Transportation Planning and Modeling

Konstadinos G. Goulias (goulias@geog.ucsb.edu)
University of California Santa Barbara, Santa Barbara, CA, USA

January 16, 2010

Prepared for the Handbook of Transportation Engineering
Editor Myer Kutz
McGraw-Hill Handbooks

29.1 Introduction

Transportation modeling and simulation aims at the design of an efficient infrastructure and service to meet our needs for accessibility and mobility. At its heart is good understanding of human behavior that includes the identification of the determinants of behavior and the change in human behavior when circumstances change either due to control (e.g., taxation, land use controls, strategies to improve efficiency), trends (e.g., demographic change of resident population, immigration, workforce shifts, aging), or unexpectedly (e.g., natural and anthropogenic disasters). This understanding is a key ingredient for decisions in transportation planning and traffic operations. Since transportation systems are the backbone connecting the vital parts of a region, in-depth understanding of transportation-related human behavior is essential to the planning, design, and operational analysis of all the systems that make a region function.

Understanding human nature requires us to collect data and analyze and develop synthetic models of human agency in its most important dimensions and the most elemental constituent parts. This includes, and it is not limited to, understanding of individual evolution along individual life cycle paths (e.g., from birth to entry in the labor force to retirement to death) and the complex interaction between an individual and the anthropogenic environment, natural environment, and the social environment. Travel behavior research is one aspect of analyzing human nature and aims at understanding how traveler values, norms, attitudes, and constraints lead to observed behavior. Traveler values and attitudes refer to motivational, cognitive, situational, and disposition factors determining human behavior. Travel behavior refers primarily to the modeling and analysis of travel demand, based on theories and analytical methods from a variety of scientific fields. These include, but are not limited to, the use of time and its allocation to activities and travel, methods to study this in a variety of time contexts and stages in the life of people, and the arrangement or artifacts and use of space at any level of social organization such as the individual, the household, the community, and other formal or
informal groups (Goulia, 2009a). This also includes the movement of goods and the provision of services having strong interfaces and relationships with the engagement in activities and the movement of persons.

Travel behavior analysis and synthesis can be examined from both objective (observed by an analyst) and subjective (perceived by the human) perspectives in an integrated manner among four dimensions of time, geographic space, social space, and institutional context. In a few occasions the models reviewed here include and integrate time and space as conceived in science with perceptions of time and space by humans in their everyday life. Research that includes theory formation, data collection, modeling, inference, and simulation methods aims at the creation of decision support systems for policy assessment and evaluation combining different views of time and space.

Another objective of understanding individual and group travel behavior is conceptual integration. Explanation of facts from different perspectives can be considered jointly to form a comprehensive understanding of people and their groups and their interactions with the natural and built environments. In this way, we may see explanations of human behavior fusing into the same universal principles. These principles eventually will lead to testable hypotheses from different perspectives offering Wilson’s, 1998, famous consilience among, for example, psychology, anthropology, economics, the natural sciences, geography, and engineering. Unavoidably this is a daunting task with many model propositions in the research domain and just a few ideas finding fertile ground in applications. The analysis-synthesis path in travel behavior offers methods that help us understand and predict behavior partially leaving many gaps (Timmermans, 2003). However, policy questions are becoming increasingly impossible to address with old tools, a large pool of researchers is actively working on new methods, and many public agencies commenced a variety of tool development projects to fill the travel behavior analysis gaps. To capture these trends, we see modeling examples with ideas from a transdisciplinary viewpoint and contributors to modeling and simulation from a variety of merged backgrounds (e.g., see the evolution of ideas in a sequence of the International Association for Travel Behaviour Research conferences - www.public.asu.edu/~rpendyal/iatbr/iatbr_index.htm - accessed January 2010).

The impressive movement forward of transportation modeling and simulation emerges from three related but distinct sources. The first source is a fundamental change in planning practice that we could name dynamic planning practice to indicate the existence of bi-directional time (from the past to the future and from the future to today), as well as, assessment cycles and adjustments taking place within the short term, medium term, and long term horizons. These cycles are also bidirectional in time. A fundamental motivation that generates the substantive problems that we need to solve and the specific policies we need to examine is a vision for a sustainable and green transport system. Problems and solutions in this general area motivate and inspire contemporary substance and content of policies throughout the world. One can identify three complementary and mutually strengthening directions in the economy, environment, and society that are the three fundamental pillars of sustainability.

Planning today is heavily influenced by dynamic thinking, which means that time and change are intrinsic in the thought processes underlying planning activities. In the past, assumptions about the existence of a tenable and general equilibrium and our ability to build the infrastructure needed to meet demand did not require careful orchestration of actions. This was
radically changed in the industrialized world to meet specific goals using available finite resources to maximize benefits. Together with our inability to build at will and a tendency to the preservation of non-renewable resources (e.g., land and open space, fossil fuels, time) we are much more motivated to think strategically and to consider in a more careful way the performance of the overall anthropogenic system as we plan, design, operate, and manage transportation systems. Any action of this type, however, requires that we have a detailed and accurate picture of our facilities, their interconnectedness, their status within the hierarchy of movements, their conditions, and their evolving role. An accurate and more complete picture like this is called an inventory herein. This inventory includes the typical information about the resident population – demographics and employment, land available and land uses, economic development and growth, and so forth. It contains data and relationships within the geographic area of interest (region) but also the region's relationship with other areas with which substantial flow of people, goods, and communication takes place. Inventories may also include data and information about cultural and historical factors. For example, statewide plans identify a variety of corridors as buffers of land and communities around major routes of the movement of people and goods. Some of these routes were created centuries ago when pioneers were still exploring uncharted lands. These routes experienced a major change when waterways were the main links among economic and military centers, and they are still evolving. Today these same routes contain as backbones railways, roadways, rivers, and often they surround major distribution locations such as ports and airports. Their nature is heavily influenced by their historical and cultural context and the path of their evolution.

Travel behavior analysts are familiar with inventories created for the regional long range plans, which subdivide the study area in traffic analysis zones with data from the Decennial Census suitably reformatted and packaged for use in a specific application (i.e., the long range regional transportation plan). Then, additional data are assigned to these same subdivisions to build a richer context for modeling and simulation. Thus, the inventory for a typical long range plan is an electronic map of where people live and work, the network(s) that connect different locations, availability of different modes on each segment of the network, as well as information about travel network performance (e.g., link capacities, speeds on links, congestion, and connectivity). The tool of choice for data storage and visualization is a Geographic Information System (GIS) (see Kwan, 1994, 1997). One of the thorniest problems within this context is maintaining an up to date inventory (e.g., characteristics of the population in each zone, presence of certain types of businesses, location and characteristics of intermodal facilities). This is a particularly important issue for periods in between decennial censuses. Year to year updates are very often required to provide "fresh" data. Many of these updates are becoming widely available and much less expensive than in the past. For example, the inventory of the highway network, with suitable additions and improvements, is available from the same private providers of in-vehicle navigation systems. In a similar way, inventories of businesses and residences can also be purchased from vendors. Although the need for inventories is undoubtedly extremely important many important issues are yet to be resolved including levels of detail we should use in updating the data we have, treatment of errors in the data and model sensitivity to these errors, frequency of data updates and treatment of missing data, and questions about merging different databases. Investment on resolving some of these issues depends on the budget (time and money) available, consequences of errors in the data, and the use of models in decision making.
Let us turn now to the core of the dynamic planning practice which is about strategy and performance.

