REGIONAL LAND USE AND INFRASTRUCTURE DYNAMICS

Norman L. Marshall
Stephen J. C. Lawe
Resource Systems Group
P. O. Box 1499, Norwich VT 05055, U. S. A.

ABSTRACT

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.

PROBLEM DEFINITION

In the United States, there is a continuing problem of "crumbling infrastructure" in the nation's urban areas. The election of President Clinton has brought a new emphasis in national policy on infrastructure as a cornerstone of "economic competitiveness." Newly appointed Secretary of Labor Robert Reich has written:

> A work force that is knowledgeable and skilled at doing complex things, and which can easily transport the fruits of its labors into the global economy, will entice global money to it. . .
>
> Without adequate skills and infrastructure, however, the relationship is likely to be the reverse—a vicious circle in which global investment can be lured only by relatively low wages and low taxes. . . (Reich 1991)

Although the problem is receiving national attention, most infrastructure problems are local and regional. At the local and regional levels, the problems are not seen as caused only by insufficient financial resources. Significant resources have been expended on these problems, often with little improvement.

This paper focuses on transportation infrastructure, where the problem is perceived as too much highway congestion. Increasing transportation capacity has been ineffective at eliminating congestion.

> Building more roads, or widening existing roadways, has been the traditional response to traffic problems. History shows, however, that this approach leads only to increased traffic and lower air quality. Congestion forces people to alter their travel routes and to avoid, if possible, driving at peak travel times. New roads may initially alleviate congestion, but soon encourage people to shift from other routes, or from other modes of transport, until the new roads are as badly congested as the old ones were. (Nadis and MacKenzie 1993)

Local land use controls have been widely used to try to prevent further increases in congestion. These policies have also been ineffective.

> By diverting future growth to other communities, growth management policies shift future traffic there, too. Finally, by spreading future development of the entire metropolitan area during any period over a larger territory than it would otherwise have occupied, growth-management policies require households to drive longer distances. That adds to the metropolitan area's total traffic flows, probably increasing future traffic congestion. (Downs 1992)

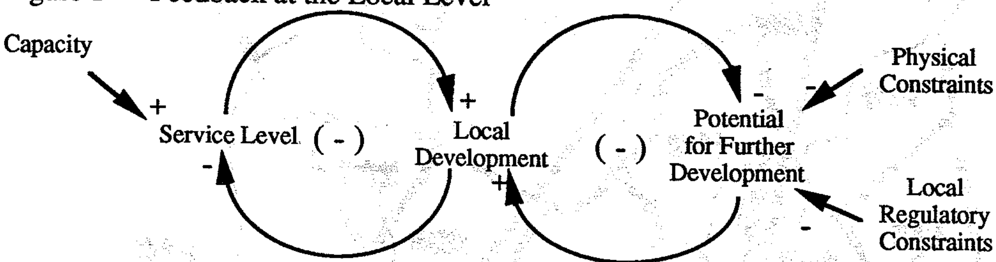
Our problem statement is: "What policies or policy combinations are most effective and efficient at closing the gap between existing infrastructure and desired infrastructure." This general problem will be explored through a case study focusing on transportation infrastructure and land use development in the three-county seacoast region of New Hampshire and Maine, a region with a population of approximately 200,000.

DYNAMIC HYPOTHESIS

Both of the quotations in the previous section describing the transportation model include feedback dynamics. The authors describe forces working through the system that work against the purposes of the original policies. These feedback structures are illustrated in Figures 1 and 2. Figure 1 shows the feedback as viewed from the perspective of a specific area. The policy resistance to increased capacity loop described by Nadis and MacKenzie is shown 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.

