Towards a Behavioral Integration of Land Use and Transportation Modeling

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Abstract

This paper examines the linkages between household choices of housing and job location, vehicle ownership, and activity and travel patterns to develop a behavioral framework for integrating land use and transportation models. It assesses the interdependence of these choices, the processes used to represent them, and alternative methodological frameworks to represent them in an operational model system.

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1 Introduction

Over the past decade, there has been growing interest in integrating transportation and land use planning, based on a recognition that land use not only influences transportation outcomes, but that transportation investments also influence land use decisions, potentially undermining the benefits of capacity expansion aimed at relieving urban congestion problems. This recognition of feedback between transportation and land use has led to calls for integrating land use and transportation models used in the metropolitan planning process. While there has been some progress in linking together aggregate transportation models with aggregate spatial-interaction or spatial-input-output models of land use, no disaggregate behavioral framework has yet been developed that explain land use and travel behavior in an integrated way.

The need to better understand the behavioral linkages between daily household activity and travel patterns, on the one hand, and long-term choices of housing and job location and vehicle ownership, on the other, has been apparent for some time. From the early pioneering efforts to link residential location, housing type, auto ownership and travel mode to work in a multinomial logit model (Lerman, 1976), and related efforts to extend this approach (Ben-Akiva *et. al.*, 1980; Ben-Akiva and de Palma, 1986; Weisbrod *et. al*., 1980; and Clarke *et. al.*, 1991; Abraham and Hunt, 1997), to the recent linking of residential location to an activity-based model through a deeply-nested logit model (Ben-Akiva and Bowman, 1998), there have been many attempts to integrate aspects of long-term household behavior with daily travel behavior.

To date, however, the framework for this integration has not been complete enough to provide a robust behavioral foundation for model development that incorporates housing and labor market behavior with travel behavior. This paper seeks to develop a research agenda to construct a suitable behavioral integration, emphasizing approaches that cross traditional disciplinary boundaries within the behavioral sciences. The paper does not provide a systematic review and assessment of existing land use and transportation modeling systems, both because there are numerous reviews already available (Anas, 1987; Harris, 1985; Kain, 1985; Paulley and Webster, 1991; Southworth, 1995; Wegener, 1994, 1995; Miller, Kriger and Hunt, 1998; Parsons Brinckerhoff, 1998), another is in progress (SAIC, forthcoming), and because the level of interaction between land use and travel in existing operational model systems is generally based on loose coupling of model components based on aggregate data transfer, rather than the desired disaggregate behavioral integration.

2 Household Choices

The focus of integrating land use and transportation modeling lies in the interdependence of four sets of household choices: residential location, job location, vehicle ownership, and daily activity and travel patterns. This section examines each choice dimension in turn, and the subsequent sections explore their interdependence, and the underlying choice and market processes.

2.1 *Residential Location*

The choice of a residential location is actually a cluster of related choices, including the decision to move from an existing residence, the choice of housing tenure (rent or own), neighborhood, and housing unit. These choices are implemented through a housing search process. There is a vast literature on residential location and mobility. Our purpose here is not to review this literature (c.f. Clark and van Lierop, 1986), but rather to identify key dimensions for the proposed conceptual framework.

Some characteristics of housing make it a very unusual commodity. The durability of buildings, relatively high cost, and fixed location collectively make housing a highly differentiated product. Each building or parcel of land could be considered quasi-unique, since it differs (slightly) from its neighbors in location. This differentiation of real estate implies varying degrees of substitutability between individual real estate products. Two adjacent houses of the same floorplan in the same subdivision would be considered highly substitutable by most consumers, for example, whereas two houses further apart, or of substantially different floorplan or construction quality would not. The differentiation of real estate products is partly a response to differences between consumer tastes and needs. Households with higher incomes, with children, or with two workers, for example, will demonstrate different consumption preferences for housing and location than will households of differing income and life cycle characteristics. Market segmentation is related to product differentiation.

Transactions costs, stage of life cycle and other factors influence mobility. Mobility and location choice have been treated as sequential or nested choices in empirical research (Waddell, 2000; Clark and van Lierop, 1986). As a further extension of this approach, upgrading of an existing residence could be considered as an alternative to moving.

The high cost of housing and other real estate has given rise to financial markets for long-term financing of mortgages, and to rental markets for housing. This adds a dimension to housing demand that includes housing tenure, and the dual roles of homeownership as a means of investment as well as consumption. Long-term considerations such as expectations of future income and real estate price appreciation therefore come into play. Models dealing with future expectations must make assumptions about how these expectations are formed.

2.2 *Job Location*

Recognition of the importance of labor market behavior in modeling activity and travel behavior is apparent in much of the recent literature on activity-based travel modeling. To date, however, it appears that the labor market behavior of household members has not been incorporated theoretically or empirically into activity-based travel modeling. The main reference to the linkage of labor market behavior and travel in the research literature has been in the context of explaining women's relatively shorter commutes than men's (Hanson and Johnston 1985; Hanson and Pratt, 1988; Madden, 1981). The potential for household adjustment of labor market behavior to a change in commuting costs, such as changing jobs or quitting work (not an unrealistic possibility for low-wage workers with high commuting costs), raises the possibility that activity-based models that treat labor market behavior as purely exogenous will overstate the effects on travel behavior.

The reasons that labor markets should be considered in the framework of land use and transportation are clear. First, households need income to pay for housing and other goods and services, which they generally obtain from selling labor in the labor market or from other income sources such as investments, retirement or welfare payments. Second, the preponderance of work at a location other than at home gives rise to the principal source of travel, which is of vital concern to the land use-transportation connection.