Strategic planning and performance-based planning changed the way we plan for the future. This has been a 20 year long process in the United States as its transportation policy at the Federal, State, and Metropolitan levels is shaped by three consecutive legislative initiatives (ISTEA, TEA-21, and SAFETEA-LU). Under all three legislative frameworks and independently of role, location and perceived need for investment, the overall goal of funding allocation has been to maximize the performance of the transportation system in its entirety and avoid major new infrastructure building initiatives. As a result, planning practice at the Federal, State, and local levels is becoming heavily performance based and designed in a way that motivates the measurement of policy and program outcomes and judging these outcomes for funding allocation. Some states have created long range plans that are strategic and they measure transportation performance. Yearly evaluative updates are also used for a state's strategic transportation plan. After a comprehensive public involvement campaign a few themes capturing the desires of the resident population are first identified. To these themes technical requirements based on planners and agency inputs are added, a large number of objectives are created and then a variety of measures of performance are developed. These measures are given target levels that evolve over time to a desired future performance for the entire state and for a finite number of corridors of statewide significance. Yearly evaluations contain measures of target achievement and they should be used to guide an agency in its investments. The interface with regions is also included in this performance-based framework. Many infrastructure improvement projects in the US are selected from lists of projects that regions (called Metropolitan Planning Organizations) submit to their state to be included in a list of projects in the Transportation Improvement Program (TIP) and become candidates for funding. Under statewide performance-based planning, these projects are evaluated with respect to their contribution in meeting the statewide performance measures and in some states the performance measures of the relevant corridor (NCHRP 446, 2000). Although these examples are far ranging in time and space, they contain operations components and yearly evaluations that: a) require data collection, modeling, and simulation at finer spatial and temporal scales than their counterpart planning feedbacks used in the long range transportation planning practice, and b) need methods that are able to coordinate the short, medium, and long term impacts. Emerging from these considerations are questions about the types of consistency we need among geographic scales for planning and operations actions to perform evaluations, policy requirements for coordination among planning activities to ensure consistency, need for suitable methods to coordinate smaller projects in broader contexts (either of policy assessment or geographical area), development of tools required to perform measurement of impacts and program evaluation at the newly defined assessment cycles, and optimal planning activity with evaluation methods.

As illustrated later in this chapter a new approach emerged in the past few years in which models of discrete choice are applied to individual decision makers that are then used to (micro)simulate most of the possible combinations of choices in a day. The result is in essence a synthetic generation of travel patterns. When the microsimulation also includes activities and duration at activity locations it becomes a synthetic schedule (called the activity-based approach to travel demand forecasting). In parallel, for forecasting purposes a synthetic population is first

Unedited Draft for Comments – January 2010
created for each land subdivision with all the relevant characteristics and then models are applied to the residents of each subdivision to represent area-wide behavior. Changes are then imposed on each individual as a response to policies and predictive scenarios of policy impacts are thus developed. The evolution of individuals, their groups, and the entire study area can be used for trend analysis that includes details at the level of decision makers (either for passenger travel and/or for freight). In addition, progression in time happens from the present to the future and one could identify paths of change by individuals and groups if the application has been designed in the proper way (e.g., keeping detailed accounting of individuals as they move in time, using models that are designed for transitions over time and so forth). In a forecasting setting progression in time follows calendar time, temporal resolution is most often a year, and the treatment of dynamics is an one-way causal stream to the future. Within the broader study of futures, forecasting is the method we use to develop projective scenarios. Performance-based planning, however, requires tools that can extrapolate from future performance targets the actions required today to reach them. In essence we also need prospective studies that start from a desirable future and move backwards to identify specific actions that will lead us to that prospect (see the review by Goulias, 2009b).

29.2. Policy and Planning

Policy actions also view the world surrounding us as an integral ecosystem placing more emphasis on its overall survival by examining direct and indirect effects of individual policy actions and entire policy packages or programs (see the examples in Meyer and Miller, 2001). This trend is not limited to transportation. Lomborg, 2001, shows that a sustainable and green vision encompasses the entire range of human activity and the entirety of the ecosystem we live in. Although these are good news, because the approach enables analyses and policies that are consistent in their vision about futures, comprehensive views also reveal that the pace of economic growth and development is in clear conflict with the biological pace of evolution with unknown consequences (Tiezzi, 2003) strengthening the view that more comprehensive analytical frameworks are required.

In fact, research syntheses that address the transportation and environment relationship by the Transportation Research Board of the National Academies (TRB, 1999, 2002), expands the envelope to incorporate ecology and natural systems and addresses human health in a more comprehensive way than in the past reiterating the urgency to address unresolved issues about environmental damage. As a result, we also experience a clear shift to policy analysis approaches that have an expanded scope and domain and they are characterized by explicit recognition of transportation system complexity and uncertainty.

Reflecting all this, sustainable transportation is now often used to indicate a shift in the mentality of the community of transportation analysts to represent a vision of a transportation system that attempts to provide services that minimize harm to the environment. In fact, in one of the most comprehensive reviews of policies in North America, Meyer and Miller, 2001, contrast the non-sustainable to the sustainable approaches. They provide a compelling argument about the change in these policies and pathways toward a more sustainable path. In the US the need to examine these new and more complex policy initiatives became increasingly pressing due to the passage of a series of legislative initiatives (Acts) and associated Federal and State
regulations on transportation policy, planning, and programming. The multi-modal character of
the new legislation, its congestion management systems and air quality requirements for many
U.S. regions motivated many new forecasting applications (Niemeier, 2003). An added
motivation is also lack of substantial funding for transportation improvement projects and a shift
to charge the firms that benefit the most from transportation system improvements creating a
need for impact fee-assessment for individual private developers. These assessments create the
need for higher resolution in the three dimensions of geography (space), time (time of day), and
social space (groups of people with common interests and missions, households, individuals)
used in typical regional forecasting models but also the domain of jurisdictions where major
decisions are made.

As Garrett and Wachs, 1996, discuss in the context of a lawsuit against a regional
planning agency in the Bay Area, traditional four-step regional simulation models (Creighton,
1970, Hutchinson, 1974, Ortuzar and Willumsen, 2001) are outpaced by the same legislative
stream of the past 20 years that defined many of the policies described above. Unlike the
“energy crisis” of the 1970s, the urgency and timeliness of modeling and simulation is becoming
more urgent, more complex, and requires an “integrated” approach. Under these initiatives,
forecasting models, in addition to long-term land use trends and air quality impacts, need to also
address issues related to technology use and information provision to travelers in the short and
medium terms. The European Union focuses on similar issues as documented in van der Hoorn,
1997. Tables 1 and 2 provide an overview of policy tools that are loosely ordered from the longer
term of land use and governance to medium and shorter term operational improvements
depending on the lag time required for their impacts to be realized.

These policy initiatives place more complex issues in the domain of regional policy
analysis and forecasting and amplify the need for methods that produce forecasts at the
individual traveler and her/his household levels instead of the traffic analysis zone level. In
addition to the long range planning activities and the typical traffic management activities,
analysts and researchers in planning need to also evaluate traveler and transportation system
manager information provision and use (e.g., location based services, smart environments
providing real time information to travelers, vehicles, and operators), combinations of
transportation management actions and their impacts (e.g, parking fee structures and city center
restrictions, congestion pricing), and combinations of environmental policy actions (e.g., carbon
taxes, health impacts of lack of bike and pedestrian facilities, and information campaigns about
health effects of pollutants).

The tools to study and plan for these policies need to also have forecasting and
backcasting/performance planning capabilities that are more accurate and detailed in space and
time. In fact, planning initiatives are moving toward parcel by parcel analysis and yearly
assessments. It is also conceivable that we need separate analyses for different seasons of a year
and days of the week to capture seasonal and within a week variations of travel. Echoing all this
and in the context of the Dutch reality Borgers, et al. (1997) have identified five information
need domains that the new envisioned policy analysis models will need to address and they are
(in a modified format from the original list):

Unedited Draft for Comments – January 2010
• social and demographic trends that may produce a structural shift in the relationship between places and time allocation by individuals invalidating existing travel behavior model systems;
• increasing scheduling and location flexibility and degrees of freedom for individuals in conducting their every day business leading to the need to consider additional choices (e.g., departure time from home, work at home, shopping by the internet, shifting activities to the weekend) in modeling travel behavior;
• changing quality and price of transport modes based on market dynamics and not on external to the travel behavior policies (e.g., the effect of deregulation in public transport);
• shifting of attitudes and potential cycles in the population outlook about travel options; and
• changing scales/jurisdictions (scale is the original term used to signify the different jurisdictions) – different policy actions in different sectors have direct and indirect effects on transportation and different policy actions in transportation have direct and indirect effects in the other sectors (typical example in the US is the welfare to work program).

The first substantive implication of all these considerations is an expanded envelope of modeling and simulation. Many processes that were left outside the realm of transportation modeling and simulation need to be included as stages of the travel model system. One notable example is the inclusion of residential location choice, work location choice, and school location choice to capture the spatial distribution and relative location of important anchor points on travel behavior and to also capture the impact of transportation system availability and level of service on these choices. In this way when implemented policies lead to improved level of service and the relative attractiveness of locations change, shifts in residential location, work location, and possibly school location can be incorporated as impacts of transportation. A similar treatment is needed for car ownership and car type choices of households or fleet sizes and composition for firms. These choices are expressed as functions of parking availability, energy and other costs and level of service offered by the transportation system (highway and transit). To account for other resources and facilities available for household travel we also need to consider processes for driver's licensing, acquiring of public transportation subscription (passes), and participation in car sharing programs. In this way, variables of car availability and public transportation availability in households can be used as determinants of travel behavior. Similar treatment is required for policies that change attitudes, perceptions and knowledge about travel options.