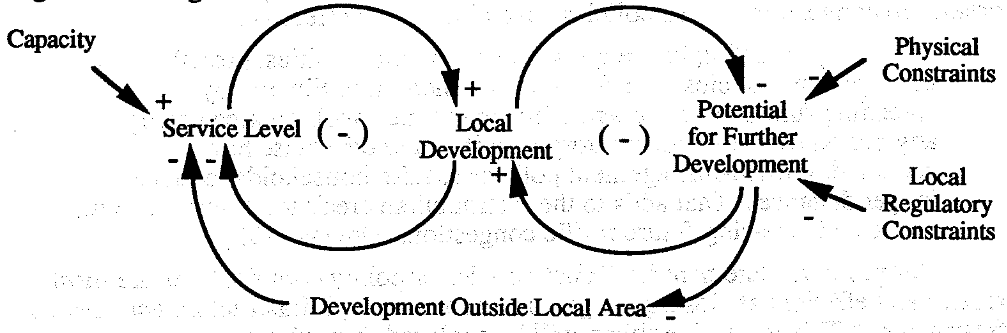
Part of the dynamic structure involving local regulatory constraints discussed by Downs is included in the loop on the right in Figure 1. Local regulatory constraints are implemented to reduce the potential for further development, and to improve the service level (or at least keep it from declining further).

Figure 1 — Feedback at the Local Level



More of the Downs dynamic structure is added in Figure 2. The desired effects of the local regulatory constraints policy is 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.

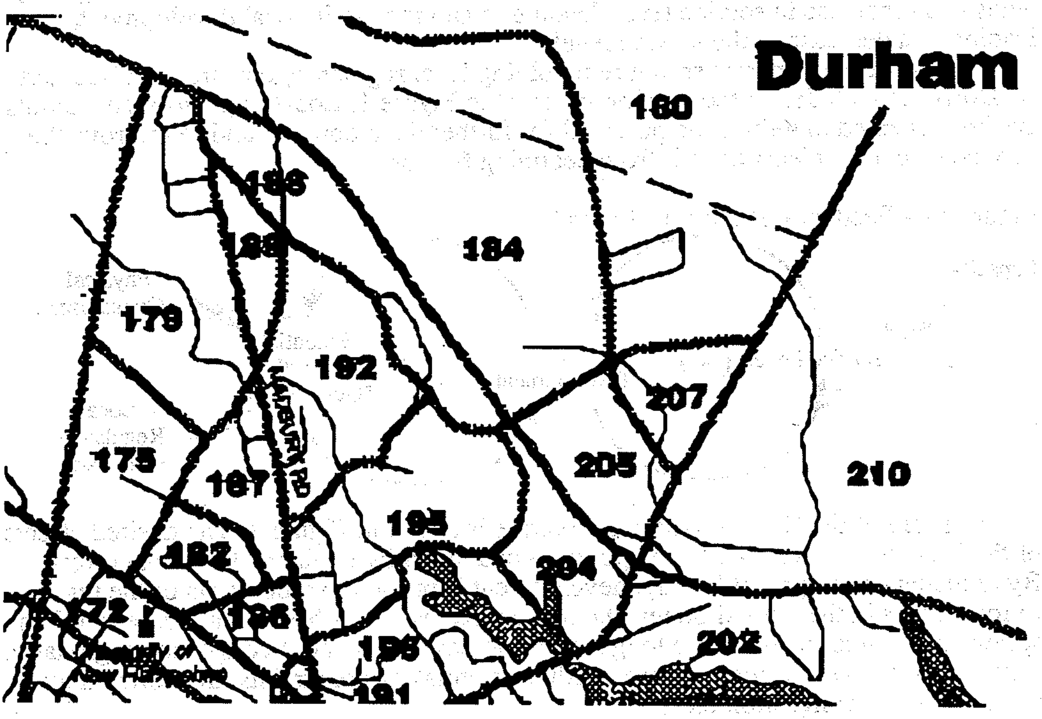
Figure 2 — Regional Feedback Effects



MODEL DESCRIPTION

A model investigating the dynamic hypothesis described above requires a spatially disaggregated structure. Our model has 464 internal zones. This level of spatial disaggregation was developed to meet the needs for detailed regional transportation planning as required by the Intermodal Surface Transportation Planning Act of 1991 and the Clean Air Act Amendments of 1990. A portion of the zone map is illustrated in Figure 3. The study area includes 24 municipalities within three counties, totaling approximately 200,000 residents, living in an area of 1300 square kilometers.

