015 (25 years from our 1990 base year):

1. *Future Trend Scenario* [a few small projects such as a modest light rail transit (LRT) extension on the east line, a few miles of new high-occupancy vehicle (HOV) lanes on Interstate-5 South, and a lot of arterial widenings in the northeast, south, and southeast areas of the region].
2. *HOV Lanes* (about 200 lane-miles of new freeway HOV lanes on all major freeways in the central urbanized area).
3. *Beltways + HOV* (HOV as above plus an outer beltway in the north and one in the south and east, both generally following corridors previously studied by the Federal Highway Administration).
4. *Light Rail Transit and Pricing* (LRT extensions on the northeast line and east line and new lines to the south and north, with improved headways for buses and LRT and more bus feeders and park and ride lots as needed, plus average all-day parking charges of \$5 in the central business district and \$2 in a few other zones).

The major improvements were scheduled mainly in 2000, 2005, and 2010, so that there would be about two rounds of land use effects, for most facilities. The total regional employment projections input were: 665,038 (1995), 823,911 (2005), and 1,031,137 (2015). All network additions were tied to maps in a SACOG publication that was part of their 1996 transportation plan (SACOG, 1996).

3.3. *Model results*

First, we discuss problems with this first implementation of TRANUS. The transit mode shares are too high, even in the base year (1990: 6% simulated vs 1% measured). One cause of this

problem is the incorrect use of the unweighted household travel survey data, which was the only source available at the time the model was calibrated. Also, TRANUS omits short trips, due to its large zones, and counts unlinked trips, whereas the SACOG travel model counts linked trips, and so about half of the discrepancy in the base year is an artifact of these differences in the trip unit. In spite of these problems with our initial model, the travel and land use results seem reasonable. The percentage increase in transit share in the LRT/travel pricing scenario (about 600%) is similar to our past modeling with SACOG's travel models, and so we consider the rank ordering of our scenarios to be reasonable.

The model was calibrated with 1990 data only and was done with limited resources. Simulated values for total daily trips by category and by mode fit closely to observed trips in the base year. The fit of screenline road volumes was also fairly good.

3.3.1. Travel results

Transit shares for the year 2015 stay low and even decline in some scenarios, except for the LRT/pricing scenario, where it goes up to 18%, in terms of passenger-miles. As can be seen from Table 1, the trips and VMT differ in reasonable ways. The new freeway HOV lanes decrease vehicle travel somewhat and the LRT/pricing scenario decreases travel substantially. All scenarios experience severe congestion in 2015, with the Trend scenario being the worst.

We ran the California emissions model, BURDEN7F, on vehicle activity data from TRANUS and got reasonable emissions rankings and differences (Table 2). The 2015 scenario with the highest VMT and highest VMT in the 2.5–37.5 mph range, the Trend scenario, had the highest TOG, carbon monoxide (CO), and particulate matter (PM). The scenario with the highest VMT in the 46.5–67.5 mph range, the HOV + Beltway scenario, has the highest nitrous oxides (NOX), which pollutant rises rapidly on a per-mile basis with speed.

Table 1
Travel results for the 2015 scenarios

Scenario	Trips (thousands)	VMT (millions)
Trend	3897	61.2
HOV + Beltway	3902	58.9
HOV	3901	60.0
LRT/Pricing	3910	46.6

Table 2
Emissions results for 2015 scenarios^a

Scenario	TOG	CO	NOX	PM
Trend	39.37	204.62	26.77	14.16
HOV + Beltway	30.42	196.06	27.60	13.65
HOV	35.08	196.14	26.69	13.90
LRT/Pricing	19.44	139.09	20.58	10.75

^a BURDEN7F California emissions model with Sacramento Co. fleet inventory for 2010. Excludes intrazonal trips and commercial freight truck travel.

User benefits are measured with the traveler surplus method, net of changes in locator surplus. The total daily benefits (net of the Trend scenario) are: Beltway + HOV \$12.7 million, HOV \$6.69 million, and LRT \$11.0 million. The Beltway + HOV scenario has the highest net benefits in 2005, 2010, and 2015 and the LRT scenario is the least beneficial in 2005, about the same as the HOV scenario in 2010, and is almost as beneficial as the Beltway + HOV scenario in 2015. Roadway congestion increases over time and the LRT useage and benefits increase in the later years, due to the increased congestion. The parking pricing increases welfare because it raises felt travel prices nearer to actual marginal costs.

