Preliminary Draft for Review

Consultant Recommendations for the Development of Phase II Databases, Models, and Forecasting Methods

Transportation and Land Use Model Integration Program
Phase I, Task 1.6

Prepared for

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The Statement of Proposal outlined an overall approach to the development of an integrated land use-transportation model for statewide modeling in Oregon. It was based upon the interpretation of the Oregon Department of Transportation (ODOT) requirements made by the consulting team. Like many such proposals, it preceded the client-consultant dialogue needed to understand the many institutional and technical issues germane to the project. In the past few months the consulting team has obtained and reviewed a large collection of documents and data, and have participated in meetings with ODOT officials. Several major issues in model specification and design were identified, and are addressed in this document.

We believe that the basic approach suggested in the Statement of Proposal remains valid and useful. It is suggested that the reader become familiar with the Scope of Work in particular before reading this document.

This document is intended to provide an overview of and consultant recommendations on key issues in model design (Phase I, Task 6). These recommendations will be discussed during an upcoming workshop with ODOT staff and the Peer Review Panel (Phase I, Task 10). It is anticipated that consensus conclusions—in some cases quite different from those contained herein—will be reached by the study team, which includes the ODOT staff, Modeling Steering Group, Peer Review Panel, and the Consulting Team.

1.0 Conceptual Model Design

There are unfortunately very few existing transportation models from which to glean design and methodological elements from—either in terms of integrated land use-transportation models or statewide transportation models. More work has been done in the former than the latter, although much of the progress to date remains centered around the application of only a few modeling packages. The Statement of Proposal was intentionally vague about many of the model implementation issues, such as details on how the land use and transportation models would be integrated, how they would interact with economic models, what software package(s) would be utilized, and in what hardware and operating systems realm. In the sections that follow these issues and others are defined and discussed. Recommendations are presented in each case.

1.1 Land Use-Transportation Model Interaction

<u>Issue:</u> The Statement of Proposal and Scope of Work call for the development of an integrated land use-transportation model at the statewide level. Neither document defines the nature and extent of integration to be achieved between what has traditionally been independent modeling approaches. The level of integration to be sought is an important input to the model specification process, and must therefore be quickly resolved. The trade-offs considered in the development of a proposed approach are listed in Table 1.

<u>Discussion:</u> The existing transportation-land use models in widespread use (i.e., TRANUS and MEPLAN) are “partially integrated” models, in that the changes in land use influenced by transportation investments are time lagged and separable (see Figure 1). While both the land use and transportation models are driven from a common set of assumptions and data, they are implemented as separate modules. Indeed, it is possible to use TRANUS or MEPLAN as a standalone transportation model. Waddell (1996) has proposed a similar scheme in which some of the components are more explicitly defined, as shown in Figure 2.

This approach, while lacking from an abstract theoretical point of view, does have some appeal. Because the transportation and land use models are separable, it means that the framework

Table 1: Levels of land use-transport model integration

Level	Pros	Cons
Fully integrated	A single, consistent model of land use and transportation decision-making by households and businesses. A single unified model would simplify and streamline software implementation.	High risk of failure. Work to date has been theoretical; implementation has not been attempted at any level. All levels of the model must be completed in order for it to work (interim products probably not possible). Difficult to maintain project schedule while attempting research and development work. Entails a heavy investment in software development. No body of knowledge and experience in model application.
Partially integrated	Comparable with current practice and existing models. Lower risk of failure. Produces a workable product that can provide the time and resources to develop a fully integrated model later. Existing software is probably up to the task (although some software development will still be required). Component models can be developed and implemented independent of other parts.	Not as theoretically pleasing as the fully integrated model. Existing limitations of the current models become more apparent when stretched into statewide application. Limited feedback between different model components.

could be extended to include an econometric model. Such a scheme seems like a natural extension of the practice at many agencies, where existing transportation models can be recalibrated and adapted to the larger framework of the integrated model.

Critics of such a scheme might argue that such a model represents only a small incremental improvement over existing practice. Inasmuch as existing models and data are reused to the maximum extent possible, the argument has some merit. However, it misses the broader picture of a modeling suite that embodies common assumptions and data. Integration at this level is a logical next step towards the development of a holistic land use-transportation modeling capability.

The partially integrated land use-transportation model, like the more traditional four-step transportation models, implies a sequence of independent choices about tripmaking. The decision to travel is made first (trip generation), where to second (trip distribution), how to get there third (mode choice), and the specific path chosen last (route choice). The interdependency between the choices has long been recognized but only recently addressed within the context of modeling practice. The approaches have ranged from simplistic (one-pass feedback of modeling output back to trip distribution or mode choice) to sophisticated (simultaneous models of trip generation, distribution, and mode choice). The latter approach constitutes what might be called a “fully integrated” transportation model, in that the interdependent decision-making is more accurately represented.

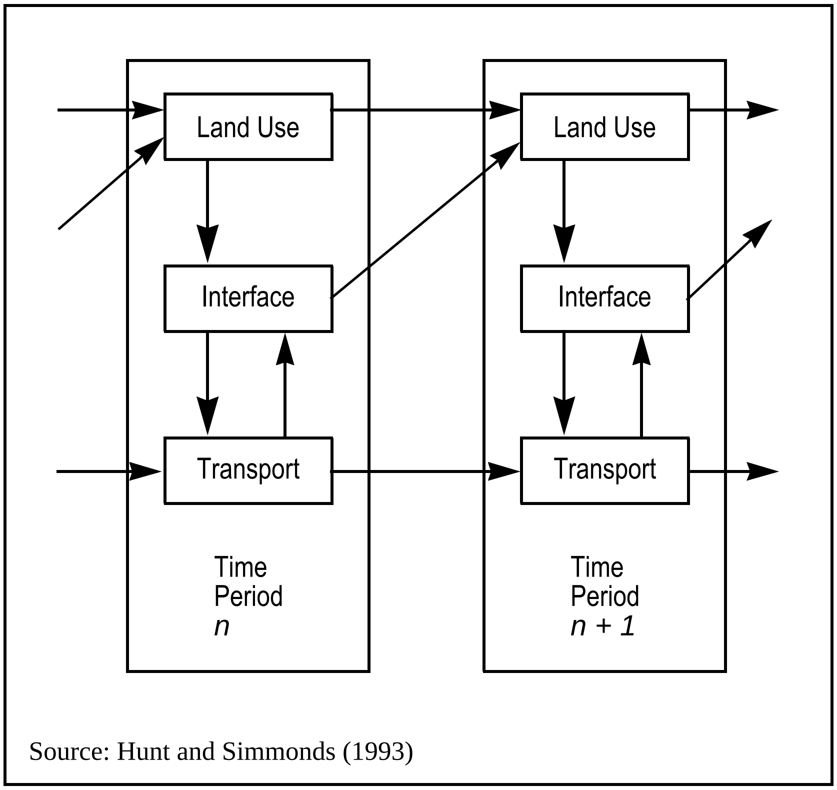
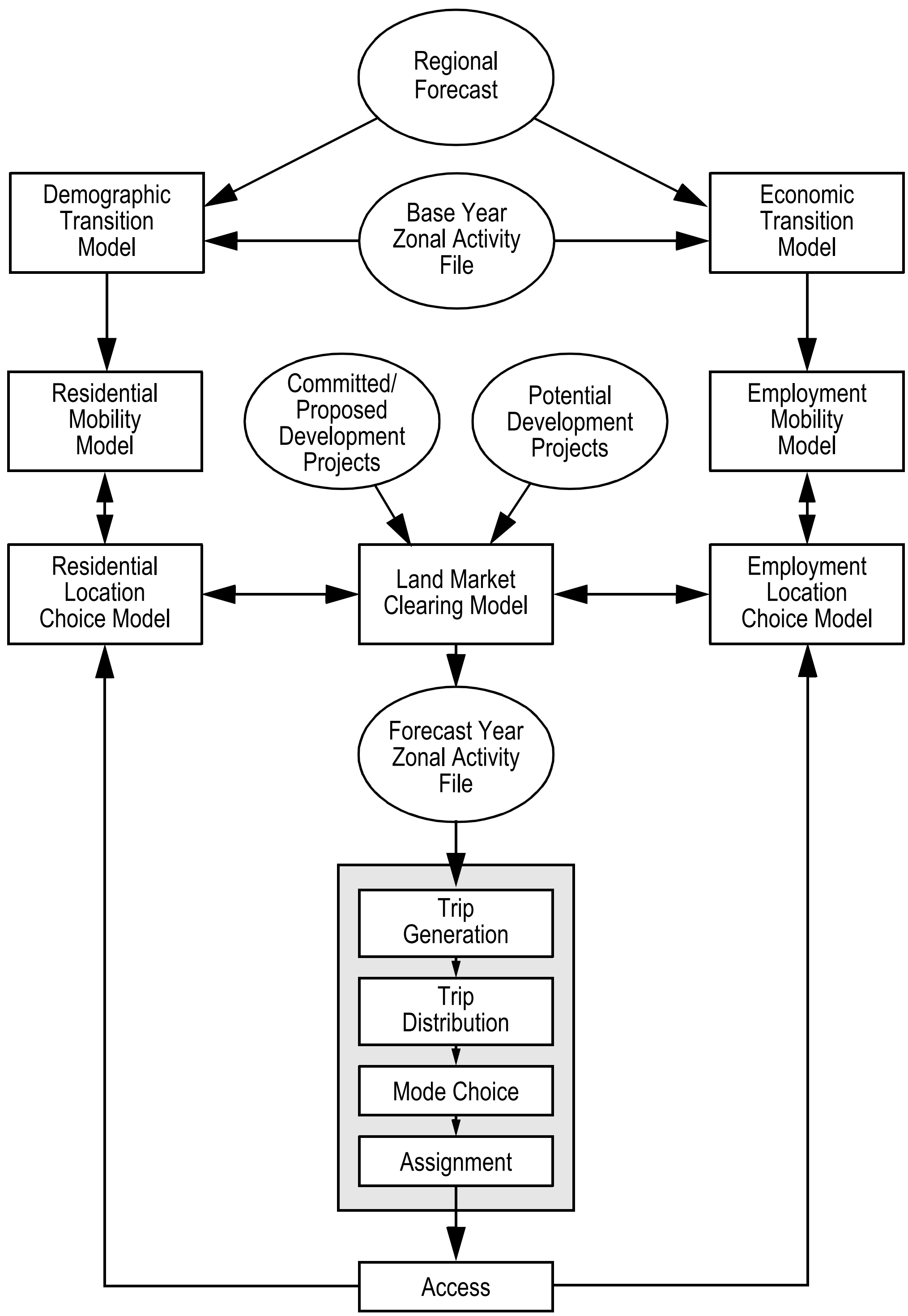


Figure 1: Time lagged effect of transportation measures

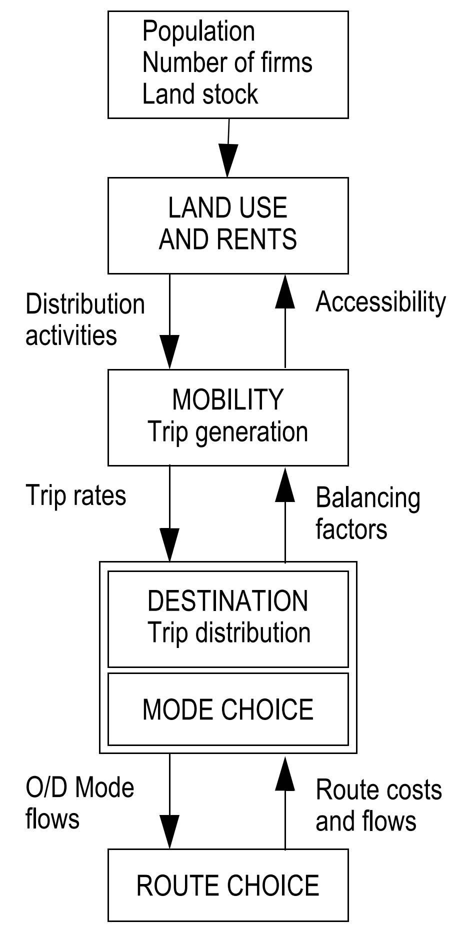
The only analogous "fully integrated" land use-transportation model was proposed recently by Martinez (1992). His model includes an extended decision chain with five components, as shown in Figure 3. The model is heavily based in microeconomic theory, and assumes that consumers make locational and travel decisions together from the same set of expectations and monetary constraints. The decisions will, of course, have different temporal impacts (for routes and modes of transport can be changed much more quickly than place of residence or employer), but the model does succeed in making a subtle but significant linkage between accessibility and the profit-maximizing assumption for both households and businesses. Rather than waiting for the lagged effects of travel decisions to be felt in later time periods, this approach implies that households and businesses will also trade-off accessibility for rents[1] in a current market. The implications of this can be illustrated in a simple example. A household wishing to minimize its transportation costs would, all other factors being equal, choose parcels of land with the greatest measure of accessibility. Such accessibility is often stated in terms of automobile (roadway) accessibility. But some households might accept parcels less accessible by roadway if they also had access to transit. But this relationship is not linear (which is recognized by current models) and the availability of the transit alternative does affect location choice (a property not included in current models). The partially integrated land use-transportation model captures this effect in the next time period (the lagged effect), whereas the Martinez model captures the effect in both the current and the next time period.