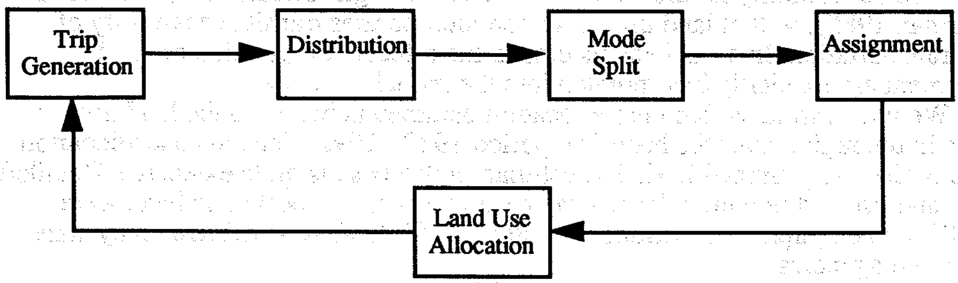
Figure 3 — Model Spatial Structure



We have developed the model for the New Hampshire Department of Transportation, three regional planning agencies, and the Pease Development Authority which is responsible for the re-development of a closed military facility. The model has been 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.

We have developed the model by making extensions to a standard transportation planning model and a published land use allocation model. An overview of the model structure is shown in Figure 4.

Figure 4 — Model Structure Overview



In Figure 4, the transportation planning model consists of four modules: Trip Generation, Distribution, Mode Split, and Assignment. These are the four parts of the standard Urban Transportation Planning System (Sosslau, et al. 1978). In the context of the causal structures shown in Figures 1 and 2, these modules provide a very detailed estimation of the effect of land use on service level. The trip generation module computes the number of trips with origins and destinations in each zone. The distribution model links the origins and destinations to form complete trips. The mode split model determines whether trips are made by public transportation or auto, and computes auto occupancy. Finally, the assignment module, calculates traffic volumes and service levels. We have programmed the first three models using the C language. For the assignment module we are using a commercial package, TMODEL2.

It is impossible to fully describe the transportation modules in this paper. However, we will mention three of the most important features. First, the modules use large amounts of locally collected data about travel behavior and the transportation network. Second, many local parameter values have been statistically estimated using local data, and other parameters have been estimated by others as standard values. Third, the model system includes many feedback loops other than those shown in Figures 1 and 2. Examples include: auto congestion causing increased use of public transportation reducing congestion; and congestion causing longer trips and increased auto occupancy, reducing congestion.

The transportation modules are linked to a land use allocation module. Operational land use allocation models were first developed by Lowry in the 1960s (Lowry 1964). In a Lowry-type model, basic employment is considered the fundamental engine of growth. It is specified by zone as a model input. Residential land use and population are allocated by zone to provide employees for basic industry. Service employment is allocated by zone to serve the new residences. The service employment requires further residential land use which, in turn, requires further service employment. In this manner a new equilibrium is approached either iteratively, or in one step through the use of optimization techniques. The allocation to zones is done with a gravity model. In general, land use is allocated to zones with shorter travel times, constrained by zonal control totals.

Putman linked land use models to transportation network models in the 1970s (Putman 1983). These Lowry/Putman models have been applied to many large urban areas in the United States. Recently, versions of the Lowry model have been added to microcomputer transportation modeling packages.

We have updated the Lowry/Putman model structure to better represent suburban growth areas in the 1990s. Instead of designating employment as "primary" and "secondary," it is categorized as retail, commercial, or industrial. Instead of housing location being determined by the workplace of the "primary worker," locational choice is based on the generalized accessibility to all destinations. Generalized accessibility is calculated using a nested logit formulation (Ben-Akiva and Lerman 1985), so that land use allocation incorporates transit accessibility of public transportation. In a final enhancement, the effects of regulation on land use development are explicitly incorporated into the model structure.