To address some of the policies of Tables 1 and 2, we need to transition to a domain that contains a variety of outputs that include shares of program participation, sensitivity to accessibility and prices, and the usual indicators of travel on networks using input variables from the processes and behaviors discussed up to this point. Although the number of vehicles per hour per lane is the typical input of traffic operations software, a variety of other variables such as speeds on network links and types of vehicles are also needed for other models such as emissions estimation.

Ideally longer term social, economic, demographic, and resource/facilities circumstances of people should be converted into yearly schedules identifying periods of vacation, workdays, special occasions, and so forth. These in turn should lead to weekly schedules separating days during which people stay at home from days during which people go to work and days during which they run errands and/or engage in other non-work and non-school related activities. In

Unedited Draft for Comments – January 2010
this way patterns of working days versus not working days can be derived in a natural (con)sequence. As we will see in a later section, a fundamental leap of faith intervenes in practice and converts all this background information into a representative day that is used to create a more or less complete sequence of activities and trips with their destinations and modes used.

In this way decisions and choices people make are organized along the time scale in terms of the time it takes for these events to occur and their implications. For example, decisions about education, careers and occupation, and residential and job location are considered first and they condition everything that happens next. These should be formulated in terms of life course long projects and not represented by a cross-sectional choice model. Similarly, decisions about yearly school and work schedules that determine work days and vacation days in a year are should also be modeled as a stream of interrelated choices. Conditional on all this are the daily schedules of individuals and the myriad of decisions determining a daily schedule, which are modeled in much more detail and paying closer attention to the mutual dependency among the different facets of a within a day schedule.

29.3 Modeling

Modeling made tremendous progress toward a comprehensive approach to build simulated worlds on computer enabling the study of complex policy scenarios (Henson et al., 2009). Although, passenger travel received the bulk of the attention, similar contributions to new research and technology are found in modeling the movement of goods (Southworth, 2003, Stefan et al., 2005, Samimi et al., 2010). The emerging framework, although incomplete, is rich in the directions taken and has considerable potential for scientific discovery, policy analysis, and more comprehensive approaches in dealing with sustainability issues.

29.3.1 Modeling Dimensions

There are four dimensions characterizing simulation models. The first is the geographic space and its conditional continuity, the second is the temporal scale and calendar continuity, the third is interconnectedness of jurisdictions, and the fourth and most important is the set of relationships in social space for individuals and their communities. The first dimension, geographic space here is intended as the physical space in which human action occurs. This dimension has played important roles in transportation planning and modeling because the first preoccupation of the transportation system designers has been to move persons from one location to another (i.e., overcoming spatial separation). Initial applications considered the territory divided into large areas (traffic analysis zones), represented by a virtual center (centroid), and connected by facilities (higher level highways). The centroids were connected to the higher level facilities using a virtual connector summarizing the characteristics of all the local roads within the zone. As computational power increased and the types of policies/strategies required increased resolution the zone became smaller and smaller. Today we expect software to handle zones that are as small as a parcel of land and transportation facilities that are as low in the hierarchy as a local road (the centroid becomes the building on a parcel and the centroid connector is the driveway of the unit and they are no longer virtual).
In modeling and simulation we are interested in understanding human action. For this reason in some applications geographic space needs to consider more than just physical features (Golledge and Stimpson, 1997, page 387) moving us into the notion of place and social space. The second dimension is time that is intended here as continuity of time, irreversibility of the temporal path, and the associated artificiality of the time period considered in many models. Models used in long range planning applications use typical days (e.g., a summer day for air pollution). In many regional long-range models the implied assumption is that we target a typical work weekday in developing models to assess policies. Households and their members, however, may not always (if at all) obey this strict definition of a typical weekday to schedule their activities and they may follow very different decision making horizons in allocating time to activities within a day, spreading activities among many days including weekends, substituting out of home with in home activities in some days but doing exactly the opposite on others, and using telecommunications only selectively (e.g., on Fridays and Mondays more often than on other days). Obviously, taking into account these scheduling activities is by far more complex than what is allowed in existing transportation planning models. The third dimension is jurisdictions and their interconnectedness. The actions of each person are “regulated” by jurisdictions with different and overlapping domains such as federal agencies, state agencies, regional authorities, municipal governments, neighborhood associations, trade associations and societies, religious groups, and formal and informal networks of families and friends. In fact, the federal government defines many rules and regulations on environmental protection. These may end up being enforced by a local jurisdiction (e.g., a regional office of an agency within a city). On the one hand, we have an organized way of governance that clearly defines jurisdictions and policy domains (e.g., real estate tax collection in the US). On the other hand, the relationships among jurisdictions and decision making about allocation of resources does not follow always this orderly governance principle of hierarchy. A somewhat different and more “bottom up” relationship is found in the social network and for this reason requires a different dimension that is the fourth and final dimension named social space and the relationships among persons within this space. For example, individuals from the same household living in a neighborhood may change their daily time allocation patterns and location visits to accommodate and/or take advantage of changes in the neighborhood and at the same time modify their activity and travel patterns because one member is actively engaging in another social network. Changes to the infrastructure and its management may motivate mutually cancelling impacts due to the different networks. This may lead to the unintended consequence of policy failure.

One important domain and entity within this social space is the household. This has been a very popular unit of analysis in transportation planning recognizing that strong relationships within a household can be used to capture behavioral variation (e.g., the simplest method is to use a household’s characteristics as explanatory variables in a regression model of travel behavior). In this way any changes in the household’s characteristics (e.g., change in the composition due to birth, death, divorce, children leaving the nest, or adults moving into the household) can be used to predict changes in travel behavior. New model systems are created to study this interaction within a household looking at the patterns of using time in a day and the changes across days and years. It is therefore very important in modeling and simulation to incorporate in the models used for policy analysis interactions among these four fundamental dimensions, which bring us to the issue of scale.
The typical long range planning analysis is defined for larger geographical areas (region, states, and countries) and addresses issues with horizons from 10 to 50 years. In many instances we may find that large geographic scale means also longer time frames applied to wider mosaics of social entities and including more diverse jurisdictions. On the other side of the spectrum issues that are relevant to smaller geographic scales are most likely to be accompanied by shorter term time frames applied to a few social entities that are relatively homogeneous and subject to the rule of very few jurisdictions. This is one important organizing principle but also an indicator of the complex relationships we attempt to recreate in our computerized models for decision support. In developing the blueprints of these models one can choose from a variety of theories (e.g., neoclassical microeconomics) and conceptual representations of the real world that help us develop these models. At the heart of our understanding of how the world (as an organization, a household, a formal or informal group, or an individual human being) works are models of decision making and conceptual representations of relationships among entities making up this world.

Transportation planning applications are about judgment and decision making of individuals and their organizations. There are different settings of decision making that we want to understand. Three of these settings are the travelers and their social units from which motivations for and constraints to their behavior emerge, the transportation managers and their organizations that serve the travelers and their social units, and the decision makers surrounding goods movement and service provision that contain a few additional actors. These applications may also include land use markets (see www.urbansim.org). Travelers received considerable attention in transportation planning and the majority of the models in practice aim at capturing their decision making process. The remaining settings, e.g. airport and port travel, received much less attention and they are poorly understood and modeled.

Conceptual models of the interaction among agents are transformed into computerized models of a city, a region, or even a state in which we utilize components that are in turn models of human judgment and decision making, e.g., travelers moving around the transportation network and visiting locations where they can participate in activities. Models of this behavior are simplified versions of strategies used by travelers when they select among options that are directly related to their desired activities. In some of these models we also make assumptions about hierarchies of motivations, plans, actions, and consequences. Some of these assumptions are explicit, e.g., when deriving the functional forms of models as in the typical disaggregate choice models or the rules in a production system, these assumptions are implicit.