1. Broadly defined in the context of this discussion as the cost of housing or commercial space. No distinction is made between renting, leasing, or owning such assets.



Source: Waddell (1996)

Figure 2: Example of a partially integrated land use-transportation model



Source: Martinez (1992).

Figure 3: 5-LUT model structure

The fully integrated model is probably more theoretically pleasing, but the lack of prior successes with them make such an approach a high-risk one for Oregon. While the model can be specified, it is unknown whether such a model will work in practice. Moreover, many of the known calibration techniques and “tricks of the trade” are not likely to be helpful with such a model.

Recommendation: A partially integrated land use-transportation model is recommended for development, using a structure similar to the one proposed by Waddell (see Figure 2). This is consistent with the Statement of Proposal, and will allow us to use a modular approach to model development. Each submodel can be isolated, changed, and tested without disrupting the remainder of the model.

1.2 Spatial Representation

Issue: As with the level of land use-transportation integration, the scope and level of detail of network and traffic analysis zones has not been determined. While a seemingly straight-forward issue, it has wide implications on model design and development, hardware and software requirements, and data requirements.

Discussion: Statewide models in existence range considerably in geographic detail considerably, ranging from very abstract representations of the roadway network and counties (New Mexico and Kentucky) to very detailed networks. The Michigan model is an example of the latter, with 2,392 traffic analysis zones, 2,308 of which are within the state's 83 counties. Nearly all functional class roadways above the local street level are included in the network.

In Oregon, travel models at three levels of geography are contemplated: the traditional urban models, a statewide model (primarily focusing on intercity travel, the focus of this study), and substate models. An example of the latter is a consolidated model for the Willamette Valley, which would extend from Portland south to Eugene. It is anticipated that the substate models will be an outgrowth of the work completed in this project. It may be possible, however, to extend the statewide model to operate on substate areas. The level of detail in the Michigan model certainly would support such activities. However, it is beyond the resources of the consulting team or the ODOT to develop networks and land use data at that level of detail during this project. Indeed, such a level of detail is unnecessary within the context of intercity modeling. The challenge will be to construct a network and zone system adequate for statewide modeling while providing a framework for increasing the level of detail in certain regions of the state. It must be possible to accomplish this without having to modify or re-calibrate the statewide model each time substate areas are developed. The resulting model would evolve in detail as it was used in substate studies and as better data become available.

Recommendations: At the lowest level of fidelity, the network and zone system must be capable of supporting statewide modeling. That is, it must be adequate to meet the requirements of this project. It must also scale to existing data, as its utility will be markedly diminished if its data requirements cannot be sustained. This level will be called a "Level 1" representation. It is proposed that the network at this level be restricted to roadways on the National Highway System (NHS) at the primary arterial level and higher. These routes carry the majority of intercity flows, and have the most comprehensive data available. Routes outside of this classification can be added as necessary at the discretion of the study team. Outside of Oregon, the network will be successively aggregated to the Interstate Highway level. A road crossing the state boundary will continue to be represented in the network until it intersects with a higher classification roadway, which in turn will continue until it reaches a roadway of the next higher classification. This will provide us with a network which quickly reduces to major highways outside of Oregon, but avoids a sudden transition of spatial representation at the state boundaries. The Oregon Highway Monitoring System (OHMS) will be the source of network data within Oregon, and the National Highway Planning Network, Version 2.02, will be used outside of Oregon.

Urban transportation models typically represent human activity within traffic analysis zones. The scheme recommended for the statewide model (Level 1) represents a significant departure from that practice. We propose modeling most components of land use, economic activity, and travel demand at the county level. As previously noted, the Portland metropolitan area represents a special case in which the metropolitan area will be treated as a whole, with the component counties treated in a unified fashion. The primary impetus for modeling at the county level is the consistency of its borders, which will facilitate time-series analyses of several variables, and the fact that it is the lowest level at which consistent data are available across the state. The adjacent states will be modeled at the county level near the Oregon border, and in groups of counties[2] away from it. Beyond them will be states modeled as a whole, possibly further aggregated into Census regions in the eastern United States.

Unlike traditional transportation models, there will be no direct linkage between the county-level estimates and forecasts and the transportation network. Within each county a number of nodes will be defined. Some will function as usual, demarcating roadway intersections ("intersection nodes"). Other nodes will represent places or activities from which trips will enter and exit the network. These "activity nodes" will correspond to named places and to certain activity locations which do not fall within named places (such as ocean terminals, logging assembly areas, state and national parks, etc.). A named place will be a community recognized as a distinct entity and for which separable socioeconomic data are available. It will also include parks and recreational areas within the state. For larger urban areas several activity nodes will be used in conjunction with the intersection nodes to better represent the urban area. For example, in Portland separate activity nodes might be defined for the central business district, the convention center area, the airport, the intermodal terminals along Marine Drive, etc. The structure will follow the zone groups used by Portland Metro, to facilitate data sharing and model integration.

An allocation process will be used to disaggregate county-level activities to the activity nodes within the county. Three allocation methods will be developed. The first will be used for counties with minimal information about land use and economic activity within the county (probably not much more than population and total employment by named place). A second method will be developed that will take advantage of existing urban area travel model data (where available), using their zonal estimates of population and employment by type to guide the allocation. Other statewide spatial databases, such as the ODOT's Potential Development Analysis coverage, will be used as well. The third and most sophisticated method will use parcel or tract level data on land use to allocate county-level forecasts to named places. This technique will be appropriate for areas where GIS coverages of relevant land use data exist, and will also permit the establishment of several activity nodes within each named place. This will allow a correspondingly finer level of network detail, such as that required for substate modeling and for the Phase III case study.

Regardless of the allocation method employed, households and businesses located outside of named places[3] will be allocated to activity nodes within the county. A candidate method for such will be to assume that such activities are evenly spread across the area of the county outside of the named places (minus any areas defined as empty). Each activity node would capture the rural activities within a given radius (say, 8-10 miles). If there are areas outside of the overlapping radii remaining within the county, an intersection node will be promoted to an activity node or one will be generated for them by the model. It is expected that the number of rural activities so allocated will be small, obviating the need for a more sophisticated allocation method.

A more detailed spatial representation, alluded to earlier, would result in a much finer level of network and activity detail. This level, which can be called "Level 2," will be appropriate for substate modeling. Except for its likely use in the Phase III case study, we will not develop Level 2

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2. The county groups will follow the definition of (U.S. Department of Commerce) Bureau of Economic Analysis (BEA) regions where possible. The BEA structure is presently under revision; we will work closely with the BEA to ensure that our county groups follow their proposed new system to the maximum extent possible. We will also ascertain whether the state DOTs in the adjacent states have substate regions already defined that might make more sense to adhere to (in order to facilitate data sharing in the future).

3. The difference between the county-level estimates of population and employment (obtained from County Business Pattern, Census, and taxation data) and the sum of households and employment for all named places within the county.

coverages during this project. The Level 2 coverages would greatly increase the level of spatial detail, probably to a level approaching less detailed urban models. Instead of a named place being represented by an activity node (or activity node group), it would be broken down into tracts or parcels, depending on the level of data available. Each tract or parcel would then become an activity node. Each named place would then be represented by a activity node group, analogous to an EMME/2 zone group. The network coverage would be extended to include major and minor arterials. Modeling could then be carried out at the desired level—county, named place, or activity nodes—and the allocation process used to disaggregate the demand to smaller units.

A third level might be defined for future use as well; it would correspond to the level of zonal detail commonly employed in urban transportation models. As such it would also likely include local streets and minor collectors in the network. In order to maintain compatibility with existing models, activity nodes in a Level 3 representation would probably be connected to the network using the usual concept of centroid connectors.

1.3 Economic Modeling

The proposed modeling approach remains unchanged from the Statement of Proposal. The thrust of the model development work contemplated for Phase II revolves around the development of the integrated land use-transportation model. It is envisioned that a statewide economic model will eventually be integrated as well. However, there are not adequate resources to attempt the development of all three components in Phase II. We have therefore suggested that an interim economic model be developed that can be extended and refined subsequently.

Issue: A need to maintain compatibility with economic forecasts prepared by the Department of Administrative Services (DAS) has been identified. The DAS is developing interim 20 year population and employment forecasts by county. It is highly desirable that the two forecasts agree with one another.

Discussion: The economic model must be capable of producing estimates of current employment and forecasts of employment at the 2-digit standard industrial classification (SIC) level. While these data will need to be available for each named place within Oregon, it is proposed that modeling be conducted at the county level, with special attention paid to the Portland metropolitan region (where groups of counties—representing the urbanized area as a whole—should be modeled as well as the component counties). The county is the smallest unit for which reliable data are available.[4] A family of allocation models will then be developed to disaggregate the county level forecasts down to named places within counties, as previously discussed.

The issue of compatibility is complicated by the fact that the two groups are using substantially different forecasting techniques. The DAS approach uses an ad hoc process of allocating statewide total employment by sector to counties, based upon both subjective and objective criteria. The process will reflect the desires of policymakers to encourage economic development in certain regions of the state or sectors of the economy as much as it will capture historical trends. We could use the DAS county-level aggregations and simply allocate them to activity nodes within the county. The primary disadvantage of such an approach is that it makes the economic variables all exogenous to the model, thereby eliminating their sensitivity to policy measures. The

4. The County Business Pattern data, available from the Bureau of the Census, will allow us to track employment and earnings for the past 25 years. Since county boundaries have not changed (whereas the urban boundaries have changed several times over the same period), these data will facilitate a robust time-series analysis.

linkage between location choice and rents, for example, would not be possible.[5] This would cripple the land use and freight modeling components, a decidedly undesirable outcome.

Both economic models will have their basis in the same time series data. This will ensure that both depart from the same current estimates of county-level population and employment. Given that elements of the methodology described in the Statement of Proposal have been employed in Oregon already, it is anticipated that the two forecasts will not differ substantially in most respects.

Recommendation: After exploring several alternatives, we have returned to our original proposal for economic modeling. Like the parallel DAS efforts, it represents an interim model. It is hoped that both economic modeling efforts benefit from the lessons learned in their respective implementations, and these lessons can guide their further (and hopefully closer) development.

