# The Development of Integrated Land Use-Transport Models in Oregon

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*Abstract*

The Oregon DOT has embarked upon a transportation and land use model integration program, designed to build a set of consistent and scalable analysis tools for studying the interaction of land use, transportation, and the environment. These models, which will operate at different spatial scales, are integrated models of land use and transportation. That is, they use consistent models of location and activity choice, as opposed to linked models of transportation and land use. Discrete choice and random utility concepts are employed throughout the model. While employed elsewhere in the world, models of this nature have only recently been attempted in the United States. The models described are aggregate models implemented in TRANUS, and are the first of their kind to be applied at the statewide and regional levels in North America.

This paper focuses upon a statewide land use-transport model for Oregon, which has been recently implemented. It focuses primarily on intercity tripmaking, and takes into account the economic interaction between places within Oregon. The market for land is represented by demand functions for several categories of households, businesses, and public uses. These socioeconomic sectors interact through a social accounting matrix, which is an extension of the regional input-output model formulation. The paper describes the collection of the data required to implement the model, as well as their role in model estimation.

The activity location and interaction component of the model is expressed in terms of production and consumption. Each sector in the model interacts with others through logit-based demand functions that vary as a function of production and transport costs. The spatial relationships are expressed in terms of flows between both sectors and zones. The structure of the activity location model are described in general

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terms, as well as the derivation of input-output flows for Oregon.

The activity flows are transformed into flows of persons and goods in an interface module. Data from passenger and freight surveys are used to convert activity flows (measured in dollars, acres, or employment) into daily vehicle and truckload equivalents. Trip matrices are generated for specific trip purposes, which are then assigned to a multimodal, multicommodity transportation network. A stochastic equilibrium assignment model is used to depict network flows and to calculate travel costs and measures of accessibility. These costs and disutilities are then fed back to the activity location model until convergence is reached. The final network costs influence activity location and interaction in the following time period. The model was calibrated to 1990-1995 data, and uses 5-year intervals for forecasts through 2025.

The resulting model can be used to examine a variety of transportation and land use policy actions and their interactions through time. The integrated structure of the model ensures that effects are consistently reflected in both the activity and destination choice models. The paper concludes with a discussion of the extension of the statewide model to the substate level in Oregon, integration with metropolitan models within the state, and ongoing research and development of both models.

*Introduction*

The Oregon Department of Transportation (ODOT) has embarked on an ambitious Transportation and Land Use Model Integration Program (TLUMIP). The metropolitan planning organizations have been key partners in the program since its inception. Now in its third year, the program seeks to develop a set of consistent, scalable land use-transportation models for use in transportation planning and policy analyses at varying scales of geography. A series of first generation models are now complete, which both demonstrate the overall validity of the concept as well as placing useful tools in the hand of Oregon transportation planners. A three-tiered modeling approach has been pursued in the work to date, focusing on statewide (intercity), substate (regional), and metropolitan levels of resolution. The substate model is actually an extension of the statewide model, both of which are discussed further in this paper. A parallel paper by Paul Waddell addresses the metropolitan model.

The design of the land use-transport model began with an assessment of the policy and investment issues the model should be capable of addressing. The need to evaluate a number of issues unique to Oregon, such as the presence of urban growth boundaries, influenced the design of the model. The study team, with the assistance of the peer review panel and modeling steering groups, identified eleven issues that the candidate model should be capable of assessing:

1. The effect of land supply on land use and location decisions
2. The effect of land supply on travel behavior
3. The effect of highway capacity increases on travel behavior
4. The effect of rail investment on highway use
5. The effect of changes in the demographic and economic composition of Oregon

6. The effect of congestion on land use and location decisions
7. The cumulative effect of retail location choice
8. The effect of large commercial development on the periphery of the growth boundaries
9. The effect of network connectivity on travel behavior
10. The effect of parking supply on travel behavior
11. The effect of urban form on mode choice

All three levels of the candidate model — statewide, substate, and metropolitan — were to be able to address the first five issues. The next four issues were more germane at the substate and metropolitan levels, while the effects of the last two were considered only within the context of a metropolitan model.

The program began with an assessment of existing models of land use and transportation in both the U.S. and abroad. A number of important conclusions were reached. Consensus was quickly reached that existing models were not well suited to examine many of the key issues identified above. The study team concluded that a series of nested logit models of location and destination choice applied at the disaggregate level offered the most promise. However, such a model had to be developed from scratch; such models had been postulated in the literature but none had been successfully implemented. The study team, working closely with the peer review panel, decided to build such a model for metropolitan areas, but concluded that significant risks precluded its development for the statewide level as well. Instead, it was decided to build a prototype statewide model using an existing modeling framework. After considerable discussion and research, the TRANUS package was selected for this task.