When designing transportation planning model interfaces for transportation planners and managers we also implicitly make assumptions about the managers’ ability to understand the input, agent representation, internal functioning, and output of these computerized models. Our objective is therefore not only to understand travel behavior and build models that describe and predict human behavior but also to devise tools that allow transportation managers to understand the assumed behavior in the models, study scenarios of policy actions, and define and explain policy implications to others. This, in essence, implies that we, the model system designers, create a platform for a relationship between planners and travelers. A similar but more direct relationship also exists between travelers and transportation managers when we design the observation methods that provide the data for modeling but also the data used to measure attitudes and opinions such as travel surveys. In fact, this relationship is studied in much more
detail in the survey design context and linked directly to the image of the agency conducting the survey and the positive or negative impression of the travelers about the sponsoring agency (Dillman, 2000). Most transportation research for modeling and simulation, however, has emphasized traveler behavior when building surveys and their models neglecting the interface with the planners. The summary of theories below, however, applies to individuals traveling in a network but also to organizations and planners in the sense used by H.A. Simon in his Administrative Behavior (1997).

29.3.2 Decision-Making Paradigms
Rational decision making is a label associated with human behavior that follows a strategy in identifying the best course of action. In summary, a decision maker solves an optimization problem and identifies the best existing solution to this problem. Within this more general strategy when an operational model is needed and this operational model provides quantitative predictions about human behavior some kind of mathematical apparatus is needed to produce the predictions. One such machinery is the subjective expected utility (Savage, 1954) formulation of human behavior. In developing alternative models to SEU Simon (1983) defines four theoretical components:

- a person’s decision is based on a utility function assigning a numerical value to each option – existence and consideration of a cardinal utility function;
- the person defines an exhaustive set of alternative strategies among which just one will be selected – ability to enumerate all strategies and their consequences;
- the person can build a probability distribution of all possible events and outcome for each alternate option – infinite computational ability; and
- the person selects the alternative that has the maximum utility – maximizing utility behavior.

This behavioral paradigm served as the basis for a rich production of models in transportation that include the mode of travel, destinations to visit as well as the household residence (see the examples in the seminal textbook by Ben-Akiva and Lerman, 1985). It served also as the theoretical framework for consumer choice models and for attempts to develop models for hypothetical situations (see the comprehensive book by Louviere, Hensher, and Swait, 2000). It has also replaced the aggregate modeling approaches to travel demand analysis as the orthodoxy against which many old and new theories and applications are compared and compete with. SEU can be considered to be a model from within a somewhat larger family of models under the label of weighted additive rule (WADD) models (Payne, Bettman, and Johnson, 1993). Real humans, however, may never behave according to SEU or related maximizing and infinitely computational capability models (Simon labels this the Olympian model, 1983). Based on exactly this argument different researchers in psychology have proposed a variety of decision making strategies (or heuristics). For example, Simon created alternate model paradigms under the label of bounded rationality – the limited extent to which rational calculation can direct human behavior (Simon, 1983, 1997) to depict a sequence of a person’s actions when searching for a suitable alternative. The modeled human is allowed to make mistakes in this search giving a more realistic description of observed behavior (see also Rubinstein, 1998). Tversky is
credited with another stream of decision making models starting with the lexicographic approach (1969), in which a person first identifies the most important attribute, compares all alternatives on the value of this attribute, and chooses the alternative with the best value on this most important attribute. Ties are resolved in a hierarchical system of attributes. Another Tversky model (1972) assumes a person selects an attribute in a probabilistic way and influenced by the importance of the attribute, all alternatives that do not meet a minimum criterion value (cutoff point) are eliminated. The process proceeds with all other attributes until just one alternative is left and that one is the chosen. This has been named the elimination by aspects strategies (EBA) model. Later, Kahneman and Tversky (1979) developed prospect theory and its subsequent version of cumulative prospect theory in Tversky and Kahneman (1992) in which a simplification step is first undertaken by the decision maker editing the alternatives. Then, a value is assigned to each outcome and a decision is made based on the sum of values multiplying each by a decision weight. Losses and gains are treated differently. All these alternatives to SEU paradigms did not go unnoticed in transportation research with early significant applications appearing in the late 1980s. In fact, more than a decade ago a conference was organized attracting a few of the most notable research contributors to summarize the state of the art in behavior paradigms and documented in Garling, Laitila, and Westin (1998). One of the earlier examples using another of Simon’s inventions, the satisficing behavior – acceptance of viable choices the may not be optimal - is a series of transportation-specific applications described in Mahmassani and Herman (1990). Subsequent contributions continue along the path of more realistic models and the most recent example, discussing a few models, by Avineri and Prashker (2003), uses cumulative prospect theory giving a preview of a movement toward more realistic travel behavior models. As Garling et al. (1998) and Avineri and Prashker (2003) point out, these paradigms are not ready for practical applications, contrary to the Mahmassani and colleagues efforts that have been applied, and additional work is required to use them in a simulation framework for applications. In addition, Payne, Bettman, and Johnson (1993) provide an excellent review of these models, a summary of the differentiating aspects among the paradigms. They also provide evidence that decision makers adapt by switching between decision making paradigms to the task and the context of their choices. They also make mistakes and they may also fail to switch strategies. As Vause (1997) discusses to some length transportation applications are possible using multiple decision making heuristics within the same general framework and employing a production system approach (Newell and Simon, 1972). A key consideration, however, that has received little attention in transportation is the definition of context within which decision making takes place. Recent production systems (Arentze and Timmermans, 2000) are significant improvements over past simulation techniques. However, travelers are still assumed to be passive in shaping the environment within which they decide to act (action space). This action space is viewed as largely made by constraints and not by their active shaping of their context within wider time intervals. Goulias (2001, 2003, 2009a) reviews and builds another framework from human development and social ecology perspective that is designed to treat decision makers in their active and passive roles and explicitly accounts for mutual influence between an agent (active autonomous decision maker) and her environment in the lifecourse.

29.3.3 Transportation Models

Unedited Draft for Comments – January 2010
Transportation modeling and simulation for planning experienced a few tremendously innovative steps forward. Interestingly these key innovations are from non-engineering fields but very often transferred and applied to transportation systems analysis and simulation by engineers. One major push forward is the development of Random Utility Models. At exactly the time that the Bay Area Rapid Transit system was studied and evaluated in the 1960s, Dan McFadden (the Year 2000 Nobel Laureate in Economics) and a team of researchers produced practical mode choice regression models at the level of an individual decision maker (see http://emlab.berkeley.edu/users/mcfadden/ - accessed June 2007). The models are based on random utility maximization (of the SEU family) and their work opened up the possibility to predict mode choice rates more accurately than ever before. These models were initially named behavioral travel-demand models (Stopher and Meyburg, 1976) and later the more appropriate term of discrete choice models (Ben-Akiva and Lerman, 1985) prevailed. Although restrictive in their assumptions, these models are still under continuous improvement and they have become the standard tool in evaluating discrete choices. Some of the most notable and recent developments advancing the state of the art and practice are:

- better understanding of the theoretical and particularly behavioral limitations of these models (Garling, Laitila, and Westin, 1998, McFadden, 1998, Golledge and Garling, 2003);

- more flexible functional forms that resolve some of the problems raised in Williams and Ortuzar (1982) allowing for different choices to be correlated when using the most popular discrete choice regression models (Koppelman and Sethi, 2000, Bhat, 2000, 2003);

- combination of revealed preference, stated choices by travelers, with stated preferences and intentions, answers to hypothetical questions by travelers, availability of data in the same choice framework to extract in a more informative way travelers willingness to use a mode and willingness to pay for a mode option (Ben-Akiva and Morikawa, 1989, Louviere, Hensher, and Swait, 2000). This latter “improvement” enables us to assess situations that are impossible to build in the real world;

- computer-based interviewing and laboratory experimentation to study more complex choice situations and the transfer of the findings to the real world (Mahmassani and Jou, 2000). This direction, however, is also accompanied by a wide variety of research studies aiming at more realistic behavioral models that go beyond mode choice and travel behavior (Golledge and Garling, 2003) and the use of technologies to enhance our understanding of information use (Auld et al., 2009); and

- expansion of the discrete choice framework using ideas from latent class models with covariates that were first developed by Lazarsfeld in the 1950s and their estimation finalized by Goodman in the 1970s (see the review in Goodman, 2002, and discrete choice applications in Bockenholdt, 2002). This family of models was used in Goulia
(1999) to study the dynamics of activity and travel behavior and in the study of choice in travel behavior (Ben-Akiva et al., 2002).