1.4 Person Travel Demand Forecasting

The proposed approach to intercity modeling remains largely unchanged from the Statement of Proposal. One key data element, the American Traveler Survey, has been delayed by the U.S. Department of Transportation. This will have a significant impact upon the project.

Issues:

1. Intercity travel is significantly different from urban area travel, and the traditional four step modeling process is probably inadequate for the task. A flexible modeling approach based upon more robust modeling methods is needed.
2. The American Traveler Survey, a key data element assumed to be available for use in this study, is unavailable. Suitable replacement data must be obtained or the model must be reduced in terms of its scope.
3. Decisions must be reached concerning the period of time to be modeled and the definition of trip purposes.

Discussion: The majority of intercity person trip models developed to date have implemented the traditional four-step sequential modeling process employed in urban areas. There is considerable evidence that such a modeling structure is inappropriate for intercity travel modeling. The nature of intercity travel is significantly different from that of urban travel. Most urban trips are of much shorter duration than intercity trips. Commuting trips are typically the activity with the longest duration outside of the home. In most other instances the activity duration with which travel is associated is short, typically lasting only a few hours. The ability to frequently return to the home affords the urban traveler the ability to chain trips, change modes, and develop optimal routings. Tripmaking for many activities is repetitive over time and season.

Intercity travel, on the other hand, is often undertaken far less frequently and over a longer duration. An intercity trip can be represented as a tour that ends with the first stop back at home. Many intercity trips will never visit the same location twice, whereas others will resemble the more familiar commuting trip. Once travel has commenced the propensity to change modes is markedly diminished. In the four-step process mode choice is modeled independently from trip generation and destination choice. In intercity modeling, mode choice can almost never be con-

5. Our economic model, conditioned to time series data, would produce an estimate of location choice that would most likely differ from estimates using the DAS forecasts. Using the DAS forecasts in place of the modeled results would violate several underlying assumptions in the endogenous economic model, produce illogical results, and probably preclude an equilibrium solution to the land use-transportation interaction.

sidered separately. Once the initial decision about mode of transport is made, all subsequent trips in the tour implicitly assume that mode[6].

The trip distribution process commonly employed in urban areas appears to perform the worst in intercity applications. The gravity model, to the extent that it is able to reproduce spatial interaction in urban areas, appears to be hopelessly deficient when applied on a statewide basis. The gravity model in essence chooses from a number of presumably equivalent destinations (in satisficing terms), with the attractiveness of any given destination diminishing rapidly with distance from the traveler's current position. Such assumptions do not hold for a number of intercity trips, where the number and location of competing activities is small. Business travel itineraries, for example, are often not related at all to distance traveled. Most vacations and recreational travel are also not deterred by distance. The cost deterrence function, used to represent the impedance of distance in gravity models, typically renders an average trip duration that follows a log-normal distribution. In contrast, intercity travel trip duration distributions often follow a random (Poisson) distribution—if they follow one at all. An example of surveyed trip durations for non-work intercity trips in southern New Mexico is shown in Figure 4.

Given these and other key differences, we suggest implementing logit models of trip generation, destination choice, and mode choice. Depending upon the data sources employed in model estimation, these steps may be combined (e.g., a combined model of trip generation and destination choice). This approach is attractive for many reasons. It will permit the specification of models which closely parallel those in the land use model. By employing many of the same behavioral assumptions and data, a degree of consistency between the models not heretofore achieved will be possible. For example, considerable overlap may exist between the residential and business location choice models and the destination choice model. Both are influenced by many of the same factors, such as zonal employment by type and size, zonal accessibility by mode of transport, distance or other measure of spatial impedance, etc. By specifying similar choice models for both models, consistent rational behavior will be extended to both models. The parallel structures should also reduce model development time and cost, as the idiosyncrasies and flaws exposed and corrected in one model will presumably eliminate such behavior in the other.

The attractiveness of discrete choice models for intercity modeling is well documented in the literature, ranging from Gerken's description of a generalized logit model (1991) to the use of non-linear utility functions in logit models, reported by Mandel *et al* (1994). Forinash and Koppelman (1993) have contributed very germane nested logit formulations for intercity mode choice modeling, which we propose implementing in this model. Lastly, several aspects of discrete choice models make them useful in the context of today's policy analysis questions. A considerable amount of research is on-going in the area of activity-based travel demand forecasting, models of which are being postulated as logit formulations. The eventual transition to such models will be far less burdensome, since their predecessors will be of the same formulation. Owing to their probabilistic nature, the random error term of the logit model can also be perturbed, allowing the analyst to examine the impact of changes in reliability upon choice behavior.

The Statement of Proposal relied heavily upon the use of the 1995 American Traveler Survey (ATS95) for developing trip generation models. As discussed in Section 3.1 below, these data will

6. There is some degree of mode choice still to be made for local trips. For example, a businessman driving from Seattle to Eugene might well walk to dinner from his hotel, or take a bus downtown. But these alternatives will mostly likely be restricted to the activity node; a trip made to Salem for dinner would almost always be made in the same automobile used to commute from Seattle.

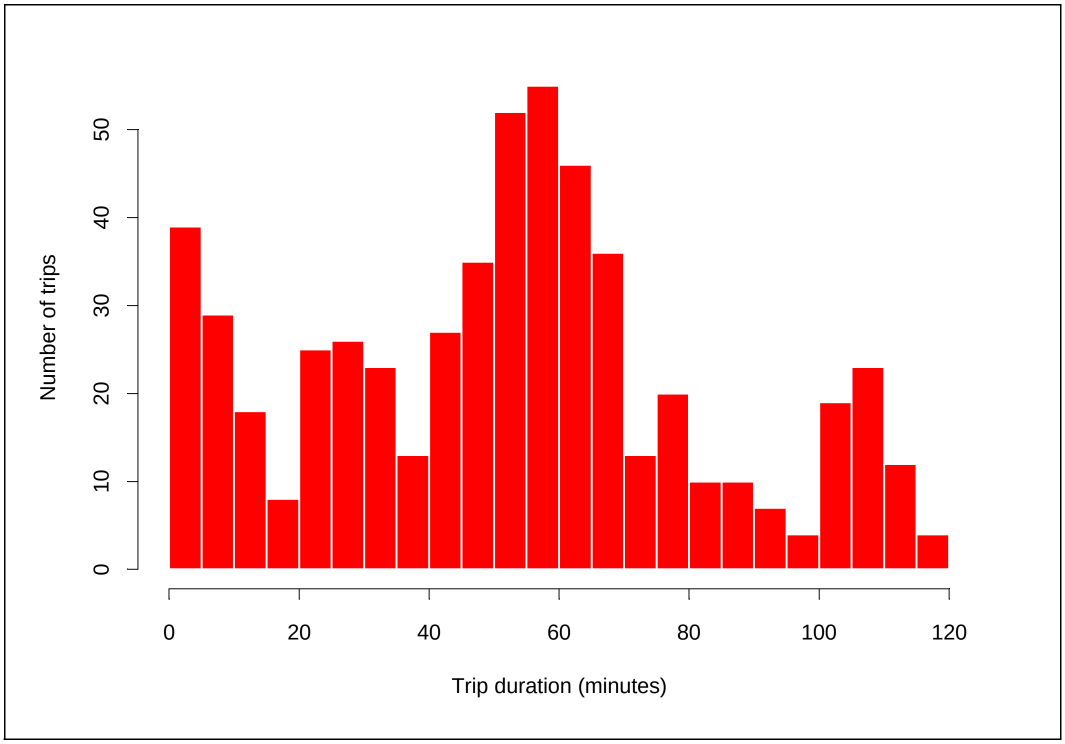


Figure 4: Average trip duration frequencies in New Mexico

not be available. Alternative sources of travel behavior data will have to be examined in detail before final recommendations for a trip generation model can be put forth. Based upon our work elsewhere, we suggest defining between three and five trip purposes. These should include at a minimum the following purposes:

1. *Commuting trips*, which are very similar to home-based work trips in urban areas. These trips typically account for about one-third of all intercity trips by auto. In addition to the ATS95, useful data about these trips are also available from the statewide Census Transportation Planning Package (CTPP). These trips may be split into home-based and non-home-based if sufficient data are available.

2. *Recreational and vacation travel* is often another large component of intercity travel, and has markedly different characteristics than other trip types. This will probably prove significant in Oregon. Unfortunately, data on these trips are almost non-existent; satisfactory results are usually obtained only by conducting traveler surveys to obtain the necessary data. The variability of these characteristics from one region of the country to another appears to be high, making the use of data from other states questionable.

3. *Personal business*, which includes shopping, school, medical or other professional service, and all other types of trips. In their recent work in Michigan, Costinett and Outwater (1996) found that these trips differ little in their incidence from urban areas. But in other models with fewer competing metropolitan areas surrounded by large rural areas, Donnelly (1992) found that such trips to the hub city are a large portion of the intercity flows. This trip purpose can be split between home-based and non-home-based generators, although the distinction is often not as important in intercity travel as it is in urban models.

The deficiencies of the traditional gravity model in intercity destination choice modeling might be overcome using discrete choice or simulation models. Indeed, the destination choice model used by major airlines in forecasting air travel demand is most often a Monte Carlo simulation. Such models will be applied using the statewide CTPP and other secondary data, as discussed in Section 3.1.

Recommendations:

1. The exact definition of trip purposes will depend upon the source of the secondary data used for model development. Three prototypical purposes have been identified based on work conducted elsewhere, and are recommended as candidate purposes for the Oregon model.

2. None of the data sources are likely to be rich enough to permit the modeling of travel below the daily level. The relatively low incidence of intercity travel may make weekly or monthly estimates of demand appropriate, with a reduction to average daily flows using traffic recorder trend data. We propose to initially attempt an average weekday model of intercity travel.

3. The work reported in the literature suggests that logit-based models of intercity travel demand perform better than traditional models. While the exact form of the final models cannot be known at this time, we recommend specifying nested logit formulations for trip generation and mode choice, possibly carried out simultaneously to preclude mode switching among individual tours. Two very different forms of destination choice models are plausible. Some researchers have suggested that the intervening opportunities model might be appropriate for intercity use, while others have employed logit models. We propose to examine both types of modeling approaches in detail, and to consider Monte Carlo simulation as an alternative to the latter.

1.5 Intercity Freight Demand Modeling

Freight models generally fall into one of two categories: *commodity flow models* and *truck models*. Commodity flow models are typically regional or national in scope, focusing on the flow of goods between markets. The flows are mode-abstract and measured in tons or dollars, a reflection of the fact that they are more commonly used in economic analyses than transport sector appraisals. Truck models, on the other hand, do not differentiate between commodities (or commodity families). They are usually no more than an estimate of truck movements as a function of land use variables, and as such are not very useful in policy analyses (they are insensitive to policy inputs) or long-term forecasting (as they fail to incorporate changes in technology, markets, or modal options). Neither type of model is entirely satisfactory for use in statewide planning, although a commodity flow model is more closely related to the type of integrated models being considered for Oregon.

We recommend a hybrid of these two separate modeling frameworks; the resulting model will be called a *freight model* so as to not confuse it with the other types. This approach is loosely based upon earlier work on a national commodity flow model in Canada, which formed the basis for the development of STAN, a multicommodity, multimodal modeling companion to EMME/2. In this hybrid approach, the flow of commodities are modeled using economic data. Models of trip generation, destination choice, and mode choice similar to that specified for the passenger model will be developed. These models will also be discrete choice formulations, and may also be combined where advantageous. Using seasonal adjustment factors derived from Oregon data and truck survey data, these flows (measured in tons) will be converted to truckloads for network assignment.