*Structure of the TRANUS Model*

The TRANUS system is a general and flexible tool for the simulation and evaluation of land use and transport policies. Unlike many other candidate models, TRANUS employs a totally consistent model of location and travel choice. It explicitly models the relationship between land use, economic activity, and the transportation system. While the framework of TRANUS is fully specified, it is flexible in the definition of the study area and its attributes; as little or as much detail can be included in the definition of the system under study. The TRANUS framework is discussed in considerable detail by De La Barra (1989).

At the heart of the modeling system is a spatially indexed input-output representation of the study area. Input-output models have been extensively used to study the interaction between sectors of the economy. The economic activity in Oregon was aggregated into twelve sectors, as shown in the upper part of Figure 1. A separate economic model was used to exogenously generate the flows between these sectors for the entire state. An important goal in our project was to maintain compatibility with economic inventories and forecasts used by other state agencies. The ability to use exogenous estimates of both the marginal totals by sector as well as their interactions allowed considerable flexibility in this regard.

The input-output framework is extended in the TRANUS system in some impor-

| CHANGES | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Land Supply / Exog. Demand | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r | r |
| **ECONOMIC FLOWS** | **PRODUCING SECTORS** | | | | | | | | | | | | | | | | | | | | |
| | Industries | | | | | | | | | | | | Households | | | Land | | | | | |
| **CONSUMING SECTORS** | AGFF | CONS | OMFG | WOOD | PRNT | TECH | TCPU | WLSE | RETL | FIRE | SERV | GOVT | HHIncLo | HHIncMi | HHIncHi | AGFF | IND | COM | SFR | MFR | RUR |
| **Industries** | | | | | | | | | | | | | | | | | | | | | |
| AGFF | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | e | | | | | |
| CONS | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | | | | |
| OMFG | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | | | | |
| WOOD | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | | | | |
| PRNT | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | | | | |
| TECH | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | e | | | |
| TCPU | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | e | | | |
| WLSE | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | e | e | | | |
| RETL | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | | e | | | |
| FIRE | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | | e | | | |
| SERV | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | | e | | | |
| GOVT | f | f | f | f | f | f | f | f | f | f | f | f | f | f | f | | | e | | | |
| **Households** | | | | | | | | | | | | | | | | | | | | | |
| HHIncLo | f | f | f | f | f | f | f | f | f | f | f | f | | | | | | | e | e | e |
| HHIncMi | f | f | f | f | f | f | f | f | f | f | f | f | | | | | | | e | e | e |
| HHIncHi | f | f | f | f | f | f | f | f | f | f | f | f | | | | | | | e | e | e |

| **TRANSPORT FLOWS** | **PRODUCING SECTORS** | | | | | | | | | | | | | | | **MODES** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Industries | | | | | | | | | | | | Households | | | | |
| **Transport Categories** | AGFF | CONS | OMFG | WOOD | PRNT | TECH | TCPU | WLSE | RETL | FIRE | SERV | GOVT | HHIncLo | HHIncMi | HHIncHi | Passenger | Freight |
| CmuteLo | | | | | | | | | | | | | 1 | | | 1 | |
| CmuteMid | | | | | | | | | | | | | | 2 | | 1 | |
| CmuteHi | | | | | | | | | | | | | | | 3 | 1 | |
| Recreation | 4 | | | | | | | | 4 | | 4 | 4 | | | | 1 | |
| HBOther | | | | | | | | | 5 | 5 | 5 | 5 | | | | 1 | |
| NHBOther | | | | | | | | | 6 | 6 | 6 | 6 | | | | 1 | |
| NHBWork | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | | | | 1 | |
| VisitorBus | | | | | | | | | | | | | | | | 1 | |
| VisitorOth | | | | | | | | | | | | | | | | 1 | |
| FreightLo | 8 | 8 | 8 | 8 | 8 | 8 | | 8 | | | | | | | | | 2 |
| FreightMid | 9 | 9 | 9 | 9 | 9 | 9 | | 9 | | | | | | | | | 2 |
| FreightHi | | | 10 | 10 | 10 | 10 | | | | | | | | | | | 2 |

| **OPERATORS** | Passenger | Freight |
|---|---|---|
| Auto | 1 | |
| Pass Rail | 2 | |
| Intercity Bus | 3 | |
| Lt Truck | | 4 |
| Hvy Truck | | 5 |
| Container | | 6 |
| Freight Rail | | 7 |