As mentioned earlier the rational economic assumption of the maximum utility model framework (that underlies many but not all of the applied disaggregate models in transportation) is very restrictive and does not appear to be a descriptive behavioral model except for a few special circumstances when the framing of decisions is carefully designed (something we cannot expect to happen every time a person travels on the network). Its replacement, however, requires conceptual models that can provide the types of outputs needed in regional planning applications.

A few additional research paths, labeled as *studies of constraints*, are also functioning as gateways into alternate approaches to replace or complement the more restrictive utility-based models. A few of these models also consider knowledge and information provision to travelers. The first aspect we consider is about the choice set in discrete choice models. Choice set is the set of alternatives from which the decision maker selects one. These alternatives need to be mutually exclusive, exhaustive, and finite in number (Train, 2003). Identification, counting, and issues related to the alternatives considered have motivated considerable research in choice set formation (Richardson, 1982, Swait and Ben-Akiva, 1987a, 1987b, Horowitz, 1991, Horowitz and Louviere, 1995). Key threat to misspecification of the choice set is the potential for incorrect predictions (Thill, 1992). When this is an issue of considerable threat as in destination choice models where the alternatives are numerous, a model of choice set formation appears to be the additional burden (Haab and Hicks, 1997). Other methods, however, also exist and they may provide additional information about the decision making processes. Models of the processes can be designed to match the study of specific policies in specific contexts. One such example and a more comprehensive approach defining the choice sets is the situational approach (Brög and Erl, 1989). The method uses in depth information from survey respondents to derive sets of reasons for which alternatives are not considered for specific choice settings (individual trips). This allows separation of analyst observed system availability from user perceived system availability (e.g., due to misinformation and willingness to consider information). This brings us to the duality between “objective choice attributes” and “subjective choice attributes.” Most transportation applications, independently of the decision making paradigm adopted, assume the analysts (modelers) measured attributes and the travelers used attributes in deciding to be the same. Due to differential perception these attribute values may not be the same. Modeling the process of perceived constraints may be far more complex when one considers the influence of the context within which decisions are made. Golledge and Stimpson (1997, pages 33-34) describe this within a conceptual model of decision making that has a cognitive feel to it. They also link the situational approach to the activity-based framework of travel extending the framework further (pages 315-328) to also include the use of time.

Chapin’s research (1974), providing one of the first comprehensive studies about time allocated to activity in space and time, is also credited for motivating the foundations of activity-based approaches to travel demand analysis. His focus has been on the propensity of individuals to participate in activities and travel linking their patterns to urban planning. At about the same time Becker also developed his theory of time allocation from a household production viewpoint (Becker, 1976) applying economic theory in a non-market sector and demonstrating the possibility of formulating time allocation models using economics reasoning (i.e., activity
choice). In parallel another approach was developing in geography and Hagerstrand’s seminal publication on time space geography (1970) presents the foundations of the approach. The idea of constraints in the movement of persons was taken a step further by this time-geography school in Lund. In that framework, the movement of persons among locations can be viewed as their movement in space and time under external constraints. Movement in time is viewed as the one way (irreversible) movement in the path while space is viewed as a three dimensional domain. It provides the third base about constraints in human paths in time and space for a variety of planning horizons. These are capability constraints (e.g., physical limitations such as speed); coupling constraints (e.g., requirements to be with other persons at the same time and place); and authority constraints (e.g., restrictions due to institutional and regulatory contexts such as the opening and closing hours of stores). Figure 1 provides a pictorial representation in space and time of a typical activity-travel pattern of two persons (P1 and P2) and the three types of constraints.

Cullen and Godson (1975) also reviewed by Arentze and Timmermans (2000) and Golledge and Stimpson (1997) appear to be the first researchers attempting to bridge the gap between the motivational (Chapin) approach to activity participation and the constraints (Hagerstrand) approach by creating a model that depicts a routine and deliberated approach to activity analysis. The Cullen and Dobson study also defined many terms often used today in activity-based approaches. For example, each activity (stay-home, work, leisure, and shopping) is an episode characterized by start time, duration, and end time. Activities are also classified into fixed and flexible and they can be engaged alone or with others. Moreover, they also analyzed sequencing of activities as well as pre-planned, routine, and on the spur of the moment activities. Within this overall theoretical framework is the idea of a project which according to Golledge and Stimpson, (1997) is a set of linked tasks that are undertaken somewhere at some time within a constraining environment (pages 268-269). This idea of the project underlies one of the most exciting developments in activity-based approaches to travel demand analysis and forecasting because seemingly unrelated activity and trip episodes can be viewed as part of a "big-picture" and given meaning and purpose completing in this way models of human agency and explaining resistance to change behavior.

Most subsequent contributions to the activity-based approach emerge in one way or another from these initial frameworks with important operational improvements (for reviews see Kitamura, 1988, Bhat and Koppelman, 1999, Arentze and Timmermans, 2000, and McNally, 2000). The basic ingredients of an activity based approach for travel demand analysis (Jones, Koppelman, and Orfeuil, 1990 and Arentze and Timmermans, 2000) are:

- explicit treatment of travel as derived demand (Manheim, 1979), i.e., participation in activities such as work, shop, and leisure motivate travel but travel could also be an activity as well (e.g., taking a drive). These activities are viewed as episodes (characterized by starting time, duration, and ending time) and they are arranged in a sequence forming a pattern of behavior that can be distinguished from other patterns (a sequence of activities in a chain of episodes). In addition, these events are not independent and their interdependency is accounted for in the theoretical framework;
The household is considered to be the fundamental social unit (decision making unit) and the interactions among household members are explicitly modeled to capture task allocation and roles within the household, relationships at one time point and change in these relationships as households move along their life cycle stages and the individual’s commitments and constraints change and these are depicted in the activity-based model; and

- explicit consideration of constraints by the spatial, temporal, and social dimensions of the environment is given. These constraints can be explicit models of time-space prisms (Lenntorp, 1976, Pendyala, 2003) or reflections of these constraints in the form of model parameters and/or rules in a production system format (Arentze and Timmermans, 2000).

Input to these models are the typical regional model data of social, economic, and demographic information of potential travelers and land use information to create schedules followed by people in their everyday life. The output are detailed lists of activities pursued, times spent in each activity, and travel information from activity to activity (including travel time, mode used, and so forth). This output is very much like a “day-timer” for each person in a given region. Figure 2 provides an example of time allocation to different activities from an application that collected activity participation data (Alam, 1998, Alam and Goulias, 1999). It displays time allocation by one segment of the population showing the proportion of persons engaging in each activity by each hour of a day. Using this type of data and information about building allocation to uses, models are used to create the output shown in Figure 3 shows the output from a model that predicts the presence of persons in each building during each hour of a day engaging in each activity type. Combining an activity model with a typical travel demand model produces “volumes” of individuals at specific locations and on the network of a city as shown in Figure 4 (a more detailed description of this study can be found in Kuhnau and Goulias, 2003, and Kuhnau, 2001).

Many planning and modeling applications aim at forecasting. Inherent in forecasting are the time changes in the behavior of individuals and their households and their response to policy actions. At the heart of behavioral change are questions about the process followed in shifting from a given pattern of behavior to another. In addition to measuring change and the relationships among behavioral indicators that change in their values over time, we are also interested in the timing, sequencing, and staging of these changes. Moreover, we are interested in the triggers that may accelerate desirable or delay undesirable changes and the identification of social and demographic segments that may follow one time path versus another in systematic patterns. Knowledge about all this is required to collect data, design policies but it is also required to design better forecasting tools to assess future impacts of policies. Developments in exploring behavioral dynamics and advancing models for them have progressed in a few arenas. First, in the data collection arena with panel surveys, repeated observation of the same persons over time that are now giving us a considerable history in developing new ideas about data collection but also about data analysis (Golob, Kitamura, and Long, 1997, Goulias and Kim, 2003) and interactive and laboratory data collection techniques (Doherty, 2003) that allow a more in-depth examination of behavioral processes. The second arena is in the development of (microeconomic) dynamic formulations for travel behavior that challenge conventional
assumptions and offer alternative formulations (Kitamura 2000). The third arena, is in the behavior from a developmental viewpoint as a single stochastic process, a staged development process (Goulias, 1999), or as the outcome from multiple processes operating at different levels (Goulias, 2002). Experimentation with new theories from social psychology emphasizing development dynamics is a potential fourth area that is just beginning to emerge (Goulias, 2003, 2009a). Behavioral dynamics are also examined using more comprehensive analyses (Goulias et al. 2007) and models (Ramadurai and Srinivasan, 2006).