Whereas passenger movements are differentiated by trip purpose, commodity flows are broken down into commodity families with similar economic and transport characteristics. In order to make the modeling process tractable, the model will include between 10 and 12 commodity families. The development of a truly multimodal model is beyond the resources of this project. We propose to restrict the model developed during Phase II to the trucking mode, as its impact on the roadway system is usually of primary concern to public sector transportation planners. Note that the modeling framework established during Phase II, however, will be truly multimodal. The expansion of the model to cover other modes will be possible with the development of modal networks and their connections to the highway network, collection of mode-specific survey data, and refinement of the freight mode choice model.

The primary source of data for the freight models will be the 1993 Commodity Flow Survey (CFS93), conducted by the U.S. Bureau of the Census. The survey describes the commodity, vehicle, and shipper characteristics of the mining, manufacturing, and selected wholesale sectors of the economy. As noted below, we will assume that these data will become available by December 1996. Because the CFS93 data will only portray flows at the state level, data from input-output accounts will be used to allocate movements to zones within the state. This approach complements the proposed economic and land use models, in that the same input-output structure will be used elsewhere in the modeling chain. By virtue of design, the data required for the freight model is the same used in all other components of the integrated statewide model. The CFS93 and input-output data must be supplemented with truck survey data collected in Phase II (described in Section 3.2). These data will be collected at several weigh stations in Oregon, and will include weight, vehicle classification, commodity classification, and origin-destination data. Because all commercial vehicles must stop at weigh stations, these surveys will be easy to design and quite inexpensive to conduct.

1.6 Transportation Supply Modeling

The demand for person and freight movements will be modeled separately but in parallel, and combined for route choice (traffic assignment). Both classes of demand will be assigned to the same highway network using a multiclass auto assignment technique. Each class will use separate link cost functions (reflecting their differing perceptions of the same network) while being simultaneously assigned. This will allow their cumulative effect to be assessed while maintaining the ability to analyze the flows of each class separately.

Congestion is rarely a factor in rural areas, and consequently not often a factor in intercity route choice modeling. Moreover, many trips have only one or at most a few competing paths, obviating the need for a sophisticated network assignment technique. We have generally found the all-or-nothing network assignment technique adequate for models of the type recommended in this document. Using the all-or-nothing technique as the starting point, we will examine the improvement gained through the use of stochastic and user-optimal static equilibrium assignment models.

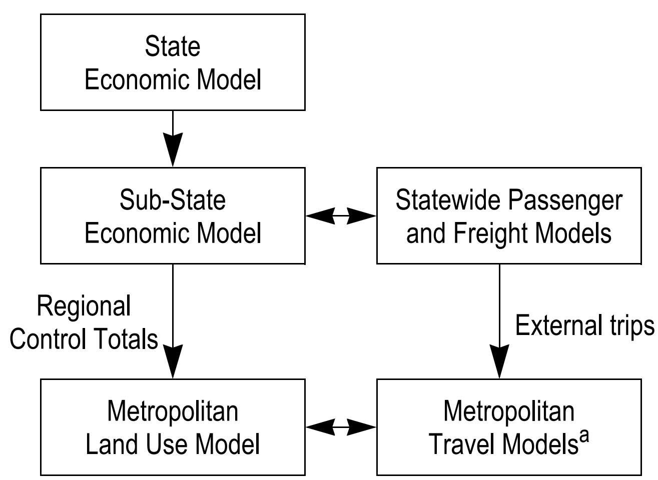
1.7 Land Use Modeling

The development of a prototype metropolitan land use model shares several considerations discussed in the recommendations for the substate economic and demographic and statewide transportation models.

Issues: The prototype land use model applies, however, to the distribution of population and employment among transportation zones within a single metropolitan area, whereas the substate allocation model applies to the entire state of Oregon, and allocates activity to locations no smaller than counties or metropolitan areas. The sub-state economic and demographic models will generate population and employment totals by county and/or metropolitan area for use on statewide transportation planning and policy analysis applications, as well as being used as regional control totals for the metropolitan land use model. The statewide passenger and freight models will likewise generate external trips for use in the existing metropolitan travel models. The metropolitan land use model to be developed within the scope of this project will need to link to the existing metropolitan travel models, in an iterative manner described earlier as a semi-integrated approach. In the long-term, more completely integrated metropolitan land use and travel models could be designed, but will clearly require redesigning the travel models, which lies beyond this scope of work. The relationship between the various model components covered in the Scope of Work is shown in Figure 5.

Discussion: The requirement to develop a prototype land use model for substate applications in Phase III suggests a potentially different approach than that used at the statewide level. At the statewide level, we are dealing with economic exchange between metropolitan areas, or counties. We are not dealing extensively with travel that can be characterized as home-to-work commutes. The exchanges are more likely to be based on the interactions between metropolitan economies, such as the shipment of goods and services from one economic sector to another. Passenger travel is likely to be of a substantially different character than intra-metropolitan daily travel behavior. Locational choices of businesses and households within the same metropolitan area are likely to be treated as much more similar substitutes than residential or business moves between metropolitan areas. These observations suggest that the underlying behavior of location and travel are substantially affected by the scale of the analysis, and that the models and approaches chosen at the statewide and metropolitan levels should be sensitive to these differences.

The TRANUS and MEPLAN models, reviewed in the context of the statewide models, appear to lend themselves well conceptually to application at a geographic scale suitable for state-



a. Existing metropolitan travel models in EMME/2 developed under previous ODOT project.

Figure 5: Relationship between the statewide and metropolitan models

wide modeling (e.g., counties or metropolitan areas as the zonal structure). Since these models are based on economic interchange between zones that represent interacting economies, the use of this type of model seems particularly appropriate for representing the economic interaction between the metropolitan areas or counties. Freight and passenger flows are generated as a result of basic levels of economic interaction between sectors of the metropolitan economies that are importing and exporting goods and services to each other.

When we focus on locational and travel behavior within individual metropolitan areas, however, the concept of transportation zones representing small economies importing and exporting goods and services to each other seems less natural and intuitive, even if we concentrate on the export of labor from the residence to the workplace. The modeling approach used by both MEPLAN and TRANUS seem less amenable to the kinds of flexible policy analysis, and high levels of geographic detail that might be required to support some of the policy analyses desired by MPOs within the State of Oregon. Typically, both of these models have been applied to zonal systems with no more than 30 to 50 zones. Analysis of transit access (and many other policy issues), on the other hand, may require very high levels of geographic detail in order to begin to characterize transit access realistically. For these reasons, we discount the use of TRANUS or MEPLAN as the primary focus of development of a prototype metropolitan land use model.

Other existing land use models that could be considered for use in this project include the DRAM/EMPAL models developed by Stephen H. Putman. It is our recommendation, based on the requirements for policy analysis identified in the scope of work, that a requirement of any model system to be considered for application to this project is a representation of the land market. Without that, crucial issues such as the impact of transportation improvements on land prices, or the impact of housing prices on residential location choices, simply cannot be addressed. Due to the absence of any land market component, or of any economic component of any sort that could support the required policy analyses, we dismiss the DRAM/EMPAL models from further consideration.

The strategy described in the original proposal is based on the modeling approach shown in Figure 2. This modeling approach has several aspects that are attractive for this project. First, it is behaviorally based, using random utility theory and implemented with nested logit models. Second, it incorporates an endogenous land market, so that analysis of policies that relate to land and housing prices can be undertaken, and to more realistically model the locational behavior of households and businesses. It is an intuitive and integrated approach that models the discrete mobility and location choices of households and businesses, and the development choices of developers. In addition the decisions of public policymakers can be explicitly modeled, either as imposing constraints on choices (e.g., through zoning), or by influencing prices (e.g., of development, through taxes, development impact fees, etc.).

Recommendations: We propose using the land use modeling framework embodied in the TRANUS model for the statewide modeling work to be completed in Phase II. We feel this approach will prove inadequate for use in substate modeling, and propose to develop a set of models based upon an earlier specification developed by Waddell. The model components proposed include demographic transition, household mobility and location, economic transition, business mobility and location, developer behavior, accessibility, and a land market clearing model. An additional software module for policy analysis would provide the primary interface to input policy assumptions and to evaluate outcomes.

2.0 Major Data Elements

A variety of data will be required for model development, testing, and application. In this section we anticipate the data requirements and their likely source(s), make a number of recommendations about data storage and retrieval, and the development of capabilities for information and data sharing. The latter aspect is an important design consideration; the inability to easily view and share data between the ODOT and MPOs will make the modeling process more cumbersome and reduce its utility to both parties.

2.1 Data Requirements for Model Application

A variety of data will be required for model application, many of which will come from sources outside of ODOT. Because we envision using an integrated land use-transportation model, many of the data will be used by more than one module, thereby eliminating duplicative data requirements. These data can generally be divided into two groups: network data and activity information. The former group includes a representation of the multimodal networks upon which the flows of people, vehicles, and goods will be arrayed. We have previously proposed to focus upon highway-based modes of transport in Phase II, a recommendation we continue to advance in light of the schedule requirements for the project. As noted earlier in Section 1.2, this network will focus primarily upon Oregon roadways, but will retain enough detail in adjacent states to realistically portray movements between them. Finally, a skeletal highway network corresponding to major elements of the Interstate highway system will be used outside of the Pacific Northwest; this peripheral network will be considerably more important in freight modeling than for person trip modeling. A listing of network attributes likely to be useful in statewide modeling is shown in Table 2.

Considerably more data will be required for the person and freight travel demand and land use models. Demographic and economic forecast data will be required at the county level, as noted in Section 1.2. The level of detail required is primarily driven by the land use model. The travel demand models will require the same type of information, but will probably use these data at a more aggregated level of detail than the land use models. This will be especially true in the substate modeling realm, where much richer GIS data will be required for model application.

The broad categories of activity data required for model application are depicted in Table 3. These data can be further divided into five categories, reflecting their scale and likely sources. The first group, regional forecasts, will be used to allocate regional changes in households and employment. As shown in the Table, the required data items consist of an inventory or forecast (for base year or future modeling, respectively) of the total number of households and employment by industry. Employment will be further broken down by size of industry. Households will be further divided into groups by head of household age, income group, and whether children are present. Other groupings may suggest themselves during model development and will be included as appropriate.

A land use database will be developed that maintains an accounting of households, housing, employment, non-residential space, land use, and prices. In order to capture information about household characteristics needed to predict location, mobility, and travel behavior, households will be stratified by various characteristics. As mentioned previously, these might include age of head of household, whether children are present, number of workers, income group, and housing tenure. These data will ideally be obtained from MPO and county sources, but several candidate synthetic methods can be employed to generate such data in cases where these data are lacking

Table 2: Prototypical highway network attributes

Classification	Exogenously supplied information	Endogenous data
Highway network	upstream and downstream nodes shaping nodes (optional) link length direction of flow eligible modes of transport functional classification area type (urban, suburban, rural) number of lanes by direction posted speed limit average weekday traffic average daily traffic average weekday truck traffic average daily truck traffic	freeflow travel time daily automobile flows daily truck flows daily intercity bus flows
Intermodal terminals	location (coordinates) modal orientation (bus terminal, airport, truck terminal, etc.) average daily movements arrival and departure profiles	mode change opportunities (e.g., auto to bus, all to air, etc.) service rates arrival and departure distributions daily flows

below the county level. One such technique based upon the use of the Public Use Microsample (PUMS) data has been proposed by Beckman, et al. (1996).

These characteristics are each important in predicting mobility, location, or travel behavior. Age of household head captures one aspect of life cycle, and other household characteristics are likely to be affected by age. The presence of children influences the choice of residential location and travel behavior. Tenure affects mobility, location choice, and travel behavior. In addition to these disaggregate effects, their aggregate nature affects the attractiveness of the neighborhood versus all other neighborhoods. Keeping track of these household characteristics will enable us to provide a rich neighborhood context that adds realism to the location choice model.