Labor supply is created by individuals offering their time and human capital, or skills, to employers in the labor market, in exchange for wages. Labor supply decisions are made within the context of the life cycle of the individual. They are intertwined with human capital investment choices related to education and training. At the later stages of the life cycle, the timing of retirement may depend on many factors, including the retirement benefits available, the relative fitness of the individual to continue working, and legal considerations. Long-term choices about the allocation of work over the life cycle are treated as substitutions between market work, household work and leisure based on the relative productivity in market work over the life cycle. Market productivity, as signaled by wages, tends to start low at the early stages of the life cycle, peak in middle age, and then gradually decline in older ages. This prompts a shift away from market work towards household work during early and late stages of life.

Education and training, migration, and job search are considered investments in human capital, and can be treated as other kinds of investment decisions. They involve an initial cost, including any opportunity costs of lost wages by not working during the investment period, and an expectation of long-term returns on the investment through a stream of higher future wages. If the net present value of the increased wages exceeds the initial cost of the investment, it is a productive investment.

Labor force participation is not a binary choice, since work may involve part time or self-employment or flexible forms of contract labor. Occupations may be chosen that are more generic and low wage, but where there are more accessible opportunities and lower risk of unemployment; or may be highly specialized and high wage, but may involve longer commutes or offer limited mobility. Education, skills and experience influence the opportunity set of occupations available to a potential worker.

The concept of a reservation wage has been advanced as a measure of the minimum wage that a job seeker will accept, based on factors such as transportation costs to the workplace, day care and other associated costs of working, opportunity costs such as lost welfare benefits, expectations of market worth, and the value of leisure time.

2.3 Vehicle Ownership

Vehicle ownership has been treated as an independent choice modeled within travel demand systems, influenced principally by socio-economic characteristics of households. More recent modeling efforts have incorporated effects of neighborhood characteristics such as urban design and transit service to improve the realism of the vehicle ownership models. To date, little systematic effort has been made to treat vehicle ownership within a broader framework of household choice regarding housing location, workplace and daily travel patterns.

2.4 Daily Activity and Travel Pattterns

Roots of the emerging activity-based approach to travel modeling may be found in the planning field in Chapin's (1974) theory of activity patterns as a basis for the derived demand for land use, in the time-geography of space-time constraints of Hägerstrand (1970), and in the microeconomics of the allocation of time and money budgets (Becker, 1965; DeSerpa, 1971; Avans, 1972; Truong and Hensher, 1985, Jara-Díaz, 1998). Recent advances in travel behavior research have resulted in substantial innovation in the use of daily activity schedules as an organizing framework for a new generation of travel models. However, collections of this research activity (Carpenter and Jones, 1983; Jones, 1990; Ettema and Timmermans, 1997) suggest substantial variation in approach.

A theme that unifies much of this work is that that the demand for travel is derived from the demand for activities, and consequently, that an activity-oriented approach will increase predictive accuracy, flexibility and policy responsiveness beyond the previous generation of trip-based models (Jones *et. al.*, 1983; Kitamura, 1988; Axhausen and Gärling, 1992; and Gärling *et. al.*, 1994). But as Ettema and Timmermans (1997) concede, skeptics are not yet convinced that large-scale activity-based models will yield sufficient improvements to justify the greater complexity, cost, and effort required to develop and implement them.

Indeed, the complexity of modeling the coordinated choices of activities and travel schedules of household members, and differing assumptions about the nature of decision-making processes, have led to a proliferation of approaches. These include microsimulation (McNally, 1997), heuristic rule-based methods (Vause, 1997), nested logit models (Ben-Akiva and Bowman, 1995), and application of artificial intelligence methods such as neural networks (Pendyala *et. al.*, 1995). Others have called for a more robust theoretical foundation rooted in behavioral theories of decision-making (Axhausen, 1993; Gärling, 1994a; Gärling *et. al.*, 1997), or microeconomic theory of time and budget constraints (Kraan, 1997; Kockelman, 2000) and extensions to include constraints on activities and consumption (Jara-Díaz and Martinez, 1999). Economic approaches using random utility maximization, and decision-theoretic approaches emphasizing simpler choice heuristics that are implemented in rule-based systems, have not been fully reconciled or integrated.

3 Interdependence

The use of activity-based travel models for applied policy analysis over the long time frames relevant for planning major transportation investments requires that the housing and labor market behavior of households be addressed endogenously. If these aspects of household behavior are treated merely as exogenous inputs to the activity-based travel models, then the possibility that households can adjust with combinations of short and long-term behavior is systematically ignored. A significant increase in transport costs, for example, could influence a household to consider adapting with any combination of daily activity and travel patterns, job locations or residential location. The increasing prevalence of metropolitan planning strategies that consider combinations of land use and transportation policies also argues for a unified and consistent framework to treat the interdependence between housing, labor and travel behavior.

3.1 Interdependence Over Time

Time is explicitly treated in activity-based models, since the scheduling of activities throughout the day requires an accounting framework for time. The accounting framework for time provides obvious benefits in terms of improving the ability of travel models to predict travel by time of day, but creates complications when we consider time frames longer than the day of travel. In the longer time frame of a year or several years, households may change in composition, acquire a vehicle, move to another house, or have a member join or depart from the labor force or change jobs. The recognition of choice behavior that varies across time frames is not new (c.f. Cullen, 1978), but the interdependence between short- and long-term choices is poorly understood and rarely addressed in modeling applications.