An example of a dynamic model system is Figure 5, in which the model consists of two major components, each corresponding to a different decision stage. The first component is the long-term activity-travel planning (LATP). This component is based on identification of a few representative patterns of behavior from observed behavior. Using these activity and travel pattern, individuals are classified into relatively few homogenous groups. The probability of belonging to each group is a function other exogenous to the system sociodemographic characteristics that can be forecasted using microsimulation (see Goulias and Kitamura, 1992, and Chung and Goulias, 1997). Implied in this model system is that individuals are more likely to start their day by choosing a general pattern of behavior defined in approximate terms. For example, a person will decide whether to follow a typical working day pattern or a non-working day pattern without knowing the detailed timing of activities, destinations, modes to use, and so forth. An individual’s choice of activity and travel patterns is considered to be a function of the person’s contemporary characteristics, household socioeconomics, and long-term activity-travel environment. The long-term activity-travel environment is introduced here to differentiate from the instantaneous activity-travel environment, e.g., congestion at specific locations and times of a day. The former is referred to a situation that the environment is evaluated based on a longer time interval (e.g., a day) while the latter on a finer time slice (e.g., an hour). A day’s pattern choice is also dependent on the distant and immediate past. The distant past (e.g., one year in this scheme but expandable) captures behavioral inertia or habit while the immediate past (i.e., one day) captures behavioral variation embedded in a weekly cycle. As the demand for travel is derived from the desire to participate in activities, travel pattern choice is considered to be a subsequent decision made after activity pattern choice. Thus, travel choice is dependent on, in addition to person characteristics, household sociodemographics, activity and travel environment, and the activity pattern choice in the past and at present. The use of this model system (LATP) up to this stage is suitable for long-range regional forecasting because of its ability to replicate policy responses in daily summary (synoptic measures of patterns) terms.

Given the predicted long-term activity and travel patterns, LATP then determines the expected daily activity and travel schedule for each person. This expected daily schedule may be viewed as an average schedule of all possible schedules a person may have had and/or considered. It should be noted here that the expected schedule is not a real schedule that can be expressed as an activity sequence with detailed timing. Rather, it is a summary of activity participation with a capability of linking all activities together. In other words, due to behavioral variation, a person’s daily schedule will change from day to day, but it is always fluctuating around an average or typical pattern. This pattern is the expected schedule. The expected schedule is generated by a time allocation system that properly allocates activity times within a day. A person’s expected daily schedule is a function of his characteristics, household socioeconomics, long-term activity-travel environment, and his long-term activity and travel
pattern membership. The output of the expected schedule, is a group of potentially linked activities with timing and other information. This schedule constitutes activity frequencies of subsistence, maintenance, out-of-home leisure and returning home activities. It also contains information on when a person leaves home for an out-of-home activity (i.e., home departure time), total daily time he is willing to spend on activity and travel including staying at home during the day (i.e., daily time budget), duration of each activity, and travel time of each trip.

The second component in the system structure is the daily activity and travel scheduling (DATS), which resembles the short-term choice in activity participation (see Figure 5). Conditional on the activity and travel pattern membership generated from LATP, DATS assumes that an individual makes his daily schedules according to the following three steps: (i) At the beginning of a given day, he decides what types of activities he needs to pursue. These activities are called the planned activity list. (ii) Knowing his activity list, he makes a planned schedule based on his experience. He may add some unplanned activities or delete some planned activities to best reflect his needs on that day. (iii) He starts to execute the items one by one according to the planned schedule. Because of uncertainty involved in the decision making process, at the end of each activity, he evaluates his current situation against his plan and decides whether or not to update his planned schedule. These three steps lead to three sub-systems of DATS: planned activity generating, daily scheduling, and schedule updating.

At the first step, the exact number of activities on the target day is determined. This represents the tasks a person plans to accomplish and is determined based on his expected schedule with a random term. The first expected schedule represents his general behavior while the random term allows for daily variation. The second step - daily scheduling - is to order all activities and travel on the planned activity list and determine their timing. Instead of searching for an optimal schedule from a set of combinatorial schedules, scheduling at this step is considered a stochastic process, which orders the activities in a probabilistic manner. Adding unplanned activities to and/or deleting activities from the planned activity list is part of the scheduling process. Yet, unlike the production system which seeks a suboptimal solution through an interactive process, the scheduling process proposed here relies on the bounded rationality decision theory, i.e., a person will choose an alternative that meets his specific requirements. Therefore, if a generated activity schedule meets the time constraints in terms of total travel time or time to return home, then the schedule (called a feasible schedule) is considered to be the planned schedule and the scheduling process terminates. If, however, the schedule is infeasible (e.g., return-home time is later than that on the activity list), the scheduling process will generate another schedule until the requirements on the activity list are met or a predetermined number of generated schedules is reached. After obtaining the planned schedule, the person begins to execute these activities sequentially. Because of the uncertainty involved in the decision making process and information gained during his activity participation, the actual activity duration and travel time may be different from the planned counterpart. For example, a shopping activity may be prolonged when a person has to spend more time on looking for some unusual items, or longer than expected travel time may be encountered when an accident occurs on the roadway. Moreover, individuals’ habits or tastes are a source of variation in activity or travel time, even when the individuals may have exactly the same observed characteristics. These differences suggest that a more appropriate treatment of activity and travel time is to add a random value to the corresponding planned time. The random value accounts for the uncertainty
in decision making and unexplained variation among individuals. As a result, the actual time becomes unexpected, which may cause a delay or advance in the planned schedule. This requires modifying the remaining activities on the schedule. In addition, while a person is executing an activity, he may gain some additional information that leads him to reschedule the remainder of his activities to best fit his need. For example, an overcrowded location (a result of many people choosing the same location for activity participation) may cause a person to change this expected location to a less preferred place. This may also be viewed as the impact imposed by others through the instantaneous activity-travel environment. For this reason, a person is given an opportunity to modify his planned schedule when he completes an activity and is about to start the next one. It should be noted that any schedule updating will affect the instantaneous activity-travel environment, which in turn, may induce further updating.

Descriptive measures of the long-term activity-travel environment obtained from these schedules may be fed back to the forecasting system. Totaling the actual schedules of all individuals is a rich source of data with which the actual number of people at a particular location at particular times can be obtained. This aggregation of patterns provides an origin-destination (OD) matrix for that time period, which is key to assessing time-sensitive policy analyses such as congestion pricing, zonal restrictions, changing work weeks, and access management. Assigning these OD matrices using a traffic assignment package would give the same types of, but more accurate information than, all of the current travel demand analysis models. The combination of LATP and DATS is repeatedly applied by simulating individuals and their characteristics as well as the context and environment within which they act. This is a typical example of stochastic dynamic microsimulation.

Another microsimulation that uses econometric models to simulate daily activity travel patterns for individuals and uses the time allocation-scheduling approach is the Comprehensive Econometric Microsimulator for Daily Activity-travel Patterns (CEMDAP) model (Bhat, et al., 2003), which is also based on land use, socio-demographic, activity system, and level-of-service (LOS) attributes. Key distinctive element of CEMDAP is its reliance on hazard-based regression models to account for the continuous nature time of activity duration. Initially released in 2003, it is continually being expanded. The current version of CEMDAP complemented by a variety of components and name CEMUS includes population synthesis as well as the activity-pattern generation and scheduling of children, which is missing from many other simulators. CEMDAP is used currently to develop a new generation model system called SimAGENT for the entire Southern California Association of Governments is which 18 million persons reside. Another model that utilizes microsimulation is the Florida Activity Mobility Simulator (FAMOS) (Pendyala et al., 2005). FAMOS encompasses two modules, the Household Attributes Generation System (HAGS) and PCATS. Together, they comprise a system for modeling the activity patterns of individuals in Florida. The output is a series of activity-travel records. FAMOS is currently being further enhanced to include intra-household interactions and capture task allocation behavior among household members and is also integrated with other models as described later in this chapter. In a similar development path are the models AURORA by Arentze, et al. (2006) FEATHERS (Forecasting Evolutionary Activity-Travel of Household and their Environmental Repercussions) that simulates activity-level scheduling decisions, within-a-day rescheduling, and learning processes in high resolutions of time and space, and from the same Dutch team also MERLIN and RAMBLAS (Veldhuisen et al., 2000).
Microsimulations have continued to gain in popularity in the activity-based modeling universe as they move from research applications to practice. Examples include the Portland Daily Activity Schedule Model, New York’s "Best Practice" Model (2002) and the Mid-Ohio Regional Planning Commission (MORPC) Model (2003), both developed by Vovsha, et al. (2002, 2003), and the San Francisco model (Jonnalagadda, et al., 2001) are currently being utilized by their respective MPO. The San Francisco model also includes destination choice models and is calibrated using household and census data. Four other models for Atlanta, Sacramento, the San Francisco Bay Area, and Denver are also microsimulation based (Bradley and Bowman, 2006).