Employment will be stratified by establishment size and industry. These data can be aggregated to the 1-digit SIC level for most applications, although the freight model will require 2-digit SIC data for the manufacturing, mining, and wholesale industries. We will analyze the County Business Pattern data to determine the levels of detail attainable in Oregon counties. Establishments will be classified according to the groupings used in the County Business Patterns (see Table 3), but may be collapsed if subsequent analyses determine that such detail is not required or available.

The development of the base year land use file will require integration of several data sources and a procedure to estimate their joint distribution. Household information is available at a small area level in the 1970, 1980, and 1990 Census STF1A and STF3A files, but insufficient information is available about joint distributions of household income and structure and the allocation of households to housing by type. The household travel surveys currently being conducted in Oregon will provide the primary data source for calibrating the residential models. Household records

Table 3: Prototypical activity groups and attributes

Group	Scope	Attributes	Source(s) of Historical Data[a]
Regional Forecast	Counties within Oregon, states outside of Oregon	Households by income group, head of household age, children present; employment by 2 digit SIC	Population: Census data and Public Use Microscale (PUMS) data; Employment: County Business Patterns
Land Use Data	Activity nodes within counties in Oregon	Households, housing, non-residential space, and land use; households stratified by income group, age of head of household, tenure, number of workers, and presence of children	County, MPO, or local land use and housing data if available; use synthetic methods calibrated with Census and PUMS data to allocate county-level data to activity nodes in the absence of local data
Employment Data	Activity nodes within counties in Oregon	Employment by 1 or 2 digit SIC by establishment size (based on number of employees: 1-4, 5-9, 10-19, 20-49, 50-99, 100-249, 250-499, and 500 and above)[b]	County, MPO, or local employment, business registration, and/or taxation records if available; use synthetic methods in the absence of better local data
Committed or Proposed Development	Activity nodes or counties within Oregon	Size and type of establishment or development and anticipated date of opening	County, MPO, or local data
Non-movers (businesses only)	Activity nodes or counties within Oregon	A parcel or specific establishment in the Land Use Data may be flagged if MPO or local data are sufficiently detailed to permit it, or as a subset of employment by industry and establishment size can be isolated in the Employment Data.	Ad hoc specification by the user, based either on County, MPO, or local data, or modified by the user for scenario testing of such effects

a. Forecast data for future years will come from models based on these data.

b. These categories are used in the County Business Patterns, and may be collapsed as appropriate for use in the model if warranted by model calibration results or data availability problems.

provide full descriptions of the demographic and economic structure of the household, as well as their housing characteristics and location. GIS techniques will be used to augment the data available directly from surveys with detailed spatial descriptions of neighborhoods and locations occupied by the households.

In addition to the land use data noted above, a database of known or anticipated development projects by activity node or municipality may be used, if available, to add to the supply of new construction in any forecast time interval. It will be treated as an exogenous policy input. The user may also wish to identify major businesses or institutions that will be excluded from the business mobility and location choice models. These can perhaps be identified as "non-movers." They might either be flagged in the land use database or as a subset of the employment by industry and establishment size for the county in which it is located.

2.2 Data Storage and Retrieval

We recommend using a standard SQL-compliant database management system (DBMS) as the repository for the data to be used by the statewide model, and making direct reads and writes to the DMBS. Candidates include Microsoft SQL Server and Oracle, both of which are currently in use by ODOT. We further recommend that the data be accessible from a GIS component, such as ArcView or VistaMap. The concept of linking the land use models and travel models together through a GIS and DBMS that is shared between them is an attractive long-term vision. Even if the existing metropolitan travel models are not redesigned in the short-run to take advantage of this direct linkage, implementing the land use model with this framework would provide immediate benefits and long-term integration potential.

The difficulties of selecting an appropriate GIS platform for integration with the models is discussed in Section 4.1. ArcView appears to be a more flexible choice than VistaMap, and other options lag behind these two. There appears to be an additional option, however, that shifts the focus from the GIS software platform to the data. ArcView supports two data formats: the native ARC/INFO format, which is a proprietary format, and the ArcView shape file format, which is an open format with published specifications. If the shape file format is used, then several options are available. First, ArcView can read the files as native data. Second, the MapObjects toolkit from ESRI allows the embedding of GIS functionality directly into custom-written software. This allows complete and seamless integration into the modeling software system, without additional overhead associated with a standalone GIS software package.

The issue of translation between the ODOT Intergraph GIS and the MPOs data in ARC/INFO have become much more straightforward recently with the advent of new software for bidirectional translation. The British Columbia government commissioned the development of a neutral GIS format called SAIC, with a public domain translator between the SAIC format and ArcView shape files and between SAIC and Intergraph Design Files. The public domain product is called FMEBC. Safe Software, the company that developed FMEBC, has further developed the product commercially as FME, with direct bidirectional translation between Intergraph and ArcView, and several other formats. Support for ARC/INFO Export and MGE formats is forthcoming. In addition, the FME product can be linked to a spatial data warehouse using ESRI's Spatial Data Engine (SDE), and made accessible via the Internet using a Web browser.

2.3 Information Sharing

An important goal of the project will be to facilitate the electronic exchange of information between the ODOT, MPOs, and other users. We have proposed to use the Internet as the primary vehicle for such exchanges. We recommend the development of a prototypical user interface, written in the Java programming language, that will provide a “front end” to the modeling components and data. This interface will be installed on the ODOT World Wide Web home page, and will permit users both within the Department and outside of it to obtain documentation; run predefined SQL queries that will retrieve, update, and summarize input data; enter model run data and execute the model; and to query and receive data for output visualization.

In contrast to our Proposal, we recommend that the development of the prototype Internet interface be deferred until Phase III. Maximum attention should be focused on making the models operational during Phase II, and efforts to design an Internet interface (or any other interface for external users) will distract from more fruitful model development work. This is not to imply that the interface will be an after-thought; the design of the modeling suite will proceed with the interface as an integral part of the design. Rather, we are suggesting that its implementation be delayed until later in the project.

3.0 Data Collection Requirements

Our initially proposed approach for this project was predicated upon the availability of two sources of travel behavior data beyond the control of either the client or the consulting team: the 1995 American Traveler Survey and the 1993 Commodity Flow Survey. They represent the best known sources of survey data on current intercity passenger travel and freight movements. At the time of the consultant proposal, both were slated to be either available at that time or shortly thereafter. Since then the anticipated release date for the ATS95 has slipped into 1997. Several state level summaries of the CFS93 have been published, but the release date for origin-destination data and other summaries suitable for model development have been pushed back again. At this writing these products will not be available until the end of 1996 at the earliest. Given the frequency with which past deadlines have not been met, one cannot be optimistic that the current deadlines will be achieved.

3.1 Person Travel Behavior Data

Issues: The inability to obtain the ATS95 data is of particular concern to us. In addition to doubts about its availability, concern is also warranted about its utility. Unlike other secondary sources of information used in previous modeling work[7], this survey has never been conducted before (and therefore never used in model development). It was hoped that the data would be available at the outset of this project in order to assess it’s utility. Aside from obtaining a copy of the questionnaire, that has not been possible. While the statewide Census Transportation Planning Package (CTPP) will be useful for studying commuting flows, no comparable source of information exists for non-work trips. Non-work trips typically account for the majority of intercity passenger movements, so the need for information about them is crucial.

Discussion: There are at least two potential sources of secondary information which may be adequate replacements for the ATS95. The first is the 1996 Oregon Travel Behavior Survey (OTBS96), from which 2-day travel diaries were obtained from 3,400 households in non-metropolitan areas across the state. Designed to complement a similar survey in the Portland metropolitan area and other MPOs, it collected information on all daily activities by each household

7. Examples include the Nationwide Personal Transportation Survey, the statewide elements of the Census Transportation Planning Package, and the 1977 and 1983 Commodity Transportation Surveys.

member. For activities involving travel, the mode of transportation, departure and arrival times, and origin-destination information were collected. There is also external station origin-destination survey data available from the MPOs which may have utility in model estimation. Combined with the Portland area and MPO survey data, it should be possible to obtain a complete picture of tripmaking by Oregon residents.

There are two potential problems with using the OTBS96 data. The number of intercity trips in the survey is likely to be quite small, precluding rigorous statistical analyses. The same is likely true of the Portland survey. More importantly, household surveys miss the sizeable number of trips which are not made by Oregon households.[8] This group would include all tourists and business travelers, commercial trips, and trips passing through Oregon. The external station surveys may fill some of this void, but additional means of obtaining information about these types of trips may be required.

A second source of secondary information, which may provide data for all trip purposes, is survey data and results obtained in other states. The State of Vermont has collected extensive data on personal and truck travel within and through the state (Crevo, *et al*., 1995; Virkud and Keyes, 1995). These data were subsequently used to develop a statewide travel model. The Indiana DOT is currently conducting a household survey to obtain data on intercity tripmaking. The Michigan DOT also has intercept survey data from many locations across the state, which date back over 25 years.[9]

These surveys can provide useful information in at least two ways. They can provide information on average intercity tripmaking rates by trip purpose. While there will be inconsistencies in the definition of trip purposes, a useful comparison should still be possible. These findings will provide a reasonability check on the OTBS96 results and will inform us about the nature and extent of travel not captured by the survey. By contrasting the different surveys it may also be possible to discern the variability in intercity trip making between states.

Even if these surveys provide reasonable and consistent trip rates, they may not be appropriate for use in Oregon. The spatial patterns of settlement and the dense intercity roadway networks of Vermont are quite different from Oregon, which probably results in different travel behavior and may preclude the direct use of their survey results. While Indiana and Michigan are closer to Oregon in size, in many areas they are more urbanized than Oregon and have competing regional hubs. Without comparable survey data from Oregon such conjectures cannot be studied further. These factors should be kept in mind, however, when considering the use of data from other areas.

Recommendations: Unless these secondary sources provide an unexpected wealth of information about tourism and recreational travel to popular national parks, modeling this component of travel in Oregon will require primary data collection. Relying upon patronage counts from several popular destinations within Oregon, we can estimate the seasonal variation in these trips. An intercept survey, conducted at the tourist and recreational destinations, can be directed at the population of interest. But since the land use and travel demand models will operate at the household

8. It is assumed that all Oregon households had an equal chance of being surveyed by one of the two travel behavior surveys, and that any non-home-based travel made by household residents would be reflected in the survey. It is also assumed, however, that a trip to or from the household by someone other than a resident would not have been captured in the survey (unless they possessed a travel diary for their own household).

9. These data are unfortunately not reported in the literature, although the Michigan DOT has collected them since 1968. Many of the data prior to 1988 are no longer retrievable and there are some limitations on the utility of the data, owing to a lack of a systematic survey sampling procedure. Despite these limitations, however, they represent the earliest and most ambitious intercity passenger surveying program we've found.

level, mechanisms to covert the results to such units will be required. This will entail the collection of more household and demographic data than might ordinarily be the case for intercept surveys. Because the collection of passenger travel survey data was not included in the proposal (the ATS95 should have an adequate sample of trips to national parks and seashores), the collection of these data will require reducing work in other areas in order to accommodate the additional costs.

3.2 Freight Data Collection

While trucks carry the largest share of goods between urban areas, both in weight and dollar terms, they are also the mode of transport for which the least amount of data are available. We initially proposed to limit the modeling of freight to truck movements for this contract, with the expectation that other modes will be added in the future. It was assumed in our cost proposal that intercept surveys of trucks at Oregon ports of entry would be required during this study. Such surveys are the only comprehensive source of average load weights by commodity and distance range, and will provide data on short-haul and less-than-truckload (LTL) movements not reflected in the CFS93. The risk of not obtaining the CFS93 in time for this project, coupled with findings from a pilot survey in Oregon, raises several issues with respect to freight data.

<u>Issues:</u>

1. A pilot survey has been conducted at the Woodburn Port (between Portland and Salem on I-5) which revealed that detailed origin-destination data cannot be collected without seriously disrupting traffic operations. In all other locations we can employ typical intercept surveying techniques to collect the required data.