The influence of longer-term choices concerning the housing and labor market, household composition, socio-economic status, and stage of life-cycle have been treated as exogenous in travel demand models. These characteristics are usually represented through market segmentation, if at all. While the importance of long-term choices in conditioning short-term activity and travel behavior is generally acknowledged, the possibility that short-term and long-term choices are mutually informed is commonly ignored.

In the economic literature, the interdependence of short and long-term choices is analyzed within a microeconomic framework of utility maximization. In this framework, the utility of residential choice is influenced by access, an economic measure of the transport user's benefit that combines information on travel accessibility and the attractiveness of opportunities at destinations (Ben-Akiva and Lerman, 1979). The interdependence of residential location and travel choices have been addressed operationally by assuming that short and long-term choices are made simultaneously so as to optimize household utility subject to daily time and budget constraints (Kraan, 1997), or can be represented as a hierarchical choice in a nested logit model of residential location and daily activity-travel patterns (Ben-Akiva and Bowman, 1998). In the nested logit model of residential location and daily activity schedule estimated by Ben-Akiva and Bowman (1998), housing type and tenure are treated as exogenous, residential location only considers accessibility related to commuting to work, and the nesting structure suggested that daily activity patterns condition residential location rather than the reverse.

3.2 Interdependence of Household Consumption and Production

Becker (1973) developed a theory of household production in which the household consumes 'commodities' that are produced with inputs of market goods and services and the time of household members. This approach fundamentally recasts consumer theory within a framework of production theory, analogous to the production theory of the firm, and highlights the importance of non-market household work. This approach aligns well with the activity-based travel approach that classifies activities into work, maintenance and leisure. It may also hold a key to a behavioral integration of daily activity and longer-term household labor and housing market behavior.

The growing empirical application of Becker's household production theory to explain the relationships between marriage, childbearing, and household allocation of time to market and household work between household members make clear that factors that have long been considered exogenous to travel and housing market behavior are not. Recent empirical research has shown substantial progress in empirical estimation of the interdependence of marriage, childbearing, labor market intensity, wages, and specialization within families. Lundberg and Rose (2000), for example, find that "the birth of the first child leads to substantial reallocations of time and effort for married couples. On average, the first child is associated with a 5 percent reduction in the mother's wage rate and a 9 percent reduction in the father's. Hours worked by mothers decline by 45 percent but there is no significant change in average hours worked by fathers." Marriage, childbearing, and divorce, in this context, are endogenous to the consideration of labor force participation, auto ownership, housing choice and travel behavior.

Data from the United States and Norway suggest relatively consistent patterns in the allocation of time across the categories or market work, household work and leisure, including consistent gender relationships, as shown in Table 1. It appears from these data that total hours spent working was approximately the same for men and women, slightly higher for both in the United States, but that women specialized in household work relative to men in both countries. Compared to data from 1880, when men in the United States spent only approximately 12.5 hours in leisure activities, and women approximately 10 hours per week, these data show a significant increase in leisure time, though women shifted substantial time from household work to market work (Fogel, 1999).

Table 1: Allocation of Weekly Hours to Work and Leisure, United States and Norway, 1980-1981

	United States		Norway	
Hours at Each Activity	Men	Women	Men	Women
Market work, including commuting, moonlighting, job search	44.0	23.9	34.2	17.6
Household work	13.8	30.5	16.8	33.0
Total work	57.8	54.4	51.0	50.6
Total leisure	41.8	41.9	45.5	45.2
Personal care, including sleep and rest	68.2	71.6	71.4	72.1

Source: Juster and Stafford (1991)

3.3 Interdependence Within Households

The analysis of housing and labor market interaction requires addressing the complication that the unit of analysis for labor market behavior is generally the individual, whereas the unit of analysis for housing market behavior is almost universally the household. The need to study labor market behavior at the intra-household level has been recognized in labor market research for some time, and various approaches have been taken to deal with intra-household decision-making of married partners, such as assuming that the preferences of the household members are identical, or that only one household member makes decisions, or that some form cooperative or non-cooperative bargaining takes place (Lundberg and Pollak, 1996). To the extent that the issue of intra-household choice is recognized explicitly in the activity-based travel modeling literature, it has been dealt with as a maximization of the composite utility of household members in considering residential location and daily activity and travel schedules (Ben-Akiva and Bowman, 1998).

Clearly, labor force participation decisions on the part of individuals do not occur independently of the household of which the person is a member. Labor supply theory that has evolved to explain intra-household specialization is based on the relative productivity of each member in market and household production activities, and on household income. If one member is relatively more productive in household work, while the other is more productive in market work, as evidenced by a higher market wage, then there will arise a specialization in market and household work. As one of these factors changes, income and substitution effects shift allocation between market work, household work, and leisure, and between household members (Ehrenberg and Smith, 2000). The allocation problem is complicated by the possibility that household members may be substitutes in the production of household production of commodities, but complements in the consumption of those commodities. For example, long work hours or non-synchronized work hours between partners means that shared meals become impossible, reducing the value of time spent at meals to both members.

3.4 Interdependence as Lifestyle Choice

The lifestyle concept has been identified as a framework for describing clusters of household choices of residential location, labor force activity and auto ownership that predispose or condition patterns of daily activity and travel behavior (Salomon, 1983, 1997; Ben-Akiva and Bowman, 1998; Wegener, Waddell and Salomon, 2000). Lifestyle has been widely embraced in the field of market research as a useful basis for market segmentation since its introduction by Lazer (1963). Lifestyle and psychographics have generally been used as interchangeable terms in marketing literature, but represent, respectively, the construct and the operationalization of this approach to market segmentation. This approach seeks to group consumers according to their motivations, interests, opinions, and patterns of activity and consumption.