All these models focus on the paths of persons in space and time within a somewhat short time horizon such a day, week, or maybe a month. The consideration of behavioral dynamics has expanded the temporal horizons to a few years. However, regional simulation models are very often designed for long range plans spanning 25 years or even longer time horizons. Within these longer horizons, changes in the spatial distribution of activity locations and residences (land use) are substantial, changes in the demographic composition and spatial distribution of demographic segments are also substantial, and changes in travel patterns, transport facilities, and quality of service offered can be extreme.

Past approaches in modeling and simulating the relationship among land use, demographics, and travel in a region attempted to disengage travel from land use and demographics and treat them as mutually exogenous in a cascading system. Interactions among them are scientifically more interesting and from a policy viewpoint pressing due to urban sprawl and suburban congestion. For these reason increasing attention is paid to their complex interdependencies. This led to a variety of attempts to develop “integrated model systems” that enable the study of scenarios of change and mutual influence between land use and travel. An earlier review of these models with heavy emphasis on discrete choice models can be found in Anas (1982). Miller (2003) and Waddell and Ulfarsson (2003) twenty years later provide two comprehensive reviews of models that have integrated many aspects in the interdependent triad of demographics-travel-land use models. Both reviews trace the history of some of the most notable developments and both link these models to the activity-based approach above. Both reviews also agree that a microeconomic and/or macroeconomic approach to modeling land and transportation interactions are not sufficient and more detailed simulation of the individuals and their organizations “acting” in an time-space domain need to be simulated in order to obtain the required output for informed decision making. They also introduce the idea of simulating interactive agents in a dynamic environment of other agents (multi-agent simulation). The vast literature is reviewed by Timmermans 2003 and Miller, 2006, from different viewpoints about progress made until now. However, they both agree that progress is rapidly made and that integration of land use and transportation models needs to move forward. Creation of integrated systems is further complicated by the emergence of an entire infrastructural system as another layer of human activity - telecommunication. Today telecommunication and transportation relationships are mostly absent from regional simulation planning and modeling as well from the most advanced land use and transportation integrated models. Considerable research findings, however, have been accumulating since the 1970s (Salomon,1986, Mokhtarian, 1990, Mahmassani and Jou, 1998, Marker and Goulias, 2000, Weilland and Purser, 2000, Patten and
Another type of technologies (named enabling herein) helped us move modeling and simulation further. A few of the most important enabling technologies are stochastic simulation, production systems, geographic information systems, interactive and technology-aided data collection approaches, and more flexible data analysis techniques. Stochastic microsimulation, as intended here and briefly described above, is an evolutionary engine software that is used to replicate the relationships among social, economic, and demographic factors with land use, time use, and travel by people. As discussed above the causal links among these groups of entities are extremely complex, non-linear, and in many instances unknown or incompletely specified. This is the reason that no closed form solution can be created for such a forecasting model system. An evolutionary engine, then, provides a realistic representation of person and household life histories (e.g., birth, death, marriages, divorces, birth of children, etc.), spatio-temporal activity opportunity evolution, and a variety of models that account for uncertainties in data, models, and behavioral variation (see Miller, 2003, and Goulias, 2002, for overviews and Sundararajan and Goulias, 2003 for an application). Production systems were first developed by Newell and Simon (1972) to explicitly depict the way humans go about solving problems. These are a series of condition-action (note the parallel with stimulus-response) statements in a sequence. From this viewpoint they are search processes that may never reach an absolute optimum and they replicate (or at least attempt to) human thought and action. Models of this kind are called computational process models (CPM) and through the use of IF ….THEN….. rules have made possible first the creation of a variety of new models and were used extensively in the ALBATROSS system mentioned above and the Kitamura and Fujii, 1998, model systems. Geographic information systems are software systems that can be used to collect, store, analyze, modify, and display large amounts of geographic data. They include layers of data that are able to incorporate relations among the variables in each layer and allow to build relationships in data across layers. One can visualize a GIS as a live map that can display almost any kind of spatio-temporal information. Maps have been used by transportation planners and engineers for long time and they are a natural interface to use in modeling and simulation (Figures 3 and 4 are GIS examples). Advanced data collection methods and devices that are technologies that merit a note, although, not strictly developed for modeling, use internet (Doherty, 2003) and geospatial technologies to build complex interviews that are interactive and dynamic (Wolf, et al., 2001, Doherty et al, 2001, Auld et al., 2009). Very important development is also the emergence of devices that can record the bulk of environmental data surrounding a person movement, classify the environment in which the individual moves, and then ask simplified questions (Hato 2006). Soft computing and non-parametric data analysis. In the data analysis we see greater strides in using data mining and artificial intelligence-borne techniques to extract travel behavior patterns (Teodorovic and Vukadinovic, 1998, Pribyl and Goulias, 2003) and advanced and less restrictive statistical methods to discover relationships in the travel behavior data (e.g., Kharoufeh and Goulias, 2002). Soft computing is increasingly finding many applications in activity-based models (see www.imob.uhasselt.be). For a more recent and accessible review see Pribyl, 2007, and the application in Pribyl and Goulias, 2005. Henson and Goulias (2006, 2009) and Goulias (2009b) provide comprehensive reviews.
Microsimulation models also evolved in the interface between land use and travel behavior. The Integrated Land Use, Transportation and Environment (ILUTE) model (Salvini and Miller, 2003) model is designed to simulate the evolution of people and their activity patterns, transportation networks, houses, commercial buildings, the economy, and the job market over time. Within this vision, Miller and Roorda (2003), developed the Toronto Area Scheduling model for Household Agents (TASHA) that uses projects to organize activity episodes into schedules of persons. Schedules for members in a household are simultaneously generated to allow for joint activities. Both ILUTE and TASHA utilize CPMs and econometric utility-based paradigms. Most recently, Ettema et al. (2006) developed PUMA (Predicting Urbanization with Multi-Agents), a full-fledged multi-agent system of urban processes that represents land use changes in a behaviorally realistic way. The evolution of new model development ideas continues in a variety of directions with one model system attempting to integrated many ideas in one system. This is the SimTRAVEL: Simulator of Transport, Routes, Activities, Vehicles, Emissions, and Land, which integrates long term choices employing Urbansim, activity and travel using an enhanced version of FAMOS, and a combination of highway and transit dynamic traffic assignment to produce estimates of emissions (http://urbanmodel.asu.edu/ - accessed January 2010). These processes eventually will include the evolution of population, businesses, and land use as well as daily activity and travel patterns of people and the goods moving in a given area.

Similarities and differences among the implemented modeling ideas are:

- A hierarchy of decisions by households is assumed that identifies longer term choices determining the shorter term choices. In this way different blocks of variables can be identified and their mutual correlation used to derive equations that are used in forecasting.

- Anchor points (Home location – work location – school location) are inserted in the first choice level and they define the overall spatial structure of activity scheduling in a day.

- Out-of-home activity purposes include work, school, shopping, meals, personal business, recreation, and escort. These expanded the original home-based and non-home based purposes in the four-step models.

- In-home activities are explicitly modeled or allowed to enter the model structure as a "stay-at-home" choice with some models allowing for activity choice at home (work, maintenance and discretionary). In this way limited substitution between at home and outside home can be reflected in the models.

- Stop frequencies and activities at stops are modeled at the day pattern and tour levels to distinguish between activities and trips that can be rescheduled with little additional efforts versus the activities and trips that cannot be rescheduled (e.g., school trips).
• Modes and destinations are modeled together. In this way the mutual influence – sequential and/or simultaneous relationships can be reflected in the model structure.

• Time is included in a few instances in activity-based models. For example, departure time for trips and tour time of day choice are modeled explicitly. Model time periods are anywhere between 30 minutes and second-by-second and time windows are used to account for scheduling. This modeling component allows to incorporate time-of-day in the modeling suites. It also allows to identify windows of activity and travel opportunities. The presence of departure time also enables models to trip matrices for any desired periods in a day. In fact, output of time periods depends on traffic assignment needs and can be adjusted almost at will.