2. There are no known substitutes for the CFS93 data. If they are not available by late fall 1996, the chances of successfully building a commodity flow model within the project timetable will be seriously jeopardized.

<u>Discussion:</u> The high volume of truck traffic moving through the Woodburn truck weigh station—perhaps the most important survey location given its proximity to Portland and its position between Portland and the urban areas to the south along I-5—suggests that a hand-out, mail-back survey might be the most appropriate survey instrument. A number of recommendations have been made[10] which should improve the response rate and allow us to control the non-response bias. We recommend completing a test survey based upon those recommendations within the next three months. If the hand-out, mail-back technique suffers from an unacceptable response rate, methods for conducting intercept surveys will be tested and refined for use at Woodburn. In order to ensure a high enough response rate, we anticipate using an intercept survey at the remaining ports in the state.

The truck surveys were intended to complement the CFS93; neither is an adequate substitute for the other. The currently projected release date for the data will delay the development of the truck model, which can be accommodated within the present project schedule. If the data do not become available as scheduled, a substantial impact on project schedule or products should be anticipated. The CFS93 is unique in that it is a survey of shippers, and will allow us to construct demand models stratified by industry group. Such a taxonomy will also facilitate the interaction of the freight model with input-output or other macroeconomic models. There are no other

10. The techniques include (1) writing to trucking associations and registered carriers describing the survey and asking for their cooperation, (2) the coding and retention of license and vehicle classification data prior to giving the survey form to the trucker, (3) including a brief description of the survey purpose with the form, and (4) sending a follow-up reminder letter requesting the information.

sources of such information, save for previous versions of the survey. The most recent predecessor was conducted in 1983, and has never been officially released due to serious data problems and low response rates from certain industries. The 1977 survey has been widely used in freight model estimation but is widely acknowledged as being too dated for current use.

Without the CFS93 data, our options are limited to building a truck model based solely on the weigh station surveys or forgoing freight modeling in Phase II. If a truck model is constructed from the port survey data only, it will be divorced from the remainder of the travel model. The implications include the requirement to forecast future flows of passengers and freight from different data, and accepting that the truck model will be insensitive to policy and economic variables that will drive the land use, economic, and passenger transportation models. The option of forgoing freight modeling altogether would allow the resources that were planned for it to be applied towards collecting additional person travel data, which is presently unbudgeted.

Recommendation: Our recommendation is to assume that the CFS93 data will be available by December 1996, allowing the proposed development of the freight model to proceed as planned. This option should then be re-examined in late 1996, at which time alternatives can be considered if the data remain unavailable. Intercept surveys of trucks at selected truck weigh stations should also be collected in order to obtain data on average load weights and to capture truck trips not accounted for in the CFS93.

4.0 Model Implementation and Geographic Information Systems

Important decisions must be made concerning the implementation of the statewide model. There are very few integrated land use-modeling packages available in the marketplace; most have proprietary bonds to their developers and often the internal workings of the model are not divulged. None appear to be ideally suited to the modeling approach recommended for Oregon. The alternatives are GIS-based solutions: developing a customized modeling system using available software components and tools, or mating a traditional transportation modeling package with a GIS system. The merits of each approach are discussed in this section.

4.1 Geographic Information Systems

Both transportation and land use activities are spatial activities by their very nature. Viewing data about such activities in their spatial context aids in comprehending and communicating patterns and trends that traditional analysis techniques cannot match. Moreover, many of the data required for model application will be available only in GIS format. The ability of GIS to handle and merge data from heterogeneous sources is an important asset, as data used in statewide modeling will come from a variety of agencies in different formats and locational referencing systems. We envision GIS serving as a “melting pot;” data required by the model will be assembled and integrated within the GIS prior to its entry to the modeling process. The output of the modeling process may also be passed through GIS for merging, display, and dissemination.

Issues:

1. The need to provide GIS capabilities to statewide model developers and users without imposing a high cost in terms of training, hardware and operating system requirements, and data translation from one vendors format to another.

2. The ideal GIS would of course be the one that the users (ODOT planning staff and MPOs) already have access to and are trained in the use of. Unfortunately, ODOT uses Intergraph MGE, while all other state agencies and the MPOs use ARC/INFO.

3. We must make maximum use of existing data and coverages, not develop a new GIS system. The project is primarily a model development effort; GIS development work should be limited to the functionality required to complete the project.

Discussion: The requirement for GIS capabilities to build, maintain, and apply the statewide model has been already discussed. The key question then becomes to what extent the statewide model is implemented within the GIS, as opposed to outside of it. The Statement of Proposal suggested a modeling system built from readily available software tools, using a GIS package as the backplane upon which they'd be arrayed. Computer programs would be written to implement those functions not available within the GIS environment, such as logit model applicators and summary programs, network checking programs, and some components of the land use models. This places a considerable burden on the GIS.

The candidate GIS must be able to build and store hierarchical transportation networks upon which flows can be routed, traced, and summarized. One litmus test is the ability of the GIS to build a skim matrix[11]; without this capability transportation network analyses cannot be undertaken. This requirement effectively limits the competition to three packages: the ESRI family of products (ARC/INFO and ArcView), the Intergraph family of products (MGE and VistaMap), and TransCAD (produced by the Caliper Corporation). Additional criteria we consider important in selecting a candidate GIS, as well as rankings we assigned to these categories, are shown in Table 4.

The ODOT uses the Intergraph MGE system running under the Microsoft Windows NT operating system, while all other state agencies and all of the MPOs use ARC/INFO running on Unix workstations. At the present time the ODOT Transportation Development Branch (TDB) does not have GIS capabilities, although they are actively seeking to obtain them. A decision must be reached soon on which of these two packages should be used, both by the TDB staff and for this particular project. The decisions are and should be intertwined; there is considerable obvious benefit to introducing only one GIS into the TDB.

The decision might ordinarily be restricted to the two systems in current use. However, neither have very compelling transportation analysis capabilities. TransCAD is unquestionably better suited to transportation applications and is therefore included in our evaluation. In addition to the traditional GIS tools and framework, TransCAD includes a large number of network assignment and analysis modules, and has procedures for implementing the classical travel demand models. It has been successfully applied in statewide modeling in Michigan, although not without its share of problems and limitations.

A new version of the software, written for the Microsoft Windows operating systems, is a vast improvement over the previous version. The software and documentation have been extensively rewritten, a powerful scripting language has been added, and the user interface has been radically improved. Despite these improvements, however, there remain some limitations. The matrix handling functions are limited and unchanged from the previous version. The program still performs many functions very slowly even on the most powerful microcomputers available, and requires a large amount of memory (64 MB at a minimum, probably 128 MB for acceptable performance on large problems).

Despite these limitations, TransCAD can probably accommodate all of the requirements for this project. Functions which are not supplied by the vendor or easily implemented in their script-

11. A matrix of zone-to-zone travel cost (typically travel time or distance), obtained by summing the desired attribute along the shortest path from each zone to all other zones.

Table 4: GIS evaluation criteria

Criteria	Score Range[a]	ArcView	ARC/ INFO	VistaMap	Intergraph MGE	Trans-CAD
Compatibility: Is the package used by the ODOT planning staff and MPOs in Oregon? Can it run on hardware they already own and for which support is available within their organization?	1-5	3	1	3	3	1
Ease of Use: Is the software easy to learn and use? Although a shell could be constructed which isolates the user from the code required to operate the statewide model, the ability to provide such does not discount difficulty in use, as it will limit the user who desires to modify or extend the model.	1-5	5	1	5	1	2
Extensible: Does the vendor provide an open architecture, particularly with respect to data import and export? Can external processes directly access these data? Does the vendor supply developer toolkits?	1-5	4	5	3	2	4
Cost: How expensive is the software and how expensive is it to maintain (are specialized personnel required)?	1-5	5	1	4	2	3
Overhead: Does the software impose special hardware or operating system requirements? Will it run unmodified on a typical ODOT desktop microcomputer?[b]	1-5	5	1	5	1	3
Network Representation: Can transportation networks be represented within the package? Does the package include capabilities for building travel time matrices and performing network assignments?	1-5	1	4	1	2	5
Total Score	6-30	23	13	21	11	18

a. The score range values are 1=Poor or non-existent, 2=Fair, 3=Good, 4=Excellent, 5=Outstanding.
b. Computer equipped with a 1 GB hard disk, 120-133 MHz Pentium processor, and 16-24 MB of random access memory.

ing language can be constructed using C++ or other object-oriented language and linked into the software. That is fortunate, because the downside of TransCAD would be that it supplies only the network analysis and rudimentary GIS tools required for this project; virtually all other elements of the transportation and land use models, in addition to the economic model and its interface, would have to be written outside of TransCAD.

We also gave TransCAD low marks for compatibility. The package is not used by any agency within Oregon, and none are contemplating adopting it. While it is not as difficult to master as ARC/INFO or MGE, it does incur a steep learning curve. A substantial amount of work would also be required to build translators between existing data and GIS coverages. While TransCAD provides the capability to read and write files in other formats, they often prove unreliable in practice. Even when they work they often do not produce the expected or desired results. Finally, the software is expensive, as is the hardware required to use it.

A variety of GIS products are available from Intergraph. The ODOT uses their MGE platform for most GIS work, and VistaMap for simple query and display requirements. The MGE suite is a full-feature GIS, although its capabilities for transportation network analyses are the weakest of the three product families considered. In all other relevant areas it matches the capabilities and limitations of ARC/INFO: it has a steep learning curve, is relatively expensive to acquire and maintain, and imposes a heavy overhead in terms of hardware and systems administration requirements. It principal advantage, and the only area in which we view it as superior to either TransCAD or the ESRI products, is that ODOT owns, uses, and appears to be quite committed to it. To the extent that many of the data useful to the modeling effort reside within the ODOT databases and geographic coverages, using MGE to be able to read and write the data in its native format is quite appealing.

VistaMap is considerably easier to learn and use. It provides users with a subset of GIS capabilities, namely the ability to query, extract, and display data from Intergraph databases and geographic coverages. It is designed to operated in a client-server environment, and allows the user to create reports and graphical displays of data. It does not permit the user to create or modify the underlying data. This type of data visualization tool has far more utility for the application at hand: it is considerably easier to learn and use, eliminates the overhead of GIS components not likely to be used by transportation modelers, and can operate with fewer hardware resources. As can be seen in Table 4, it ranked much higher than the more complex MGE option.

ARC/INFO has many of the same strengths and weaknesses of MGE, and it fared about as well in our evaluation. It's transportation network analysis tools are more refined and provide more extensive capabilities than does MGE Network, which is reflected by their relative scores. Unlike MGE, ARC/INFO is available only on Unix workstations[12], a significant drawback also reflected in its score. Its adoption by user agencies is, like MGE, one of its strengths. In fact, every MPO and state agency outside of ODOT uses ARC/INFO as their GIS platform. Maintaining compatibility with those organizations and their data are also an important selection criteria. However, like MGE it is too complex and demanding to be of use in this project.

ArcView is similar to VistaMap, providing data query and visualization capabilities within a small, compact program. It is, however, far more flexible than VistaMap. Not only does it have a built-in scripting language almost as powerful as TransCAD, but a programming interface known

12. ESRI has announced plans to port ARC/INFO to Windows NT, but at this time we cannot ascertain the status of the conversion nor obtain an estimate of its expected shipping date. We feel that decisions should be made on the basis of software and hardware currently available to the ODOT in order to maintain the project schedule.

as MapObjects (an OLE component toolkit) is also available. The resulting power and flexibility to integrate other applications and data stands out as an important asset. Designed to facilitate geographical queries on remote data, it also does not carry the overhead of a full GIS package. One can learn how to use it in one afternoon. An optional Network Analyst module is available, but appears to fall far short of the functionality provided by TransCAD or any other transportation modeling package. ArcView would prove immediately useful, as it would provide access to the wide range of geographic data available outside of ODOT. Many agencies already use ArcView, eliminating the need to introduce new software.

