A Comparison of Regional Models Using Different Levels Of Geographic Aggregation

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Abstract

We have developed several models linking land use changes and transportation for different regions with populations ranging from 100,000 to 2,000,000. The models are used in long-term planning for land use, transportation, and air quality. The level of detail desired by clients requires that the models have a high degree of spatial disaggregation, typically several hundred zones.

The spatial detail is a strength of the models, but it is achieved at a cost. Model development is time-consuming and expensive. Even on the fastest microcomputers, model run time is measured in hours. Testing new model structures and making structural enhancements is slow and difficult. The complexity of the models inhibits experimentation and learning by clients. Simpler models are needed to aid in prototype development and in communication and training.

We compared results of policy simulations from regional models with three levels of spatial disaggregation. The most detailed models are as described above. For a highly-aggregated example, we developed a system dynamics model with two concentric rings using STELLA software. Finally we evaluated two simplified grid models with intermediate levels of spatial disaggregation.

The STELLA model is able to demonstrate some of the policy results, and is an excellent tool for model development. In some ways, the grid models combine the worst of both worlds. They are neither simple nor fully detailed. The detailed models exhibit the most rich behaviors. We are developing techniques to move from STELLA structures directly to the more disaggregated models.

A Comparison of Regional Models Using Different Levels of Geographic Aggregation

INTRODUCTION

In almost all urban areas, existing infrastructure (transportation, water, sewer, social services) lags behind desired infrastructure. Planning new infrastructure depends on future land use forecasts. The distribution of future land use is also dependent on available infrastructure. Due to this feedback, the infrastructure shortfall problem is resistant to solution through infrastructure improvements and local land use regulations. We have developed regional land use/infrastructure planning models that combine fairly simple system dynamics structures with spatially disaggregated databases. The models provide insights about the effectiveness of alternative policies, using detail of the local area that planners need.

We have developed several models linking land use changes and transportation for different regions with populations ranging from 100,000 to 2,000,000. These models must have a spatially disaggregated structure. At last year's Systems Dynamics Conference we presented a highly-disaggregated model with 464 internal zones (Marshall and Lawe 1993). This level of spatial disaggregation was developed to meet the needs for detailed regional transportation planning for an area of 1300 square kilometers with 200,000 residents. The model was tailored to the clients' needs. The clients require detailed transportation/land use scenarios that are realistic, are 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 by land use policy decisions.

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In this paper, we compare results of policy simulations from regional models with three levels of spatial disaggregation. The most detailed models are as described above, with several hundred realistic zones. For a highly-aggregated example, we developed a system dynamics model with two concentric rings using STELLA software. Finally we evaluated two simplified grid models, with nineteen and forty nine rectangular zones.

SIMPLIFIED MODEL

The simplified model was developed using STELLA software. Our goal was to use as small a subset of model elements from the detailed models, while keeping the dynamic behaviors of the detailed models. Rather than hundreds of spatial zones, the model includes two concentric rings — Urban and Suburban. Instead of a detailed breakdown among land use categories, only two were used — Residences and Workplaces. Only one travel mode (automobile) and one type of trip (residence to workplace) were included. These simplifications are summarized in Table 1.

Table 1: Comparison of Disaggregated and Simplified Regional Models

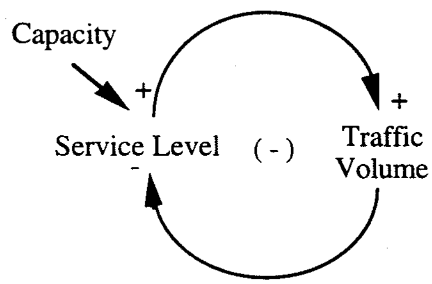
Element	Complex	Simplified
Land Use Types	3-8	2
Zones	300+	2
Trip Types	5-8	1
Travel Modes	3-5	1
Road Segments	1000+	4

The completed model includes only four major stock variables, plus four additional stock variables representing first order delays. The major stocks are Urban Residences, Urban Workplaces, Suburban Residences, and Suburban Workplaces. The first order delays are perception delays of the generalized travel cost (money and time) from one zone to another.

There is one perceived cost for urban-to-urban trips, another for urban-to-suburban trips, another for suburban-to-urban trips, and a fourth for suburban-to-suburban trips. An additional simplification could be made by combining the urban-to-suburban and suburban-to-urban costs. However, making a distinction allows testing additional policies including differential parking costs and reversing highway lanes by time of day. In general, if there are n zones, there will be n^2 cost functions.

The model includes a rich feedback structure based on the perceived generalized cost variables. One of the most important components of perceived generalized cost is travel time. Travel time in the model is a function of the service level. Service level is computed as a function of the ratio of traffic volume to highway capacity. In the short-term, traffic volumes adjust to perceived cost levels as shown in Figure 1.