Concerns about the generalizability and stability of activities and attitudes stimulated further research on more fundamental and stable drivers of behavior. Vinson, Scott and Lamont (1977), for example, suggest a hierarchical ordering of values; activities, interests, and opinions (Plummer, 1974); and product benefits as a means of organizing these concepts according to immediacy of the relationship to actual consumer behavior. This line of research has argued that values are a useful basis for segmentation because there are relatively few core values, they are more central and closely related to behavior than are personality traits, and more directly tied to motivation than attitudes (Valette-Florence, 1986).

In a related form of market segmentation now used widely in market research, demographics, geography, lifestyle and consumption behavior are combined to classify neighborhoods as lifestyle clusters. Geodemographics, as this approach has come to be known, was popularized by Weiss (1988), and is now widely used to classify zip codes in the United States for targeted marketing. It is based on the assumption that lies behind the old adage that "Birds of a feather flock together," namely that neighbors are likely to be similar in socioeconomic characteristics, lifestyles and consumption behavior (Mitchell, 1995).

To date, however, lifestyle has been treated in the market research literature as a form of market segmentation in housing demand or other consumption behavior (Bagley and Mokhtarian, 1999; Feitelson, 1993; Michman, 1991; Wedel and Kamakura, 1998), making lifestyle an exogenous basis for classification. The use of lifestyle for market segmentation begs the question of how individuals and households choose lifestyles, or adapt or change them over the course of their life cycle or in response to changing conditions. It therefore does not solve the more fundamental problem of developing a behavioral framework that permits the analysis of the relationships between long-term and short-term choices and between household members.

3.5 Interdependence Between Housing and Labor Markets

Household actions take place within multiple interdependent markets for housing, labor and travel. The term markets broadly represents an action-space within which transactions are conducted between consumers and suppliers. Modeling based on household choices must therefore represent actions within the framework of these markets – even if a purely microeconomic approach is not taken.

Individuals and households act as consumers in the real estate, goods and services and transportation markets; as suppliers of labor; and as borrowers and investors. Within each of these markets, actors can choose to become active participants in the market, obtain information or initiate a search, and conclude a transaction or choose to continue searching or withdraw from active market participation. Assumptions made about participation in markets, the level of information available, the exhaustiveness of the search, the time required to adjust to changes in conditions, and other influences on the search and transaction process define the nature of aggregate market processes and outcomes, producing either imperfect markets operating in disequilibrium, or perfect markets in stable equilibrium.

The relationships between labor and housing market choices have received relatively little systematic research attention in relation to travel behavior, even though the resulting demand for travel to work is at the center of travel modeling. Perhaps much of this can be blamed on the long-standing assumption underlying urban economic theory that residential location choice is conditional on the exogenous choice of workplace (Muth, 1969). There has been no shortage of empirical evidence to contradict that assumption (Waddell, 1993), and the preponderance of two-earner households in recent decades makes this an intuitively untenable assumption, but the assumption persists in much current work. To the extent that travel-related research has addressed the linkage of residence and workplace, it has been principally in relation to the hypothesis of a spatial mismatch between the residential location of low-income minorities and the location of employment opportunities for them (Kain, 1968; Ihlandfelt, 1992; O'Regan and Quigley, 1999), and on jobs-housing balance (Cervero, 1996; Levine, 1998). There are relatively few attempts to address at a more general theoretical level the interactions between housing and labor markets (Allen and Hammett, 1991), or empirical efforts to sort out the complex interdependence between residential and workplace choice within the household (Siegel, 1975; Simpson, 1980, 1987; Linneman and Graves, 1983; Merriman and Hellerstein, 1994; Waddell, 1997).

4 Decision Processes

4.1 Job and Housing Search Processes

In residential location or job choice, the household or worker first undertakes a decision to search, and then proceeds through a search process that may end in a satisfactory completion with a new home or job, or may not. Search theory originated with the one-period, fixed-sample size model (Stigler, 1961) in which the consumer samples alternatives (varies search intensity) to find the lowest price. The sequential search model (McCall, J., 1970; Rothschild, 1974) is a multi-period search process that limits the searcher to one observation per period. These two aspects of search, intensity and duration, were combined by various researchers into an 'optimal search model' (Gal, Landsbers and Levykson, 1981; Benhabib and Bull, 1983; Morgan and Manning, 1985; and McKenna, 1986). This approach has been recently applied to examine housing search behavior and the effects of brokers on the intensity and duration of search (Baryla, E., L. Zumpano and H. Elder, 2000). Search theory also figures prominently in recent research examining the relationship between housing consumption and labor supply (Rowendal, J. 1998; Ommeren, J., P. Rietvend and P. Nijkamp, 1997; Ommeren, J., 1999).

4.2 Uncertainty and Risk in Decision-making

The neoclassical, mainstream, economic view of consumer decision-making is expressed succinctly by Coddington (1975, p. 151):

> Instead of asking how reason can be applied to the knowledge that men can or do have of their economic circumstances, [neoclassical economic theory] asks how reason can be applied to circumstances that are perfectly known – problems of ignorance, uncertainty, risk, deception, delusion, perception, conjecture, adaptation and learning – are then tackled as a complication or refinement of the theory…

The representation of decision-making processes of individuals and households over short and long time frames, and how they cope with constraints, ignorance, and risk has been the subject of substantial research and debate in economics and elsewhere in the social sciences. These assumptions are critical preconditions, however, to specifying the nature of interactions within markets for real estate, labor and goods and services that form the basis for land use and transportation interaction. Are consumers rational 'maximizers' that choose the maximize utility alternative with full information on all possible alternatives as in neoclassical consumer theory, or 'satisficers' that use simple heuristics to limit their search and choose between a small number of alternatives (Vause, 1997), perhaps seeking to minimize loss more than maximize gain, or do they act in the face of risk and uncertainty using imagination and creativity (Shackle, 1949, 1966; Mises, 1962)? The assumptions made regarding the nature of choice behavior fundamentally shape the modeling strategy, giving rise to partial or general equilibrium approaches consistent with mainstream neoclassical economics (Samuelson, 1954), or disequilibrium adaptive approaches proposed by non-mainstream economists and other behavioral disciplines (High, 1990, Heap *et. al.*, 1992).