Recommendations: Each package has its own strengths and weaknesses. We recommend using ArcView as the GIS platform for this project for several reasons. Its previously cited flexibility, both in terms of its scripting language and MapObjects, makes the package very attractive from a model implementation standpoint. Virtually any modeling component not available as part of ArcView can be written and incorporated into the framework. It comes the closest to providing the flexible GIS backplane that we envisioned in the Proposal.

We believe that using ArcView will provide an easier-to-maintain GIS interface, as data translation from the ODOT's Intergraph system would only be done once, when importing geographic coverages from the Mapping Section's most current data. It is not anticipated that these data would have to be imported often; most of the attribute changes in highway network data do not affect the model and will not necessitate changes in the transportation modeling networks. The advantage of such an arrangement is depicted in Figure 6, which highlights the degree to which a single translation point will reduce the software application and maintenance overhead. The same analogue could also be extended to TransCAD, where translation would have to occur on all linkages between the statewide model and external data sources.

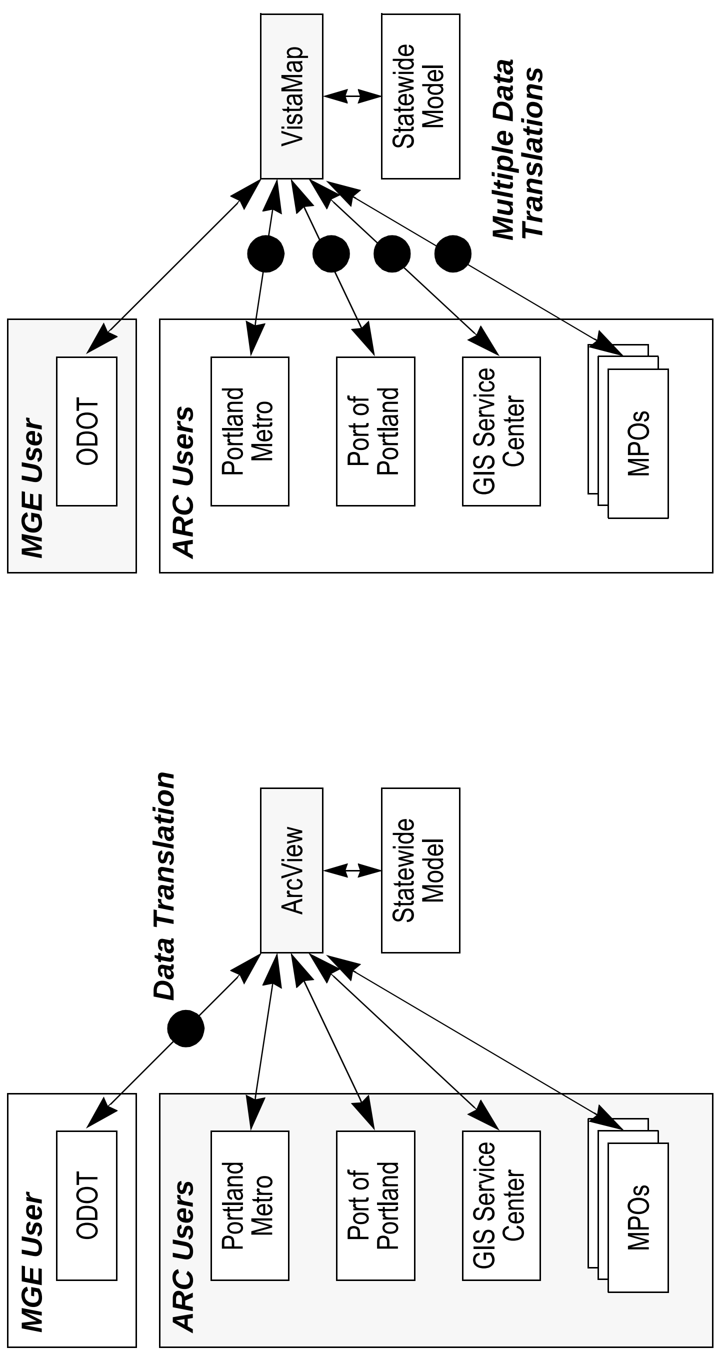
4.2 Land Use-Transportation Models

Of all of the integrated land use-transportation models reviewed, only two (MEPLAN and TRANUS) appear to have been applied to a wide range of studies. There are also a number of separate land use and transportation models in existence which might provide some of the desired functionality. In this section we present a cursory evaluation of the available software platforms and offer recommendations for the Phase II approach.

Issues:

1. There are only a handful of integrated land use-transportation models in existence, most of which have proprietary ties that limit their flexibility.
2. A decision must be made whether to use an existing land use-transportation model, add land use modeling components to an existing transportation model, or write the software to implement a new model, such as proposed by Waddell (see Figure 2).

Discussion: Commendable progress has been made in the development of statewide travel forecasting standards in Oregon, which are supported by the ODOT and the MPOs. A considerable amount of work has gone into training, data collection and analysis, and the development of a common modeling protocol across the state. All transportation modeling within Oregon is carried out using the EMME/2 package, widely regarded as the most flexible and innovative transportation modeling package available. By contrast, there are no known operational land use models in Oregon, although work is underway by the Portland Metro to build one for the Portland metropolitan area.



In the case where Arcview is used as the GIS for the statewide model integration, data translation from MGE to ARC format occurs only twice (once in each direction) but only along one link.

In the case where MGE or VistaMap is used as the GIS component, data translation from MGE to ARC format occurs at least eight times (once in each direction) and along at least four links.

Figure 6: Data translation requirements

A set of evaluation criteria similar to those used for GIS are presented in Table 5. Even more so than its predecessor, the criteria are weighted towards compatibility with current practice. It is comparatively more important in this case, as the statewide and urban models will need to share data as well as common definitions and assumptions about travel behavior. The ability to use common procedures and data objects on both levels is a very important goal, for it will streamline the model application process. In addition to the ratings in Table 5, each of the packages are discussed below.

MEPLAN and TRANUS have quite a bit in common despite their separate development. Of the two, more is known about the internal workings of the TRANUS package. The underlying principles are outlined in a textbook on integrated land use-transportation modeling by de la Barra (1989), one of the principal authors of the package. The documentation also provides considerable details on the mathematical structure of the model (Modelistica, 1995). The software is inexpensive, although some amount of consulting assistance and instruction would be required to apply the model.

The principal advantage to implementing the statewide model within TRANUS is its established framework. The model has been used successfully in practice in both urban and regionwide applications. To the extent that it is a proven model, the risk of model failure would be reduced by its use. Many of the components in Waddell's prototype (see Figure 2) exist within the TRANUS framework, although sometimes in different forms. There is no explicit macroeconomic model within the structure, although input-output tables are used to define the relationship between industries and the flow of goods between them. Forecasts of economic growth are exogenously supplied; linking an economic model of the type contemplated for this project with TRANUS appears to be straightforward.

There are several distractions associated with the model as well. It is not GIS-based, and would have to mated with one in order to facilitate the exchange of data between ODOT and external databases and the model. Adopting TRANUS also implies "buying into" the theoretical structure of the model and its components. The transportation elements of the model are based on multinomial logit (MNL) formulations and cost functions which are unfamiliar to many transportation modelers and unproven in broad practice (although, as noted, there is a considerable amount of literature which supports the notion of discrete choice modeling techniques for intercity modeling). The weaknesses of the MNL compared to the nested logit model are well documented. Moreover, stochastic methods such as Monte Carlo simulation are more adept at handling a large number of alternatives, such as in destination choice modeling. Finally, there appears to be little flexibility to change algorithms or components without resorting to having the developer re-write sections of TRANUS. Intermediate outputs cannot be easily captured, and while the documentation does depict several separate modules, it does not appear possible to remove one and replace it with a different one written expressly for Oregon.

An alternative is to integrate a traditional transportation modeling package with a GIS capable of handling the land use modeling functions. Under this scheme all of the transportation analyses could be conducted within the familiar framework—and confines—of EMME/2 or STAN. Since EMME/2 has been adopted for use statewide for transportation analyses, and is without peer in flexibility and utility among transport modeling packages, we see little value in evaluating other packages. Moreover, we are aware of no feature in any competing package (save TransCAD, already discussed) which warrants special mention. STAN is a companion package to EMME/2, used for commodity flow modeling. It extends the EMME/2 framework by introducing the concept of product families. Up to 26 different product groups can be modeled simulta-

Table 5: Land use-transportation model evaluation criteria

Criteria	Score Range[a]	Integrated land use-transport models			Transportation models		
		MEPLAN	TRANUS	Custom	EMME/2	STAN	TransCAD
Compatible: Is the package used in Oregon? Can the package replicate the Oregon modeling process?[b] Does it use the same terminology, data, and algorithms?	2-10	6	8	10	10	10	8
Complete: Both land use and transport components?	1-5	5	5	5	1	1	1
Comprehensive: Does the package embody procedures or methods to carry out the four step modeling process, as well advanced modeling techniques? Is the structure of the modeling framework amenable to activity-based travel modeling?	1-5	3	3	5	5	4	5
Extensible: Does the vendor provide an open architecture, particularly with respect to data import and export? Can external processes directly access these data? Is a scripting or macro language available for user-defined processes?	1-5	1	4	5	4	4	5
Cost: How expensive is the software? Is extensive vendor support required to implement the model?	1-5	3	5	1	2	2	3
Portable: Are the underlying methods and models well documented and published? Are the file formats published?	1-5	1	4	5	5	5	4
Multimodal: Can both person and freight movements be modeled within the same framework? Are multiclass assignment and evaluation capabilities available?	1-5	3	3	5	2	5	4
Total Score	8-40	22	32	36	29	31	30

a. The score range values are 1=Poor or non-existent, 2=Fair, 3=Good, 4=Excellent, 5=Outstanding. For the Compatible criteria only, these scores are doubled.

b. See “Travel demand model development and application guidelines,” prepared for the ODOT by PBQ&D, 30 June 1996. Copies are available through the ODOT Transportation Development Branch, or can be downloaded from http://www.odot.state.or.us/planning/tdb/modeling/index.html.

neously, including network assignment. If freight modeling is undertaken in Phase II (as is recommended), then STAN is more appropriate for use in statewide modeling. People, and thus person travel, would be modeled as a single commodity, in addition to the 10-12 commodity groups modeled as freight.

Using STAN as the transportation modeling component would also eliminate the need for network analysis capability within the GIS. Under this scenario the GIS would only need to import the assigned link flows and display and manipulate the results. ArcView would still be an excellent choice in this regard.

The last alternative would be to develop the statewide model using custom software. Given that many of the modeling techniques proposed are either not implemented in currently available software or are awkward to apply, this approach has merit. It would ensure the maximum amount of flexibility, in that the programs could be modified by the consulting team in order to achieve the functionality desired. By using object-oriented programming techniques, components could be reused to the maximum extent possible, reducing the size and development cost of the software. For example, a considerable amount of overlap will likely exist between the destination and location choice models; these could be applied using the same modules. Moreover, these modules could be written to directly access data from a variety of sources, reducing the execution time and number of steps required to apply the model. The internal workings of the model would be open for evaluation, as the ODOT would also have the source code for this model.

There are several disadvantages to following this approach. One is the risk of schedule slippage. This approach would place the burden of software development as well as model development on the consulting team, and place them in the position of having to develop both concurrently. Resources will have to be dedicated to software development, reducing the amount of work in model development and application that can be accomplished in Phases II and III. The trade off comes down to balancing the limitations and risk associated with importing an integrated land use-transportation model (e.g., lack of flexibility, possibility that it will not work in a statewide setting) to the cost of developing the software in-house.