We have estimated land use allocation parameters based on the land use changes in the region over the historical period 1980 - 1992. The land use allocation module is also programmed in C. The estimation database is quite extensive. Detailed current land use and potential development estimates at the local zone level were derived from geographical information system (GIS) databases maintained by state and regional agencies.

The entire model system is run on DOS microcomputers with a shell programmed in C to sequence the modules. The sequencing proceeds as follows:

- A1) The 1992 land use is passed to the trip generation module .
- A2) The four modules of the transportation model are run in sequence to produce accessibility and congestion measures.
- A3) Accessibility and congestion serve as inputs to the transportation model and all four modules are run again in sequence.
- An) This process continues until the accessibility and congestion measures converge.

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- B1) The final 1992 accessibility and congestion measures are input to the land use allocation module which calculates land use for the year 1996 (a time step or "DT" of 4 years).
- B2) The 1996 transportation network is defined (mostly exogenously, although the modeler may choose to modify the network based on the results in prior time steps).
- B3) The transportation modules are run as in case A above, and the process continues.

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The iterative process of running the transportation model is used to capture equilibrium of travel times that occurs on a regional level through vehicles switching onto less congested roadways.

POLICY ANALYSES

To assess the implication of selected policy options, we ran the model for the period 1992 to 2012 using step increments ("DT's") of 4 years. The following policy analyses were considered:

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

No Feedback Test — The model was run using the travel times generated from the 1992 base condition as the basis for land use allocation to assess the sensitivity of the land use model to accessibility. This is sensitivity test only, not a realistic scenario.

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.

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

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

Controls and Cost —The allowable density decrease was combined with the gasoline tax increase .

To assess the results of these scenarios, several measures were taken for the entire roadway system:

1) vehicle miles of travel per capita, during the afternoon peak hour,
2) vehicle hours of travel per capita during the afternoon peak hour, and
3) vehicle hours of delay per capita during the afternoon peak hour.

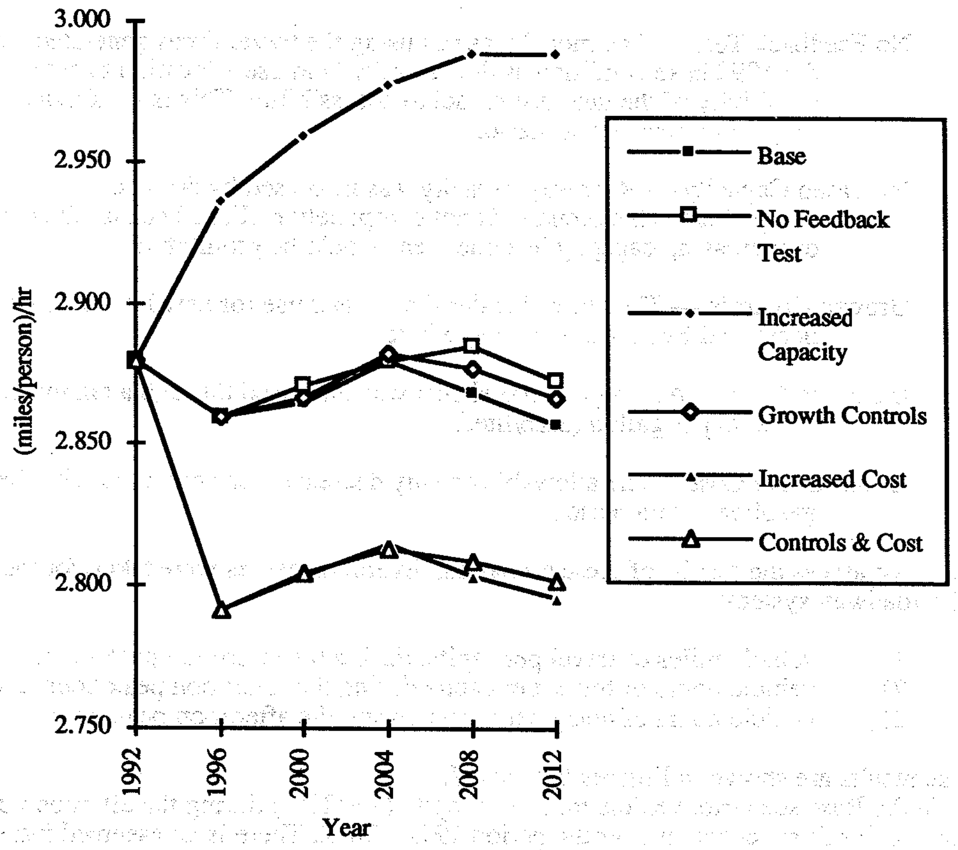
These results are shown in Figures 5, 6, and 7.