Behavioral and neo-Austrian branches of economics, market research, and psychology reverse the neoclassical approach. The decision-making process of the consumer, with all its attendant problems, are at the center of attention in the literature on behavioral theory of decision making (Abelson and Levy, 1985; Payne *et. al.*, 1992; Heap *et. al.*, 1998 for reviews of this literature). Gärling *et. al.* (1997) apply behavioral theories of decision making within the context of activity and travel, focusing on the integration of the outcomes of multiple choices. Behavioral theories of decision making recognize that is is unlikely that multi-person households can be perfectly informed as they coordinate and optimize their individual and collective choices of housing, labor supply, human capital investment, goods and services, and allocation of time and travel over present and future time periods. In order to model such complex behavior, theories should be based on more realistic assumptions about consumer decisions.

Kay (1982, 1984) generalized neoclassical firm production theory to account for strategic and tactical behavior in the face of uncertainty. He interpreted the pricing and output choices for a particular product that a firm makes, given the mix and scale of production of all the outputs of the firm, as tactical behavior. Strategic behavior, by contrast, includes decisions about what mix of products to produce, given the available information about costs and revenues. Earl (1984, 1986) used these insights and other aspects of behavioral decision theory to extend household production theory beyond the neoclassical approach to decision making. Approaches such as this to strategic and adaptive decision-making by households seem potentially promising for integrating short and long-term household choice behavior.

The short-term behavior is tactical in the sense that it is focused on the logistics of coordinating and scheduling the household during the course of the day, making appropriate substitutions of time, travel and activities within the constraints imposed by commitments that cannot be modified during the day. Longer-term choices are strategic in the sense that they shape the overall lifestyle of the household, and are chosen with general expectations of the preferred range of daily activity and travel patterns, but not perhaps with full knowledge of these details.

4.3 Market Processes

The neoclassical economic description of the operation of markets was developed by Walras (1874) and extended by Arrow and Debreu (1954), among others. A concise summary of this view of markets is given by Heap *et. al.* (1992, p. 186):

> Now consider any list of prices, one for each good and type of labour. For each consumption good there will be demands (by consumers) and supplies (by firms). Similarly, for each raw material and for each type of labour there will be demands (from firms) and supplies (by consumers). The market for a particular good or type of labour is said to *clear* if there is neither excess demand nor excess supply; the total amount demanded is exactly in balance with the total amount supplied. There is a state of *competitive equilibrium* (or Walrasian equilibrium) if all markets clear simultaneously. Another way of putting this is to say that in equilibrium, the plans of all agents are consistent with one another. Each agent decides independently, in light of its own objective and the list of market prices, how much of each good to buy and sell. But all these independent decisions mesh together in such a way that every plan can be carried out.

Given certain assumptions, it has been proved that every economy has a competitive equilibrium, that any competitive equilibrium is Pareto-efficient (no-one can be made better off without making someone else worse off), and that every Pareto-efficient allocation of resources can be achieved through some competitive equilibrium (Heap, *et. al.* 1992). The analytical power of this neoclassical approach cannot be denied, but there has been no shortage of criticism regarding its assumptions. To begin, how are we to understand that the competitive equilibrium is reached?

Walras proposed treating the market as being coordinated by a fictitious auctioneer (recall that all agents are price takers in perfectly competitive markets), calling out tentative prices in the market for each good, tabulating demand and supply at that price, and revising the prices called out until all agents find mutually-satisfactory prices to conduct transactions, at which point demand and supply equate in all markets, and all transactions are conducted simultaneously. The use of the auctioneer to finesse the interactions within markets to achieve competitive equilibrium leaves much to be desired. It does not, for example, motivate prices or price adjustments.

A second view of markets derives from Edgeworth's (1881) view of the economy as a bazaar rather than an auction, with everyone engaged in bargaining with everyone else. This approach provided a pioneering example of what has recently emerged as cooperative game theory (Heap *et. al.*, 1992, p. 191). The only constraint imposed on the behavior of this market is the law of property: no-one can be forced to trade if they are unwilling, and if two parties agree to a trade, no-one else may stop them. Edgeworth hypothesized, and Debreu and Scarf (1963) later proved, that with a sufficiently large number of traders, the core of the bargaining game would contain only the competitive equilibrium.

A third view of equilibrium is found in the models of land use emerging within urban economics. Alonso (1964) develops the monocentric model of land use using a bid-auction approach to equilibrium, in which consumers bid for parcels at every location, and at each location the land is allocated to the highest bidder. This approach treats land as a quasi-unique commodity, making demand elastic and supply inelastic at any given location, and placing market power to determine prices in the hands of the consumer.

Regardless of the approach used to reach competitive equilibrium, such an equilibrium may fail to produce an efficient outcome if the assumption that all agents are price takers is violated by monopolistic competition (consider antitrust laws and recent litigation against Microsoft for evidence of this concern) or by economies of scale in the production of a good. In addition, it requires the unrealistic assumptions of no public goods or externalities to produce efficient outcomes. And finally, Pareto-efficiency requires that agents perfectly anticipate the future, since agents act on plans that involve both the present and the future, such as investments or durable goods. Optimality theorems therefore require the existence of contingency markets for future goods.