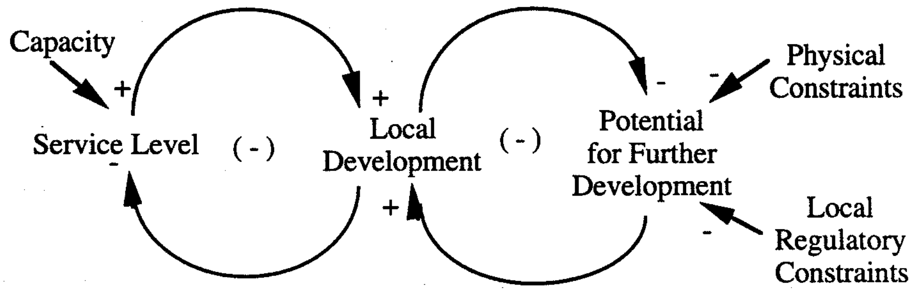
Figure 1: Short-Term Traffic Volume Adjustment.



As traffic volumes for a zone-to-zone pair increase, the service level declines, and tends to push down traffic volumes.

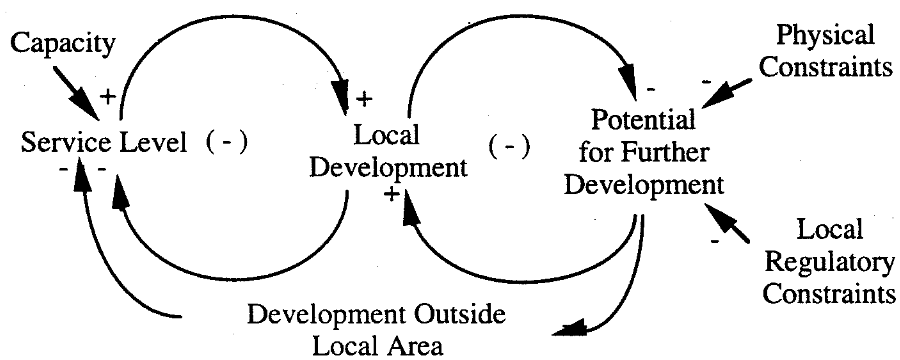
Over a longer-term time period, land use feedback forces are important. These feedback structures are illustrated in Figures 2 and 3. Figure 2 shows the feedback as viewed from the perspective of a specific area or zone. Policy resistance to increased capacity is illustrated in the loop on the left. An increase in capacity leads to an increase in service level, leading to an increase in local development, leading to a decrease in the service level. However, as shown on the right development can be limited by physical and regulatory constraints. Local regulatory constraints may be implemented to reduce the potential for further development, and to improve the service level (or at least keep it from declining further).

Figure 2: Long-Term Land Use Dynamics at the Local Level.



In Figure 3, the desired effects of the local regulatory constraints policy are countered by unplanned regional effects. By reducing development locally, development is pushed to other parts of the region. In most cases in the United States, the unplanned result has been an increase in urban sprawl, and longer trips. These longer trips increase the level of congestion regionally. If major roads pass through the area with the regulatory constraints, the policy may even aggravate congestion there.

Figure 3: Long-Term Land Use Dynamics at the Regional Level.