In the Base scenario, vehicle miles per capita (VMTPC) during the afternoon peak hour remains fairly constant over the period 1992 - 2012. There is an assumed increase in population of 35 percent over the period. This causes increased congestion and decreased trip lengths, pushing towards a reduction in VMTPC. However, this pressure is counteracted by an increase in personal trip making caused by an assumed increase in the number of jobs per capita. In the Base case, these opposing forces have approximately equal strength.

Two of the other scenarios exhibit similar behavior. Towards the end of the simulation, the Growth Controls scenario shows a very small increase in VMTPC which is consistent with Downs' urban sprawl hypothesis. VMTPC also increases in the No Feedback scenario, illustrating that the feedback from accessibility through land use allocation is important. The changes in VMTPC are small in these two scenarios because the majority of the land uses are unchanged after twenty years.

VMTPC increases sharply in the Increased Capacity Case which is consistent with the Nadis and MacKenzie hypothesis. VMTPC drops considerably in the two scenarios with a large increase in gasoline tax, but there is no further drop after the first time step.

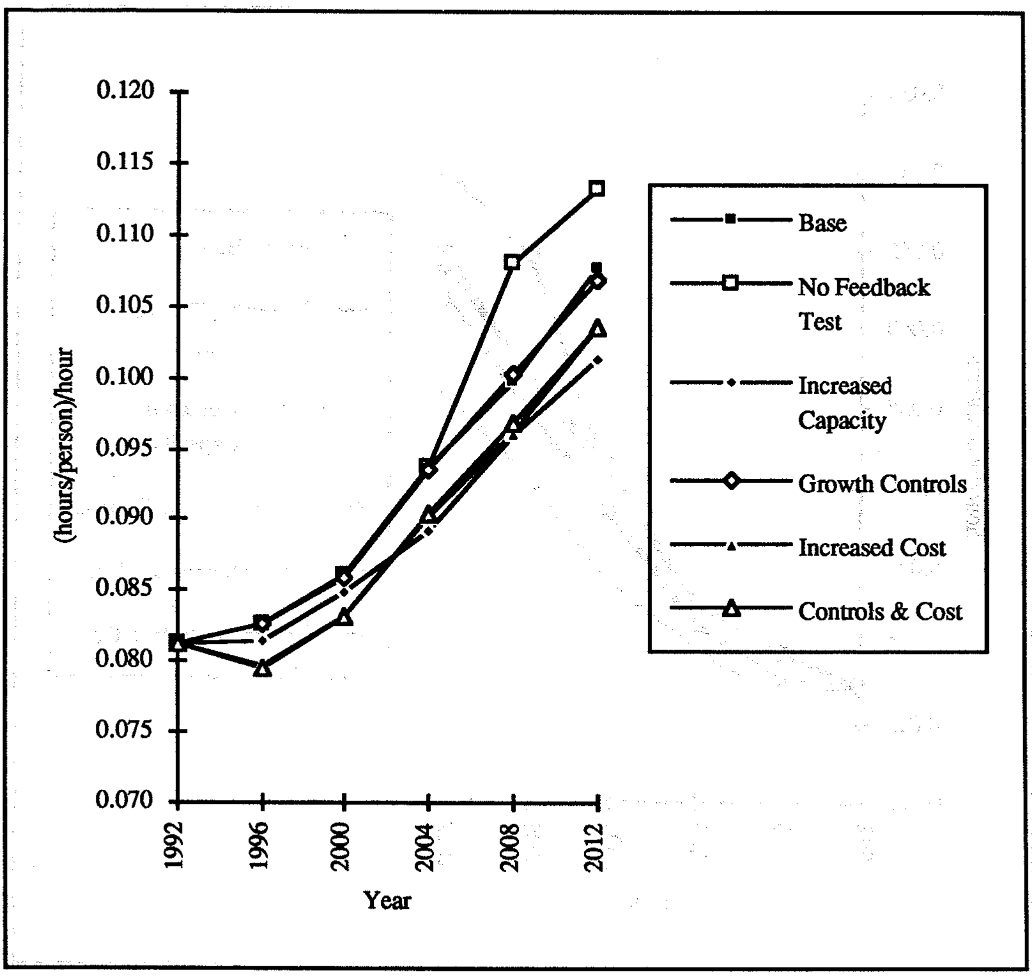
Figure 5: Vehicle Miles of Travel per Capita (VMTPC) During the Afternoon Peak Hour