The Austrian school provides an alternative view of market processes, focusing on the lack of information that agents have, and on their active entrepreneurial search for opportunities for gain (Hayek, 1948; Kirzner, 1973). Entrepeneurship provides the motivation missing in the Walrasian view of the market, with agents being alert to and seizing opportunities, and acting with limited information about the ultimate consequences of their actions. The view emphasizes the dynamic operation of markets in disequilibrium, rather than focusing on the hypothetical achievement of a state of equilibrium perhaps never achieved in reality.

There are differing implications for interpreting the way agents act within markets, in particular for defining the appropriate role of governmental intervention. Neoclassical assumptions have led to the development of welfare economics, and provide a basis for intervention in imperfect markets. Austrian economists have argued that governmental intervention is generally unwarranted, and will stifle entrepreneurial action. And more subjective interpretations of the actions of agents (see Shackle, 1949), suggests a role for government to stabilize confidence, and to dampen swings of pessimism and optimism (one might interpret the role of the Federal Reserve Bank in this light). Given the important role of governmental institutions in shaping local real estate and labor markets through interventions in the form of transportation infrastructure investments and urban development policy, these implications are significant. The Austrian approach, in spite of plausible assumptions about individual decision making and the operation of markets, is both antithetical to the possibility that governmental intervention is warranted, and has scrupulously avoided formalism, so it is not of much use in developing models of urban systems that can be used to assist in urban policy formation. Some of its theoretical contributions towards understanding market disequilibrium may well prove useful in this endeavor, however.

4.4 Expectations, Planning, Learning and Adaptation

To what extent do households correctly anticipate the future? Do they have perfect foresight regarding the outcome of all possible current and future consumption decisions, as is assumed in some microeconomic general equilibrium approaches? Or are they myopic, relying only on the recent past to guide their decisions, as is common in other microeconomic work and in some rule-based simulation approaches? To what degree do decision makers plan their actions into the future? Do they learn from experience and adapt their decision making in light of new information and experience? These are fundamental questions about the nature of the decision process that differentiate approaches to the modeling of household choice. The assumptions made about these aspects of the choice process heavily influence the viability of alternative modeling frameworks, addressed in the next section.

5 Methodological Frameworks

The research challenges outlined in the preceding sections have been approached using a variety of methodological frameworks. This section explores some of the main frameworks that have been used, such as random utility maximization and decision heuristics, and highlights some emerging approaches that warrant further attention, such as multi-agent simulation and Bayesian networks.

5.1 Random Utility Models

The household choice of residential location, job location, vehicle ownership and daily activity and travel pattern is a discrete multi-dimensional choice problem. These choices can be modeled sequentially or simultaneously using Random Utility Maxinization (RUM) models (McFadden, 1973). Multi-dimensional problems have been widely treated with a model structure that allows for joint and conditional discrete choices that are dependent on a large number of discrete or continuous explanatory variables. The decision makers are households and individuals. If decision makers are assumed to make rational choices, that is, when faced with choices that offer different utilities, a rational decision maker selects the alternative offering the highest utility, this leads directly to random utility models.

The most widely applied model structures have been the multinomial logit model and the nested logit model. The multinomial logit model can estimate the probability of a decision maker choosing an alternative from a large number of possible alternatives but it suffers from the assumption of independence for irrelevant alternatives (IIA property). The nested logit model reduces the effect of IIA by grouping related alternatives in conditional nests. The technique allows the lower conditional nests to affect the choice in upper nests through an inclusive value (McFadden, 1973), resulting in a model structure that allows for joint multi-dimensional choice which can be sequentially conditioned on previous choices.

There are many other random utility model structures that may be more appropriate in specific cases. For example, multinomial probit has been used less than logit because it is computationally more burdensome, but it offers the benefit of not suffering from the IIA property (see Daganzo, 1979). There are also other variants of the logit model that allow for heterogeneity among the decision makers and that do not have the IIA property or have it to a lesser degree. Such variants will not be discussed here because the basic theory is the same and the details of particular models are beyond the scope of this paper.

Since random utility models are based on the assumption of rational decision makers, choosing the alternative that offers the highest utility, these models have a behavioral element and are not purely statistical in nature. These model can therefore be grouped with behavioral disaggregate models (see Clark and Lierop, 1986). The models can handle aggregations of alternatives but that requires correction factors for the models to remain consistent (see McFadden, 1978, Ben-Akiva and Lerman, 1985).

One immediately obvious difficulty with multi-dimensional choice models is the possibly large number of alternatives. The estimation and model setup can be cumbersome, both computationally and in data collection. McFadden (1978) shows that a random sample of alternatives gives consistent estimates. This allows researchers to reduce the number of alternatives by selecting a random sample of alternatives. Ben-Akiva and Lerman (1985) describe other techniques of sampling alternatives.

5.1.1 Hierarchical choices

The modeling of residential location and travel behavior may appear to have a natural hierarchy, but this is not a correct interpretation of the nested logit model. A household may choose a neighborhood to live in first and conditioned on the neighborhood may choose a residence. Conditioned on the neighborhood and residence the household may choose vehicle ownership and a daily activity pattern. This hierarchy would fit the nested-logit structure, but it is not necessary that households make the choices in that order. The model order should emerge from the estimation. The grouping in nested-logit is not the result of a behavioral hierarchy of choice, it is merely a grouping that groups alternatives that are highly correlated with each other within the group but less so with alternatives in other groups. The rationale is to address violations of the IIA property but not necessarily to organize the choices in the same way that the decision makers view them.