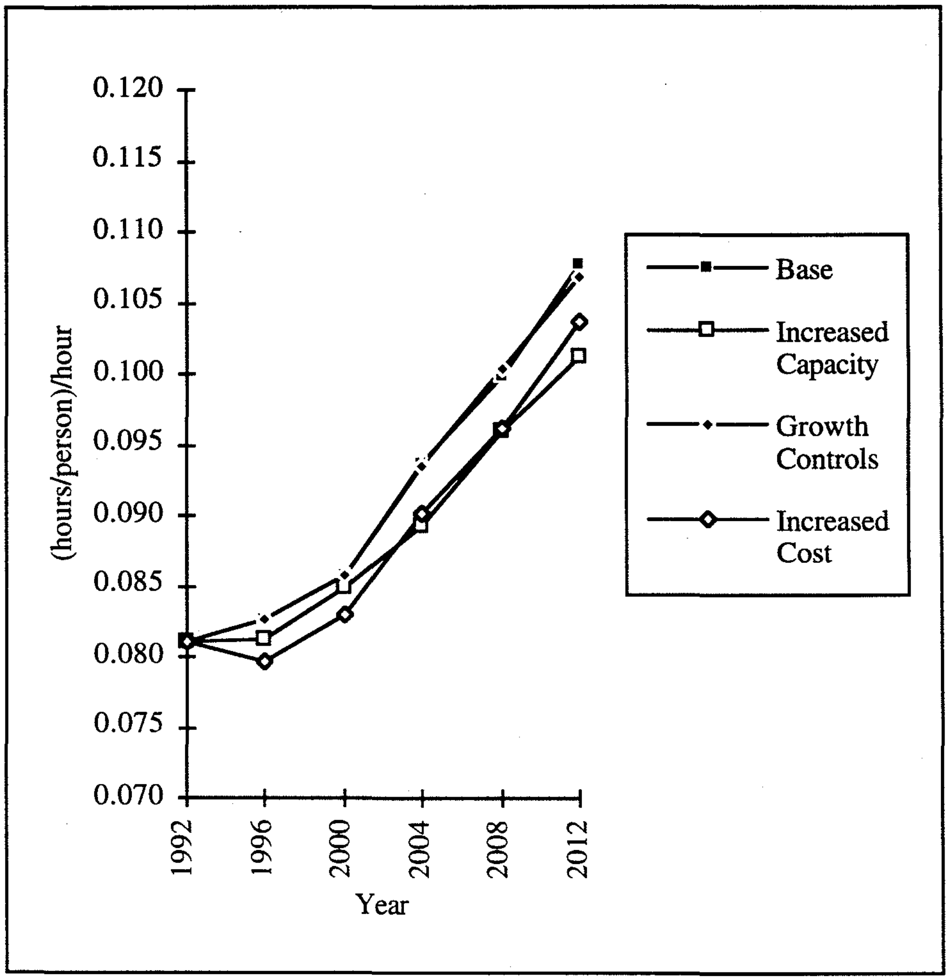
Both the detailed and simplified models incorporate the model structures required to simulate the dynamic forces illustrated in Figures 1, 2 and 3. Are model results comparable? Figures 4 and 5 compare model outputs for an important indicator variable — Vehicle Hours of Travel Per Capita During the Peak Hour of Travel.

Each figure includes a base scenario and three policy scenarios. The scenarios are:

1) Base — A base run was performed assuming no change in infrastructure capacity beyond 1996.

2) Increased Capacity — Roadway capacity was increased by 50 percent everywhere. This scenario is not completely realistic because the costs of increasing capacity in some areas would be prohibitive.

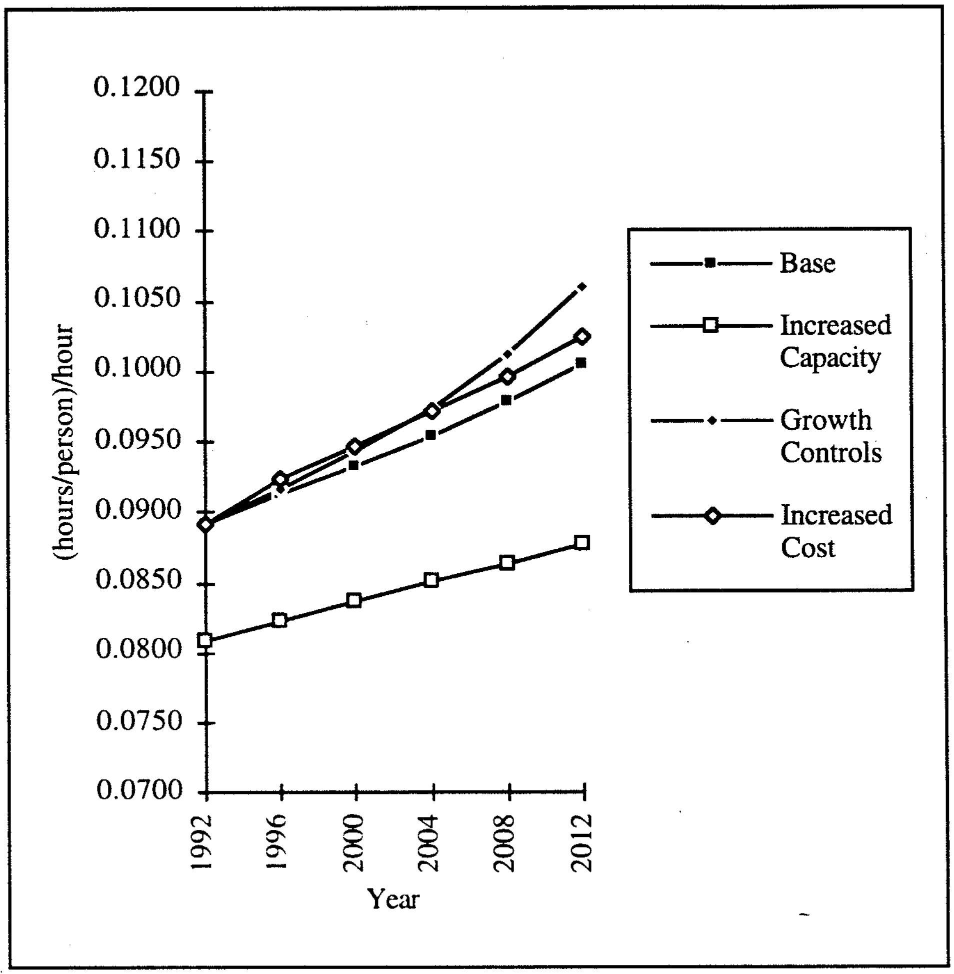
Figure 4: Vehicle Hours of Delay Per Capita During the Peak Hour of Travel — Detailed Model



3) Growth Controls — The allowable density of land use for new land uses was decreased by 50 percent everywhere.