All scenarios show an increase in vehicle hours of travel per capita (VHTPC) during the afternoon peak hour. These increases result from increased trip making due to an increase in jobs per capita and increased congestion. The increase is greatest in the No Feedback scenario, which again shows the importance of the feedback through land use allocation in controlling congestion.

In the Growth Controls scenario, VHTPC is almost the same in the Base Scenario. This supports Down's hypothesis in that the system is insensitive to a reduction in allowed density. The other three scenarios all include modest reductions in VHTPC relative to the Base scenario. However, these reductions are not nearly sufficient to keep VHTPC from growing over the period 1992 - 2012.

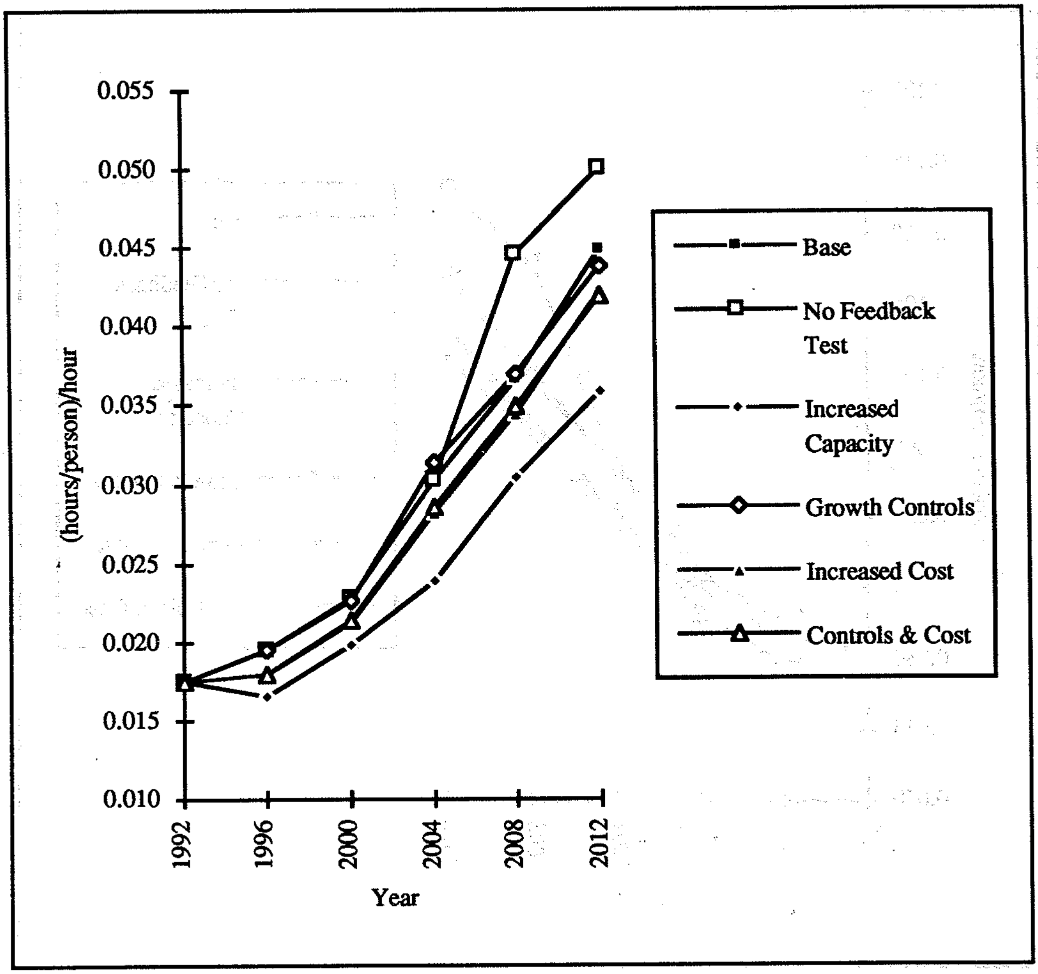
Figure 6: Vehicle Hours of Travel per Capita (VHTPC) During the Afternoon Peak Hour