With about 4 million trips per day, these net benefits come out to about \$2–3 per trip, values about 200–1000% of the values we have estimated from using SACOG's travel demand model on similar scenarios in this region. We will investigate the specification of the utility functions in TRANUS and compare these with the Small–Rosen traveler welfare method (compensating variation) that we have used in our past travel modeling. We will also run TRANUS with fixed land use patterns across the scenarios, to see how much locational changes contribute to the net benefits. This test will isolate the traveler surplus component of welfare.

TRANUS projects much more widespread network congestion than does the SACOG travel model, which leads to higher cost savings from adding capacity in TRANUS simulations. The higher modeled congestion is partly due to the more realistic capacity restriction functions used in TRANUS, that avoid severe over-congestion of a small number of routes. Also, the mean trip length in TRANUS is almost double that in the travel models, due to the large zone size in our study and the omission of intrazonal trips. This almost doubles welfare changes per trip.

3.3.2. *Land use results*

The differences in household locations for the 2015 policy scenarios, net of the Trend Scenario, were aggregated into eight superzones for analysis purposes. All of the differences are less than 13% of the total growth in households for each superzone, over 25 years. However, most of the transportation improvements take place in 2000–2010 and so the land uses only have about 10–15 years to respond. Viewed this way (over a 10–15-year base of growth), the largest percentage changes are about twice as large (25%).

The Beltway + HOV scenario brought about increased residential demand in the zones near to the beltways and reduced development in the other outlying zones. The HOV scenario drew development to the northeast and east outlying zones, well-served by the HOV lanes and not constrained with agricultural zoning. The LRT scenario increased development in the zones served by the new lines. All of the scenarios resulted in reasonable land use shifts. The employment changes are similar, but are all smaller than 9% of the 25-year growth in any superzone, because employment locators are less sensitive to changes in land rents.

Differences in land consumption are somewhat higher than changes in households or employment. Variations go up to 20% of total increase in any superzone over the 25-year period. The beltways are particularly effective in attracting low-density development into the east areas of the region. Based on our extensive experience with the SACOG travel models and our knowledge of the region's land markets, these results seem broadly reasonable.

We took the land use growth projections (acres by land use type, for each of 58 zones) for 2015 from TRANUS and fed them to a rule-based land allocation model using GIS as its data structure. In the next section we present and discuss this exercise.

4. The GIS model

The GIS-based model we chose in order to disaggregate the land use results from TRANUS is the California Urban Futures Model (CUFM) by John Landis at UC Berkeley. It is a nonlinear programming model that allocates residential land development to polygons, which are ranked according to profitability for the developer (Landis, 1995). Profitability is calculated as a function of accessibility to roads and services, slope, local government fees, land prices, and several other variables. Developable land units (DLUs) are created by overlaying a variety of GIS coverages, such as city boundaries, wetlands, slope, land use type, and roads. Landis applied CUFM, by itself, to several counties in California. We wanted to use CUFM for second-stage land use allocations, *within* each TRANUS zone. Linking the two models in this way allows us to perform market-based policy experiments with TRANUS and use CUFM to produce detailed land use maps (GIS coverages) for environmental impact assessment.

We simplified the allocation ranking function to be a simple additive weighted function of accessibility to services and we applied our version of the model to employment land uses also. Since TRANUS gets development “roughly right” by allocating it to the 58 zones according to bidding, we felt we could use a simplified version of CUFM to allocate all land uses, within each zone. We allocated only for the horizon year, in this case 2015.