Eliasson and Mattsson (2000) develop a theoretical nested logit model of residential zone, house type, car ownership and travel pattern. Ben-Akiva and Bowman (1998) used a nested-logit structure to estimate residential location and the daily activity pattern. They anticipated the residential location choice to be first and the daily activity pattern to be conditioned on location. What they found was that the residential location was conditioned on the type of daily activity pattern while the actual details of the activity pattern, for example the mode, were conditioned on location. While counter-intuitive from a behavioral perspective, this result is merely a statistical artifact.

Sometimes we can use theory to suggest a structure since some choices are or are likely to be conditioned on other choices. However, often we do not know which choice is conditioned on which. For example in residential location models, the workplace location is often assumed to be a marginal choice, or completely exogenous to the residential location. Clearly the choices are dependent on each other and belong in the same model, but the order is likely to vary by household and circumstance. Waddell (1993) found that the accessibility to work in residential location was as important as the accessibility to the residence in workplace location, and that estimation rejected alternative nesting structures, leading to a joint estimation of residence and workplace. Abraham and Hunt (1997) also use this reasoning to model workplace and residential location jointly, i.e. on the same level of nesting.

It is not necessarily clear, *a priori*, which decisions are choice-dimensions and which are attributes of a choice. Households select a neighborhood, house type, and dwelling unit, but they also select things that typically are taken to be attributes of the chosen alternative. For example, the number of bedrooms, lot size, unit size, and others. Households trade these attributes for each other in making their final housing unit choice. In principle some of these attributes could be additional choice-dimensions. The unit choice could then be first between detached housing units and apartments but each could be split into one bedroom units, a two bedroom unit and so on. This suggests that a nesting of attribute choices under a more general housing unit choice could be appropriate.

5.1.2 Linking long and short-term choices

Some choices are clearly short-term and others are long-term. It is important to link them together in an appropriate fashion. It appears to be logical to assume that short-term choices are conditioned on long-term choices. Long-term choices are, for example, residential location, workplace location, and vehicle ownership. The household lifecycle is also important for long-term estimation.

Ben-Akiva and Bowman (1998) estimate a model that contains elements of both long-term and short-term choices. Since residential location is a long-term choice they suggest that this could be the effect of the household long-term lifestyle choice. They found that the short-term choices of the details of the daily schedule where conditioned on the daily activity pattern and residential location. Their results therefore indicate that long-term and short-term choices can be properly estimated in a nested-logit structure with the short-term choices conditioned on the long-term choices.

5.1.3 Linking household and individual choices

Certain choices are mainly household choices and others are mainly individual choices but all choices are likely to be a mixture of both. The residential location is likely to be a household choice since all the individuals must be taken into account while the individuals are likely to have more to say about where they work. The choices are linked, however, and should be represented as such in model estimation. Lerman (1976), and Waddell (1993) avoided the interaction between multiple workers by restricting the study to single-worker households. In other cases the workplace of one worker has been used.

Abraham and Hunt (1997) estimate a model of residential location, workplaces and mode choices for multiple-worker households. They do this in a nested-logit model. They use a different nesting structure for households with different numbers of workers. They use nesting factors that are functions of the socio-economic variables associated with particular workers and therefore allow different workers to have different effects on the overall model. In a typical logit model these nesting factors are set to unity. Abraham and Hunt (1997) explain that they nest the workers' mode choices so that a worker with a lower nesting factor is conditioned on a worker with a higher value. They therefore allow individual workers in a household to affect the household residential location.

Ben-Akiva and Bowman (1998) also take this interaction into account in their residential location model. They also use nested-logit formulation. They estimate the choice of a daily activity schedule for household individuals conditioned on residential location. This allows different members of the household to affect the residential location choice differently depending on what daily activity schedule opportunities the location offers them individually. This is important because one location can be good for one person but bad for another person in the household.

These recent papers show that the current trend is to improve the linking of household and individual choices in one model. This can be done through the use of the nested-logit model. Abraham and Hunt (1997) nest the household members in a conditional chain of nests, while Ben-Akiva and Bowman (1998) insert the expected utility from individual choice models into the household residential location choice.

5.1.4 Dynamic modeling

Most often the estimation of residential location and travel behavior depends on cross-sectional data, i.e. they are fixed at a certain point in time. This clearly gives a limited picture since some housing decisions occur over time. It is costly for individuals to change their residential location and the decision to move therefore has a certain inertia that is difficult to capture without modeling the time dimension. It is also difficult, or impossible, for decision makers to change their long-term choices as soon as their socio-economic variables change. For example, when income changes it is difficult for a household to move right away to adjust their consumption. So mobility, socio-economic variables and life cycle changes are all changing over time and it would be beneficial to somehow capture that in a model.

To estimate a model with a time dimension we need data to be collected over time, i.e. panel data. Such data is costly to collect and it is therefore relatively rarely done. When we do have panel data and seek to estimate a discrete choice model new problems arise. Since we now have multiple observations from each decision maker (household or individuals) the stochastic part of the utility will be correlated across the observations from one decision maker. This correlation can be computationally difficult to handle. For a discussion on estimating logit models of panel data see for example Börsch-Supan (1987).

5.1.5 Limits to RUM

It may be the case that the complexity of the full treatment of the interaction of intra-household decision-making regarding residential location (and mobility and housing tenure), job location (and labor market participation and hours worked), vehicle ownership, and daily activity and travel patterns exceed the limits of random utility modeling. The requirement of organizing the choices into hierarchical nesting structures is particularly limiting and cumbersome, and may not adequately represent the variation in model structures that exist in real behavior. The constraints of random utility modeling, however, may not be as binding as the lack of suitable data and theory to fully integrate these choice dimensions.