Unfortunately, none of these alternatives stand out above the others. The TRANUS model has the virtue of prior successes, a compelling attribute. The software, however, would define the range of land use and transportation modeling approaches considered, and may preclude many promising methods. It's adoption would require the most radical changes to the consultant work program, as it would require the restructuring of the team to accommodate another consulting firm (and the reduction or elimination of current roles). It would, however, provide capabilities within the reach of the current state-of-the-art, upon which ODOT could build or modify as additional data and experience with the model were gained.

Recommendations: Based upon evaluation scores alone, the development of custom software for model implementation appears to have the most merit. However, there are also some compelling reasons for electing to use an existing integrated land use-transportation model. We believe that the former provides ODOT with the maximum flexibility to implement state-of-the-art travel and land use forecasting techniques, which will be important in the long run. Starting out with an established integrated model reduces that flexibility but at the same time reduces the risk of short-term (e.g., this contract) failure. Both of these approaches are superior to the others discussed.

We recommend adopting a hybrid of these two approaches. The structure of the proposed approach at a broad level is shown in Figure 7. It builds upon the strengths of both approaches by combining them. TRANUS is recommended for use in the short term, supplemented by custom programs to implement modeling components either not included with it or for which a different

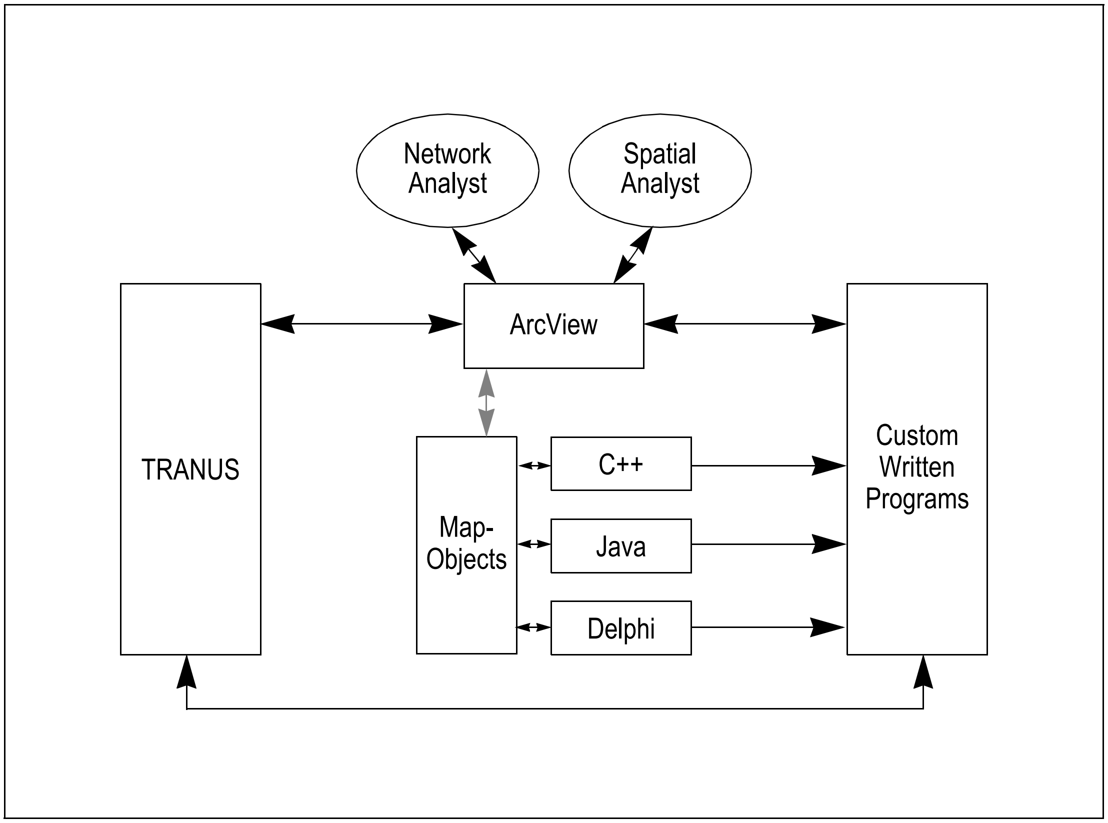


Figure 7: High-level model components

modeling approach is desired. ArcView will serve as the GIS backbone of the system, where the data from different sources will be assembled, checked, merged, and formatted as needed by TRANUS. While some of the visualization, particularly of network flows, will still be carried out within TRANUS, we also envision using the GIS platform for graphic displays. Finally, the structure presented in Figure 7 will allow us to shift our resources from one side to the other as requirements dictate. In other words, the role of TRANUS can be reduced over time to play a minor role and more emphasis placed on the custom software (on the right hand side of the Figure), or vice versa. This will allow the ODOT maximum flexibility while always allowing them to fall back upon the established structure and models embodied within TRANUS.

4.3 Software Issues

The development of a modeling framework has already been addressed. In this section the need for specialized software and tools for model development will be reviewed. The primary objective in this case is to use industry-standard tools and techniques that will facilitate the design of efficient, reusable, and extensible objects and functions.

<u>Issues:</u>

1. Custom software developed for this project must be written such that later modifications can be carried out by ODOT staff, other users, and other consultants.

2. Industry standard software for statistical analyses and model calibration should be used so that users and other researchers can easily interpret and verify the results obtained.

Discussion: As noted earlier, customized software will be written to carry out modeling functions unavailable, too limiting, or inefficiently implemented elsewhere. Several of these functions, for example, will involve the application and reporting of nested logit models. These objects (data structures and methods) will be written so that they can be used in both the land use and transportation models. An object-oriented language such as C++ or Java would be ideal tools. Borland's Delphi is a rapid application development (RAD) toolkit, based on their object-oriented Pascal language. It has a rich set of user interface tools that could significantly reduce the software development time. The use of Java will enable us to develop a prototypical user interface using the Department's World Wide Web page. Internal and external users could use the same interface to the model and its utility programs, reducing the training and software maintenance burden. Moreover, an Internet-based interface will allow the Department to maintain one version of the statewide model while enabling access at will to external users.

A number of statistical and data analysis programs will be used in model development. For statistical analyses, the Statistical Analysis System (SAS) and S-Plus will be used predominately. Both are widely used programs with which the consulting team has experience. S-Plus, in addition to its other features, can also be used directly with ESRI products. LIMDEP, an econometric analysis package, will be used to calibrate discrete choice models. None of the final products will contain modeling components which requires these packages. Rather, their output will be used to estimate and calibrate model parameters and coefficients.

Recommendations:

1. Industry standard object-oriented languages such as C++, Java, and Borland's Delphi should be used for the development of deliverable modeling components. ANSI standard programming techniques and function calls will be used in all programs.

2. Statistical analyses and model testing will be carried out using the Statistical Analysis System (SAS), S-Plus, LIMDEP, and other industry-standard programs. A copy of the input data and output will be included as appropriate in working papers and technical reports.

5.0 Summary of Recommendations

A number of issues have been addressed in this paper. A summary of the recommendations provided by the consultant is summarized in Table 6. A resolution of each of these items will permit the consulting team to prepare a detailed model specification and to develop a work plan for Phase II of this project.

Table 6: Summary of recommendations

Topic	Recommendation	Page
Land use-transportation model interaction	Adopt a partially integrated land use model.	5
Spatial representation	Develop a three-tiered network and activity representation for statewide modeling. Level 1 will be used for statewide (intercity) modeling, while Levels 2 and 3 will be implemented at a later date.	6-8
Economic modeling	Produce an interim model as outlined in the Statement of Proposal, accepting that it may not be wholly compatible with ongoing parallel DAS efforts	10

Table 6: Summary of recommendations (Continued)

Topic	Recommendation	Page
Person travel demand forecasting	Trip purposes will be defined which focus on commuting, recreational and vacation travel, and personal business.	12
	Develop travel demand models at the daily level (data permitting) or at the weekly level.	12
	Build a set of nested logit models of trip generation, distribution, and mode choice (possibly combining two or all three steps together in a simultaneous model).	12
Intercity freight demand modeling	Develop a hybrid commodity flow-truck travel demand model based upon CFS93 and truck survey data, as outlined in the Statement of Proposal.	12-13
Land use modeling	Use the TRANUS modeling framework for statewide modeling and a more detailed model for sub-state modeling.	15
Data requirements for model application	The development of regional forecasts of households and employment, land use and development, and non-moving establishments; and the development of the Level 1 transportation network.	17-19
Data storage and retrieval	Utilization of SQL database management systems compatible with those used by ODOT, plus the adoption of ESRI shapefile format as the standard GIS coverage format.	19
Information sharing	Incorporate Internet-based use interface as guiding design principle but delay its implementation until Phase III.	19-20
Person travel behavior data	Increased reliance on the OTBS and MPO external station surveys in place of the American Traveler Survey, supplemented with additional recreational surveys.	21
Freight data collection	Assume that the already delayed CFS93 data will be become available in time for development of the freight model. and conduct a limited number of weigh stations truck interviews.	23
GIS	Adopt ArcView 3.0 as the GIS platform used for this project.	27
Land use-transport models	Develop a hybrid modeling approach using TRANUS, ArcView, and custom-written software to carry out the land use and transportation modeling in Phase II.	31
Software issues	Use ANSI standard object-oriented programming tools and techniques for all custom-written software.	33
	Use industry-standard statistical packages (SAS, S-Plus, and LIMDEP) for model development work.	33

References

Beckman, R., *et al*. (1996) "Creating synthetic baseline populations." Report No. LA-UR-95-1985, Los Alamos National Laboratory. (Forthcoming in *Transportation Research B*.)

Crevo, C., *et al.* (1995) "Design and conduct of a statewide household travel survey in Vermont." *Transportation Research Record* 1477, 26-30.

de la Barra, T. (1989) Integrated land use-transportation modeling. Cambridge University Press, London.

Donnelly, R. and Arens, B. (1995) "The Michigan statewide truck travel forecasting model." Report No. FHWA-PL-96-112. Prepared for the Michigan Department of Transportation, Lansing, MI, by Parsons Brinckerhoff Quade & Douglas, Inc.

Donnelly, R. (1992) "IH-10 Corridor Study: Modeling Methodology." Technical Report prepared for the New Mexico State Highway and Transportation Department, Santa Fe, NM, by Barton-Aschman Associates, Inc.

Forinash, C.V. and Koppelman, F.S. (1993) "Application and interpretation of nested logit models of intercity mode choice." *Transportation Research Record* 1413, 98-106.

Gerken, J. (1990) "Generalized logit model." *Transportation Research B* 25, 75-88.

Hunt, J.D. and Simmonds, D. (1993) "Theory and application of an integrated land use and transport modeling framework." *Environment and Planning B* 20, 221-244.

Mandel, B. *et al*. (1994) "Linear or non-linear utility functions in logit models? The impact on German high speed rail demand forecasts." *Transportation Research B* 28, 91-102.

Martinez, F. (1992) "Towards the 5-stage land use-transportation model. *Land Use, Development and Globalization, VI. Selected Proceedings of the 6th World Conference on Transportation Research*, Lyon.

Modelistica. (1995) "TRANUS: Integrated land use and transport modeling system: Technical description." Available from Modelistica or from http://www.xcity.com/modelistica.

Virkud, U. and Keyes, C. (1995) "Design and implementation of a statewide roadside origin-destination survey in Vermont." *Transportation Research Record* 1477, 15-25.

Waddell, P. (1996) "Integrating land use and transportation models: A discrete choice approach to modeling urban development." Paper presented at the 75th Annual Meeting of the Transportation Research Board, Washington, D.C.