We allocate Industrial land uses first and they may only go to polygons that are industrially designated in the local land use plans. Then, we allocate Commercial High-Density, then Residential High-Density, then Commercial Low-Density, then Residential Low-Density, and last Residential Very-Low Density. This last category we broke out as a percentage of Residential Low-Density acres by assumption (based on past land development in each county). We see this category as important, because of the substantial amount of large-lot rural residential development that is occurring in the eastern part of our region. All land uses are allocated by accessibility, except for Residential Very-Low Density, which is randomly allocated to DLUs to simulate amenity-seeking locational behavior. Widespread Agricultural Exclusive land use designations are used by us in Sacramento and Yolo counties, because these counties have enforced these limits for over 25 years now and intend to continue doing so. None of our urban land uses may go into these zones.

Table 3 lists the layers making up the DLUs in our version of CUFM. We cannot easily add more layers, as we have reached the 100,000 polygon limit in ARC/INFO, for Sacramento county (splitting a county is a lot of added work). We produced databases separately for each of our four counties and joined them for regional coverages, resulting in 272,000 polygons for the region, going down to about 10 acres in size. We do not identify parcel boundaries or private owners.

Some layers can be used as development prohibitions, by switching them on in the setup file and then CUFM designates those acres as “not developable” and these areas are held out from development discretely in the allocation. Prohibitions can be switched on for public land ownership, protected habitats, wetlands and riparian areas with or without 500 m buffers, floodplains, and prime farmlands. We have experience with the use of development constraints from our earlier work with GIS (Johnston et al., 1975; Singer et al., 1975).

Table 3 also lists the various polygons that have accessibility weights in our developability ranking function. Incorporated cities are a 5, because of their full range of services, and other (small) urban areas get a weight of 1. There is also an exponential decay function of distance from

Table 3
The allocation model GIS layers

DLU-creating layers	Potential prohibition?	Developability priority	Priority weight
City boundaries	n/a	+	5
Distance from incorporated cities	n/a	+	expon. f. ≤ 4
Freeway ramp + 1000 m buffer	n/a	+	5
Highways + 1000 m	n/a	+	3
Sac Airport + 3000 m	n/a	+	3
Sac Port + 3000 m	n/a	+	3
Freeway ramp + 3000 m	n/a	+	2
Sphere of influence (SOI)	n/a	+	2
LRT stations + 500 m	n/a	+	2
LRT stations + 1000 m	n/a	+	1
Major arterial + 500 m	n/a	+	1
Major arterial + 1000 m	n/a	+	1
SOI + 1000 m	n/a	+	1
SOI + 2000 m	n/a	+	1
Urban	n/a	+	1
Urban + 1000 m	n/a	+	1
Region analysis districts (RAD)	n/a	n/a	n/a
County boundaries	n/a	n/a	n/a
Minor traffic analysis zones	Y	n/a	n/a
Public land ownership	Y	n/a	n/a
Natural Diversity Database	Y	n/a	n/a
Significant Natural Areas (SNA)	Y	n/a	n/a
SNA + 500 m	Y	n/a	n/a
Water bodies	Y	n/a	n/a
Wetland	Y	n/a	n/a
Wetland + 500 m	Y	n/a	n/a
Stream/river/lake/pond + 100 m	Y	n/a	n/a
100-year floodplain	Y	n/a	n/a
Farmland	Y	n/a	n/a
Slope (> 25%)	Y	n/a	n/a

incorporated cities, with a weight of 4 or less. Within 1000 m of a freeway ramp gets a 5, within 1000 m of a major highway gets 3 points, and so on. Total developability ranking is a function of the added weights factored by a nonlinear function of slope.

All polygons are given values for each data layer and these are summed for the polygons in the union map. The DLUs *within* each TRANUS zone are ranked. The land use acreages from TRANUS for each zone are allocated in order, from industrial to residential very-low-density. The residual land use is agriculture/forestry.

The advantages of using a GIS to disaggregate land use projections from 58 zones to 272,000 polygons are a better visualization of development patterns for the public and their decision-makers and the ability to use the detailed land use layer in environmental impact models. This was a rapid implementation, using existing software and modifying it, to test the concept of linking an urban model to a GIS model.