The results for vehicle hours of delay per capita (VHDPC) are similar to those for VHTPC. All scenarios show an increase during the afternoon peak hour. Again, the increase is greatest in the No Feedback scenario.

All of the other scenarios show reductions in VHDPC relative to the Base Scenario. These differences are very small except for in the Increased Capacity scenario. Even with the 50 percent increase in capacity throughout the network, VHDPC doubles over the simulation period.

Figure 7: Vehicle Hours of Delay per Capita (VHDPC) During the Afternoon Peak Hour



CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

The most striking aspect of the simulation results is the insensitivity of the model to policy interventions. For the most part, we believe that this policy insensitivity is also true in the real world. The current model includes three of four important feedback loops acting to reduce travel as a result of increased cost and/or congestion. First, new land uses will choose locations that are accessible by shorter distances. Second, persons will choose shorter trips. Third, persons will be more likely to share a vehicle or to use public transit. There is a fourth affect that should be added. The number of trips made should be reduced.

The analysis results illustrate that land use allocation dynamics are a critical part of the infrastructure capacity system. However, policies that act through control of new land uses act very slowly. For this reason, some have argued that these policies should be abandoned. We disagree. Although land use policies act very slowly, the effects are equally long lasting. We expect that land use policies implemented now will prove to have been valuable twenty or thirty years from now when these issues are still debated. The land use policies must be carefully chosen. High density development should be encouraged in some areas, and discouraged in others.

Our next steps are to test much more specific policy scenarios in the region for possible implementation. These policy scenarios will include:

- roadway improvements,
- construction of new public transportation systems,
- high-occupancy vehicle lanes,
- tolls on highways,
- expensive parking, and
- development of concentrated land use centers accessible to public transportation.

We are also working to apply the model to two other metropolitan areas, including the four-county, Tampa Bay region in Florida, with 2 million people We expect to do other similar projects over the next few years, again focusing on the interaction between transportation infrastructure and land use. We plan to make incremental improvements in the model system over the course of these projects, including a dynamic trip generation module

We believe that the methodology could have much wider application. The current model includes sewer and septic capacity in determining development constraints, but other infrastructure could be modeled also. The model could be adapted to urban areas in developing countries with very different infrastructure issues. The model structure could be enhanced along many dimensions, possibly even to address the types of urban policy issues that were the focus of *Urban Dynamics* including economic development.

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