• Human interaction, although limited for now to the within-household interaction, is incorporated by relating the day pattern of one person to the day patterns of other persons within a household, their joint activities and trip making are explicitly modeled (joint recreation, escort trips), and allocation of activity-roles are also modeled.

• Spatial aspects of a region are accounted for using methods that produce spatially distributed synthetic populations using as external control totals averages and relative frequencies of population characteristics.

• Accessibility measures are used to capture spatial interaction among activity locations and the level of service offered by the transportation systems. These are also the indicators used to account for feedback among the lower level in the hierarchy decisions (e.g., activity location choices, routes followed, congestion) and the higher level such as residence location choice.

• Spatial resolution is heavily dependent on data availability and it reached already the level of a parcel and/or building at its most disaggregate level. Outputs of models are then aggregated to whatever level is required by traffic assignment, mode specific studies (nonmotorized and/or transit) and reporting needs and requirements.

29.4 Future Directions

The plethora of advances reviewed in this chapter includes models and experiments to create computerized virtual worlds and synthetic schedules at the most elementary level of decision making using microsimulation and computational process models; data collection methods and new methods to collect extreme details about behavior and to estimate, validate, and verify models using advanced hardware, software, and data analysis techniques; and integration of models from different domains to reflect additional interdependencies such as land use and telecommunications.

Much more work remains to be done in order to develop models that can answer more complex questions from policy analysis and for this reason a few steps are outlined here. In
policy and program evaluation, transportation analysis appears to be narrowly applied to only one method of assessment that does not follow the ideal of a randomized controlled trial and does not explicitly define what experimental setting we are using for our assessments. Unfortunately this weakens our findings about policy analysis and planning activities. Although we have many laboratory experiments that were done for intelligent transportation systems we lack studies and guidelines to develop experimental and quasi-experimental procedures to guide us in policy development and large scale data collection.

In addition, many issues remain unresolved in the areas of coordination among scale in time and space and related issues. In addition very little is known about model sensitivity and data error tolerance and their mapping to strategy evaluations. This is partially due to the lack of tools that are able to make these assessments but also due to lack of scrutiny of these issues and their implications on impact assessment.

Regarding strategic planning and evaluation, we also lack models designed to be used in scenario building exercises such as backcasting and related assessments (Robinson, 1982). The models about change are usually defined for forecasting and simple time inversion may not work to make them usable in backcasting. This area does not have the long tradition of modeling and simulation to help us develop suitable models with a few exceptions such as Miller and Demetsky, 1999, and Sadek et al., 2002.

In the new research and technology area, since we are dealing with the behavior of persons, it is unavoidable to consider perceptions of time and space. What role should perceptions of time and space (Golledge and Gärling, 2004) play in behavioral models and what is the most appropriate use of these perceptions? The multiple dimensions of time such as tempo, duration, and clock time are neglected in behavioral models.

Human interaction is considered important and is receiving attention in research Golob and McNally, 1997, Chandrasekharan and Goulias, 1999, Simma and Axhausen, 2001, Gliebe and Koppelman 2002, Goulias and Kim, 2005, Zhang et al. 2005, but only partially accounted for in applications as illustrated by Vovsha and Petersen (2005) and Pribyl (2004). Future applications will increasingly pay attention to motivations for human interactions and the nature of these interactions. This is particularly important in the relationship between land use policies and travel behavior (Yoon and Goulias, 2009, 2010) and the important issue of perceptions of place and related urban form (Deutsch and Goulias, 2010).

As we move closer to models that can satisfy the dynamic policy and planning need adopting a lifecourse perspective appears to be a better model framework (Goulias, 2009a). This, however, requires data that are longitudinal and offer trajectories of individual paths. They also offer the opportunity to create richer and multidimensional theoretical frameworks. This type of modeling and simulation is also better suited for specifying models of everyday action that are connected with the lives of people as they progress in linked lives and their environment over time. Most important, however, is their explicit modeling of relations that should not be just a static explanation of the number of contacts and the amount of time people spend in activities and on travel. In order to capture the behavioral process underlying the outcomes we observe in typical household surveys we also need to identify relations and their evolution over time as well as their differing nature across different contexts.
References


Unedited Draft for Comments – January 2010

Deutsch K. E. and K. G. Goulias (2010) Exploring Sense-of-Place Attitudes as Indicators of Travel Behavior. Paper to be presented at the 89th Annual Transportation Research Board Meeting and included in the CD ROM proceedings (Paper 10-0070).


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010

Mahmassani H.S. and R. Herman (1990) Interactive experiments for the study of tripmaker behaviour dynamics in congested commuting systems, in *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*. A compendium of papers from the 1989 Oxford Conference. Avebury, UK.


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


Unedited Draft for Comments – January 2010


<table>
<thead>
<tr>
<th>Type of policy tool</th>
<th>Brief description</th>
<th>Source of information*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Land use design and attention to neighborhood design for non-motorized travel</td>
<td><a href="http://www.compassblueprint.org">www.compassblueprint.org</a>  <a href="http://www.ecoiq.com/onlineresources/center/">http://www.ecoiq.com/onlineresources/center/</a></td>
</tr>
<tr>
<td></td>
<td>City boundaries are divided into incorporated, within the sphere of influence, and external to manage growth</td>
<td><a href="http://countypolicy.co.la.ca.us/BOSPolicyFrame.htm">countypolicy.co.la.ca.us/BOSPolicyFrame.htm</a>  <a href="http://www.ite.org/activeliving/files/Jeff_Summary.pdf">www.ite.org/activeliving/files/Jeff_Summary.pdf</a></td>
</tr>
<tr>
<td></td>
<td>Public involvement</td>
<td><a href="http://www.fhwa.dot.gov/reports/pittd/content.htm">www.fhwa.dot.gov/reports/pittd/content.htm</a></td>
</tr>
<tr>
<td></td>
<td>Health Promotion</td>
<td><a href="http://www.activelivingbydesign.org">www.activelivingbydesign.org</a></td>
</tr>
<tr>
<td>Pricing and Taxation</td>
<td>Congestion pricing and toll collection programs</td>
<td><a href="http://www.vtpi.org/london.pdf">www.vtpi.org/london.pdf</a></td>
</tr>
<tr>
<td></td>
<td>Parking fee management to restrict access by space and time</td>
<td><a href="http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c13.pdf">http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c13.pdf</a></td>
</tr>
</tbody>
</table>

*accessed January 2010
Table 2: Typical Tools for the Planner and Operations Manager in Transportation (continued)

<table>
<thead>
<tr>
<th>Type of policy tool</th>
<th>Brief description</th>
<th>Other source of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Shifting</td>
<td>Programs that change the workweek of individuals and firms</td>
<td><a href="http://www.its.dot.gov/PODOCS/REPTS_PR/13669/section05.htm">www.its.dot.gov/PODOCS/REPTS_PR/13669/section05.htm</a></td>
</tr>
<tr>
<td>Operational Improvements</td>
<td>Goods movements (freight) programs to improve operations</td>
<td><a href="http://ntl.bts.gov/DOCS/harvey.html">ntl.bts.gov/DOCS/harvey.html</a></td>
</tr>
<tr>
<td></td>
<td>Highway system improvements in traffic operations and flow</td>
<td><a href="http://www.dot.ca.gov/dist11/operations/trfimprv.htm">http://www.dot.ca.gov/dist11/operations/trfimprv.htm</a></td>
</tr>
</tbody>
</table>

*accessed January 2010*
Figure 1 A two-person (P1 and P2) activity-travel pattern and the time and space limits imposed by constraints. H indicates home, W indicates work, L indicates leisure, and S indicates shopping (source: Pribyl, 2004).

Figure 2 Time allocation to different activities in a day by staff members of a university (source: Alam, 1998)
Figure 3 Persons and activities assigned to buildings at four different times in a day (source: Alam, 1998)
Zone Presence and Travel Demand Output for Time Segment 8:00 – 9:00 AM

Zone Presence and Travel Demand Output for Time Segment 12:00 – 1:00 PM
Figure 4 Persons and activities assigned to buildings and travel to the network in four different time period in a day (source: Goulias, Zekkos, and Eom, 2004)
Figure 5. System Structure of a Dynamic Travel Model (source: Ma, 1997)

Legend:
- External component
- Component not modeled in the proposed system
- Component modeled in the proposed system