The weaknesses of the approach used are:

1. the “existing urban” land use layer for 1990 was crude (with no polygons smaller than 10 acres) and so we could not get a detailed depiction of vacant infill sites for new development;
2. we ignored private land ownership and so could not project important developer decisions discretely;
3. our new development polygons were large, due to the use of the DLU method and so we could not depict the size and number of rural residential sites accurately;
4. the use of polygons (vector mapping) is slow, compared to cell-based (raster) mapping;
5. we did not have digital general plan (allowable land use) layers for our four counties and many cities and so could not use these land use designations as constraints (we hand digitized the industrial and agricultural exclusive designations and used them only);
6. we used only three residential density categories, which does not depict rural residential uses accurately enough to project impacts on habitats with confidence; and
7. our hybrid software ran on UNIX machines (in ARCINFO) and on desktop PCs (in ArcView), which required lots of programming and created many data transfer headaches.

Our GIS results seem reasonable. High-value uses are allocated to highly serviced sites in cities or near freeway ramps. The poor quality of the existing urban layer resulted in simple concentric circles of new development around some freeway ramps, but the allocations are broadly reasonable.

5. Conclusions

This project demonstrated the feasibility of linking an integrated urban model and a GIS to produce a spatially detailed set of land use maps. The concept is modular: one could use any other urban model and one could use any GIS model as the second-stage land allocation model. This pairing of model types uses the strengths of each. The urban model gets land uses roughly right through economic competition among the zones and then the GIS-based model disaggregates the projected land uses into fairly small polygons.

We completed this first phase on a very low budget (about \$100,000, with student labor and the TRANUS team working at a discount) in about 18 months. We used network, land use, and travel survey data available from most regional transportation agencies in the US. The digital property sales data we used are available for almost all metropolitan regions in the US for a small charge and go back to 1980 in most cases. Most of our GIS coverages are available throughout the US. ARCINFO and ArcView are used by many local planning departments in the US and throughout the world.

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References

- de la Barra, T., 1989. *Integrated Land Use and Transport Modelling*. Cambridge University Press, New York.
- de la Barra, T., Perez, B., Vera, N., 1984. TRANUS-J: putting large models into small computers. *Env. and Planning B*, 87–101.
- Echenique, M., 1983. The use of planning models in developing countries: some case studies. In: Nijkamp, P. (Ed.), *Urban and Regional Policy Analysis in Developing Countries*. Gower, London.
- Hunt, J.D., Simmonds, D.C., 1993. Theory and application of an integrated land-use and transport modelling framework. *Env. and Planning B*, 221–244.
- Johnston, R.A., Thorpe, L.D., Long, T., 1975. *Land Use Mapping Programs*. 3rd ed. with user's manual. Dept. Environmental Science and Policy, University of California, Davis, CA.
- Klosterman, R.E., 1994. An introduction to the literature on large-scale urban models. *J. of the Am. Planning Assoc.* 60, 41–44.
- Landis, J.D., 1995. Imagining land use futures. *J. of the Am. Planning Assoc.* 61, 438–457.
- Paulley, N.J., Webster, F.V., 1991. Overview of an international study to compare models and evaluate land-use and transport policies. *Transp. Reviews* 11, 97–222.
- SACOG, 1996. Working paper #3. 1996 Metropolitan Transportation Plan. Analysis of Options.
- Simmonds, D.C., 1994. The 'martin centre model' in practice: strengths and weaknesses. *Env. and Planning B*, 619–628.
- Singer, M.J., Johnston, R., Thorpe, L., 1975. *Land Use Mapping Programs (LUMP): Computer Help for Land Use Decision Making*. *California Agriculture* 29, 12–14 July.
- Travel Model Improvement Program, 1995. *Land Use Modeling Conference Proceedings*, 19–21 February 1995. FHWA, Washington, DC
- Transportation, 1991. *Transportation, Urban Form and the Environment*. TRB Special Report 231. Washington, DC.
- Webster, F.V., Bly, P.H., Paulley, N.J., 1988. *Urban Land-Use and Transport Interaction*. Avebury. Brookfield, MA.
- Webster, F.V., Paulley, N.J., 1990. An international study on land-use and transport interaction. *Transp. Reviews* 10, 287–308.
- Wegener, M., 1994. Operational urban models. *J. of the Am. Planning Assoc.* 60, 17–29.