Figure 1: Flow relationships in the Statewide Model

tant ways. It is extended into a spatial dimension in a manner analogous to traditional travel forecasting models; in effect creating the input-output table shown in Figure 1 for each of the 142 zones in the model. In this manner economic flows, measured in annual dollar terms, flow not only between sectors but also between zones. In order to introduce the land use and demographic components, sectors were defined for three types of households (low, medium, and high income) as well as for several land markets. The markets include single and multi-family urban residential land, rural residential land, commercial, industrial, and agricultural and forest lands. The resulting matrix has been termed a social accounting matrix in order to distinguish it from the simpler input-output models. In the matrix shown in Figure 1, businesses consume the output of other businesses, land, and households. In the case of the latter, the demand for households is for labor; the dollar flows moving in the opposite direction represent wages and benefits.

The TRANUS system is deeply grounded in random utility theory and discrete choice modeling. The latter are most often implemented as logit models. Their ability to be ordered in nests permits them to be used for modeling decision chains. In TRANUS they are generalized beyond their traditional application in mode choice modeling. All decisions at all levels in TRANUS, from location choice to route and mode choice, are modeled using logit models. In a sense, TRANUS can be viewed as a long chain of nested logit models. The random term of the function is used to account for the variation in the modeled behavior, as well as to account for non-modeled factors. This framework is used to model the spatial accounting matrix. Logit-based demand functions are defined to allocate the flow of goods between sectors and zones. These functions are bounded by minimum and maximum values, elasticities, and spatial dispersion parameters. The social accounting matrix and the demand functions collectively make up the activity location component of the model.

The economic flows in the social accounting matrix are measured in annual dollars, which are tractable for the purposes of depicting the flows between sectors of the economy, but are not meaningful when expressed as transportation demand. A land use-transport interface is used to transform the flows in dollar terms to equivalent flows of persons and goods. This is shown in the middle of Figure 1, where transportable flows[3] are transformed into trip purposes found in traditional transportation models. Travel survey data were fused with data from the Public Use Microsample (PUMS) data to arrive at the factors used to render the economic flows in terms of trips. Once expressed in terms of trips, the flows by purpose are matched up with eligible modes of transport and assigned to a multimodal transportation network. A stochastic user equilibrium assignment technique is used for route choice and network assignment.

One important product of the network assignment is the calculation of accessibility indices for each zone. These indices are used directly by the activity location model, where it influences the spatial interaction between sectors. Indeed, the activity

[3]Some sectors, such as the land sectors, are not transportable. The economic flows to and from them are not included in the transport model, although trips to and from them are.

location model attempts to balance the cost of land with accessibility; decision-makers are assumed to make trade-offs between the two factors within the constraint of available income. The feedback does not occur instantaneously, however, but rather becomes an input to the model in the following time period. This lagged effect represents the delay in which such effects are perceived by households and businesses in the real world. The progression of the model through time is shown in Figure 2. In the statewide and substate models, a time interval of five years was used.

To use the model in forecasting mode, increments of exogenous variables are specified. Such variables include employment by sector, imports, exports, and available land by sector. These increments can be specified for the entire study area (the entire state of Oregon in this case) as well as for specific zones. Transport costs and activity patterns from the previous time interval become the starting point for the new interval. The model attempts to balance supply and demand by sector and zone iteratively; a price mechanism is used to adjust price up or down as appropriate. The model steps through time in five year increments, beginning in our base year of 1990.