4) Increased Cost — Automobile travel cost was increased through a tax increase of $2.00 per gallon ($.26/liter).

Figure 5: Vehicle Hours of Delay Per Capita During the Peak Hour of Travel — Simplified Model



The results of the policy simulations with the two models exhibit some similarities. In both models, growth in population and employment without additional highway capacity causes more congestion and increases in time spent traveling. Both models also exhibit a high degree of policy insensitivity. For the most part, we believe that this policy insensitivity is also true in the real world. Policies that act through control of new land uses act very slowly.

There are important differences between the output from the two models. Most striking are the very different results for the increased capacity policy. This policy appears to be quite effective in the simple model but is relatively ineffective in the detailed model. Features of the detailed model that more accurately model policy sensitivity to this policy include changing mode choice (less carpooling and transit use), and a much richer representation of the highway network.

Although less dramatic, the rank ordering of the other policies is also different. In the detailed model, increasing travel cost reduces time spent traveling. In the simplified model, it increases total travel time. Why are the results different? In the simplified model, the higher costs lead to a large increase in travel within the higher density urban area, leading to a very high level of congestion there. We think that this is probably an inaccurate result of model simplification. Defining an urban-to-urban high[illegible] system as independent from the rest of the highway system is not very accurate. It is probable [illegible]at model coefficients could be developed that would produce results more similar to the detailed model. However, the model would then have been demonstrated to have an undesirable level of parameter sensitivity.

The simplified model is able to achieve some of the intended purposes. It is a good development tool. Its weakness as a policy evaluation tool also limits its value as a education and communication tool. We are planning to address at least some of these deficiencies by making enhancements to model structure. In particular, alternative transportation modes will be included. A third or even a fourth concentric ring may be added. However, the complexity of model coding increases very quickly. With four zones, there would be sixteen generalized cost functions. Even with these changes, the models may not be adequate for policy analysis.

GRID MODELS

An intermediate level of abstraction between detailed micro-zones and large concentric rings are models that divide an area into a grid. We have experimented with a seven-by-seven grid model with forty nine zones. We have also reviewed a published model.

Our forty-nine cell grid model was developed in a spreadsheet program to aid in development for our first disaggregated model. Spreadsheets provide some advantages over STELLA in disaggregated modelling. They handle values for many different zones, and equations can be easily replicated. Spreadsheets also are more accessible than C, the programming language used in the detailed regional models. However, model structure is difficult to change in a spreadsheet model, even compared to a higher language such as C. Our current spreadsheet model has a very simple structure that is incapable of performing all of the policy tests described above for the other models.

We evaluated a model used by Downs in evaluating the effectiveness of land use policies in affecting urban congestion. This model (Downs 1992) represents a hybrid of the concentric ring and grid ideas, with rings of one, four, four, and ten zones, for a total of nineteen zones.

The book is generally well argued, and at first glance the model appears quite interesting. However, the geographic and spatial complexity tends to obscure an underlying structural simplicity. The model simply assumes random travel behavior with different assumed land use patterns. Each trip is as likely to be made to the furthest destination as the closest. None of the dynamic structure shown in Figures 1, 2, and 3 is included. That the model is not sensitive to land use policy is not surprising![1]

These two examples have made us unenthusiastic for these models with intermediate complexity. Structure in the models is difficult to code and is not transparent. Therefore, these models are not especially useful for model development, communication, or training. On the other hand, it has not been demonstrated that they are useful for policy analysis either.

[1]It is interesting that the preferred alternative, increases in pricing, is evaluated using a completely different model. An economic demand curve is used. How are these price-induced reductions in demand achieved if travel is randomly distributed?

CONCLUSIONS

The STELLA model is able to demonstrate some of the policy results, and is an excellent tool for model development. In some ways, the grid models combine the worst of both worlds. They are neither simple nor fully detailed. The detailed models exhibit the most rich behaviors.

We are working with a client to develop techniques to move from STELLA structures directly to the more disaggregated models. If this work is successful, we will be able to do model development, communication, and training with STELLA, but to do the policy analyses with detailed models. Since the model structures would be identical, this would combine the best of both worlds.

REFERENCES

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