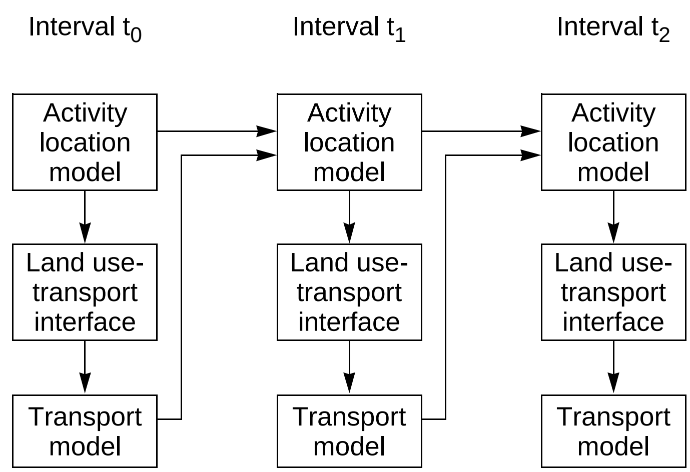

Figure 2: Relationship between components over time

*Development of the Substate Model*

The statewide model divided Oregon into 142 zones. At this level of resolution the model could be applied to studies of intercity flows or of large changes in land use (such as the relaxation of the urban growth boundaries). The statewide model was also viewed as the backplane upon which a finer level of zonal and network detail could be arrayed in order to carry out major corridor studies. Many of the corridors identified as likely candidates for evaluation using the model were only partially included within the boundaries of the traditional urban travel modeling areas, and some corridors connected two metropolitan areas. A prototype substate model was designed for use in these studies. It was decided that the Willamette Valley, the eleven counties in Northwest Oregon that contained the majority of the state’s population and employment, would be focus of the substate modeling efforts. This area extends from Vancouver, Washington in the north to Eugene, Oregon in the south, and includes most of the popular tourist destinations in the state.

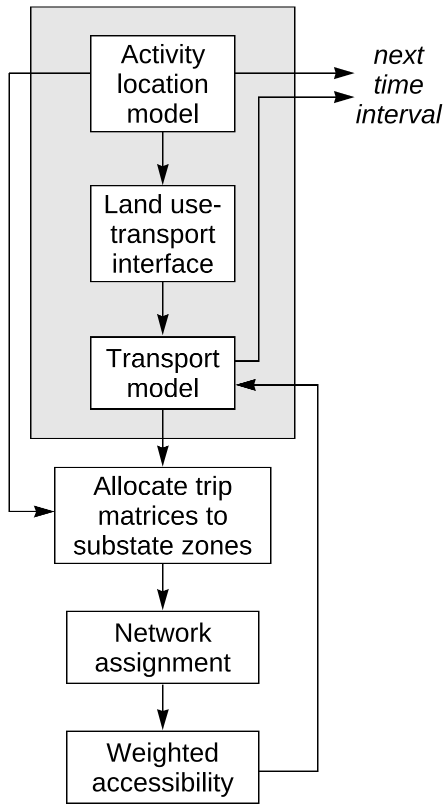


Figure 3: Substate modeling framework

Using the candidate corridors and the zone systems of the existing urban travel demand forecasting models as a guide, the study team broke the substate area into approximately 350 zones. Census tracts were used to define the zone boundaries. All but one of the metropolitan planning organizations used tracts to define the traffic analysis zones in their travel forecasting models, allowing their zone system to nest beneath the substate model zone system.

A typical application of the TRANUS framework encompassed between 25 and 50 zones. The statewide model (142 zones) already pushed the limit on the number of zones that could be handled using it.[4] Because of concerns about data availability and model performance, it was decided to pursue a hybrid modeling approach, illustrated in Figure 3. The statewide model was used to simulate the interaction between sectors. Once the statewide model iterates to convergence, the trip matrices by purpose are exported to an external program that synthetically allocates the origins and destinations (at the statewide zone system) to the substate modeling zones. The flows are evenly distributed to the substate zones nested beneath each statewide zone if no better information is available. In the most parts of the Willamette Valley, however, land use data at the substate zone level are used to apportion the flows. These expanded trip matrices are then assigned to a finer roadway network than is used at the statewide level, which allows a broader range of alternatives to be modeled at an appropriate scale.

The TRANUS transport model is used for the substate network assignment, maintaining a consistent methodology and user interface. Finally, the substate model zone-to-zone impedances and accessibility indices are passed back up to the statewide model. A weighted average, based on the share each substate zone comprises of the statewide zone it is nested beneath, is used aggregate the values back up to the statewide zone system. If the resulting statewide zonal accessibility indices change in a sig-

[4]The software is not limited to a maximum number of zones. The limit on number of zones is more a function of the ability of the user to obtain the required data for model calibration, and the immense amount of output which the user has to grapple with in order to understand how the model is working. Recall that each zone has up to 21 sectors active within it, as well as several derived trip purposes — a lot more information than a traditional model would encompass.

nificant way, the statewide model is run again with the new values. This feedback loop continues until a user-specified degree of convergence between the substate and state-wide transport model results is achieved.

*Model Calibration Targets*

A surprising finding of the research into current practice was that no clearly defined model calibration or validation criteria existed for integrated land use-transport models. The study team and peer review panel together developed several criteria for assessing model performance:

1. Match production by sector and zone
2. Match number of trips and average trip distances by trip purpose
3. Minimize zone-specific constants by sector
4. Network flows to match counts by mode of transport, with emphasis on interurban routes
5. Match increments of land to changes in land price
6. Match CTPP distribution for commuting flows

Each of these criteria have specific numeric targets. The network flows, for example, must fall within specified ranges based on total observed volume. Some of the targets are more liberal than for traditional urban travel models, owing to the greater complexity of the integrated model. In addition, several subjective tests of model performance were developed. In each case the model was required to produce sensible and reasonable results, although specific numeric targets could not be defined:

7. Destination and route choice response behavior
8. Trip generation sensitivities
9. Path and transport cost testing

The statewide model met the calibration targets and was judged to perform well. The substate model is still under development and has not yet been subjected to rigorous calibration. These criteria appear to be achievable regardless of the geographic scale the model is applied, although additional thinking needs to go into the development of criteria for the land use side of the model. Even in their present form, the standards can be useful for measuring the performance of any integrated land use-transport model.

*Data Requirements*

A common obstacle to the use of land use-transport models has been the amount of data required beyond those needed for traditional travel forecasting models. The widespread deployment of geographic information systems have provided many of the required data and tools needed to manipulate and render them. Many of the data required to develop and apply integrated land use-transport models are not overly burdensome to acquire, although they are unfamiliar to most transportation planners.

The data required to develop the statewide and substate models in Oregon are shown in Table 1. The transport supply and demand data are comparable to those

**Table 1: Land Use-Transport Model Data Requirements**

| Land use and socioeconomic data | Land use-transport interface data |
|---|---|
| Base year socioeconomic data (input-output accounts, induced production, etc.) | Time and volume conversion factors, directionality of flows |
| Exports by sector | Intrazonal costs |
| Imports by sector | Exogenously defined trips |
| Restrictions on internal production by zone and sector | **Transport supply and demand data** |
| Location utility function parameters | Network (link endpoints, length, capacity, etc.) |
| Demand function parameters | Transit lines |
| Demand substitutions | Trip purpose characteristics (available modes, value of travel and waiting time, etc.) |
| Attractors of exogenous demand | Trip purpose characteristics (available modes, value of travel and waiting time, etc.) |
| Attractors for induced production | Trip generation and mode split parameters (elasticity, dispersion, and scaling factors) |
| Global increments of exogenous production and consumption | Energy and operating costs |
| Increments of exogenous demand, production, and external zone exports and imports | Vehicle operating characteristics |
| Increments of endogenous location attractors, production restrictions, and value added to production | User charges (fares and tariffs) |
| | Speed-flow curve parameters (for network assignment) |

required to develop traditional travel demand forecasting models. The same is true for the land use-transport interface data, except that factors must be developed to translate flows in dollars to equivalent person and freight movements.

Robust land price and supply data proved to be the most difficult to obtain. Residential land sale transaction data were readily available, but non-residential sales were not very plentiful even over a five-year period. We eventually convened a Delphi panel of commercial realtors to help derive current and historical trends in non-residential land prices for the three metropolitan areas in the Willamette Valley (Salem, Eugene, and the Portland/Vancouver area). The use of Delphi panels to collect certain types of land data is likely to play a larger role in future model development work.

*Future Directions*

The first generation prototype models are nearing completion, and the results have been very positive. The model development work is ongoing; the following tasks are planned for the next stage of the program:

- Reassessment of the system architecture
- Begin work on the second generation models

- Continued refinement of the land price and supply data
- Better user interface, to include tighter GIS integration and a scenario manager
- Tighter linkages with Portland Metro and Port of Portland work
- Incorporation of the 1995 American Traveler Survey results

These efforts will begin in the summer of 1998 and are expected to last from 18 to 24 months.

*Conclusion*

The goal of the first phase of the TLUMIP was to develop a set of prototypical integrated land use-transport models at the statewide, substate, and metropolitan levels. The statewide model has been implemented and calibrated in TRANUS, and the substate and metropolitan models are nearing completion. The prototypical models will be implemented and used by ODOT staff for planning and policy analysis work while the second generation models are under development. The experience gained to date suggests that integrated land use-transport models are plausible and can provide policy-makers and planners with timely information about the interaction between land use, transportation, and the environment. The models developed to date have proven that such models can be developed and deployed by transportation planning agencies in the U.S. in a cost-effective manner.

*References*

De La Barra, Tomas. (1989) Integrated Land Use-Transport Modeling. London: Cambridge University Press.