5.2 Decision Heuristics

An alternative approach to the microeconomic random utility maximization techniques outlined in the preceding section is the use of rule-based, or heuristic simulation of household decision processes. These techniques have been used to develop operational activity-based travel model systems, such as the Albatross system (Arentze and Timmermans, 2000) and AMOS (Pendyala *et. al.* 1995). This approach has also been extended to represent learning and adaptation in choice making (Aentze and Timmermans, 2000; Timmermans *et. al.* 2000). A rule-based approach has also been applied to housing market decisions (Oskamp, 1997).

In the more complex of the rule-based approaches, multi-dimensional choices are decomposed into decision trees (Arentze and Timmermans, 2001) or into decision plan nets (Oskamp, 1997, Whan Park *et. al.* 1981). To date, no single model system has been constructed using this approach that encompasses the key household choice dimensions of housing, job, vehicle and travel patterns.

Rule-based approaches such as these have been criticized by proponents of the economic approaches as being too deterministic, and as lacking a consistent theoretical foundation such as microeconomics. The counter-arguments suggest that microeconomic approaches have been too restrictive and unrealistic in their assumptions, requiring that choosers have unreasonable information about the present and future, and making perfectly rational decisions on the basis of this perfect information. There may be some validity to both of these sets of concerns, generating promising research opportunities that attempt to hybridize the more interesting features of heuristic approaches, such as the flexible structure and representation of learning and adaptation, with aspects of microeconomic treatment of utility maximization subject to constraints.

5.3 Multi-agent Simulation

Multi-agent simulation emerged from simple cellular-automata approaches, and has recently evolved to simulate complex social interaction of individual agents (Axtell and Epstein, 1996). Much of the current development of this approach is based on the SWARM platform (Langton, *et. al*. 1995). Applications of multi-agent simulation have emerged to represent social interaction, such as Ascape (Parker, 1998), spatial processes such as pedestrian flows (Batty *et. al.* 1998), and economic interactions (Tesfastion, 2000).

The evolution of game theory, a branch of economics, has yielded substantial empirical application, and may provide a promising framework to explore the interaction of agents within markets under less restrictive assumptions than the neoclassical approach of perfectly competitive markets in general equilibrium. Although much of the work in game theory is extremely complex, it is interesting to note that in a competition initiated by Axelrod (1984) to have game theorists participate in a repeated Prisoner's Dilemma tournament, in which the contestants wrote their rules into computer programs and these were matched against each other. In both the initial tournament and a later one, tit-for-tat, a simple four-line program written by Anatol Rapoport won. According to Axelrod, the success of the strategy was based on beginning cooperatively, reciprocating nice and nasty behavior quickly, not envying others who try to obtain a quick profit, and staying simple. This kind of competition between simple rules of behavior may illustrate a promising avenue for development of models of market interaction that allow variation in the decision rules used by agents, and allow market outcomes to emerge from the experiences of success and failure of these individual interactions.

Of considerable interest for the purposes of our research is the recent emergence of agent-based computational economics (ACE), a research approach defined by its practitioners as ‘the computational study of economics modeled as evolving systems of autonomous interacting agents.’ (Tesfastion, 2000). This new field within economics seeks to understand how global regularities such as market processes emerge from the individual actions of market agents, through the repeated interactions of agents seeking their own self-interest, and without the aid of a central coordinator such as the Walrasian auctioneer. The view of economies as self-organizing systems follows in the tradition of Smith (1937) and Hayek (1948), as well as the works of Schelling (1978), Axelrod (1984) and Arthur (1994). Similarly, its view of economies as evolving follows the work of Schumpeter (1942) and Alchian (1950) on the evolution of economic systems.

An introduction and overview to this field is given by Epstein and Axtell (1996). Examples of applications of the ACE approach include endogenous expectations in asset pricing (Arifovic, 1994; Arthur *et. al.*, 1997), agent-based models of competition and collaboration (Axelrod, 1997), oligopolistic behavior (Marks, 1992), evolutionary games (Samuelson, 1997), and evolutionary labor markets (Tesfastion, 1999).

Agent-based computational economics uses powerful new computational tools to extend the previous work on economic self-organization in four ways, as Tesfastion (2000) summarizes:

> In brief, then, ACE is a methodology that blends concepts and tools from evolutionary economics, cognitive science, and computer science in a manner that may ultimately permit three important developments: (a) The constructive grounding of economic theories in the thinking and interactions of autonomous agents; (b) the testing, refinement, and extension of these theories through careful computational experiments, statistical analysis of findings, and appropriate comparisons with analytical studies, econometric studies, field studies, and human-subject laboratory studies; and (c) the formulation and testing of conceptually integrated socioeconomic theories compatible with theory and data from many different fields of social science currently separated by artificial disciplinary boundaries.

These claims may seem a bit optimistic, but the approach does seem to provide a synthesis of conceptual and computational elements that are compatible with the line of development we are proposing for the integration of household market behavior within an adaptive household production framework. The household production function, strategic and adaptive changes to sustain lifestyle choices or to shift from one lifestyle pattern to another as conditions and life cycle change, and the representation of households engaging in housing and job search would be simulated as agent-agent and agent-environment interactions within a spatially-detailed representation of the urban housing and labor markets.

5.4 Bayesian Networks

Bayesian Networks represent an alternative framework to the preceding approaches to modeling household choices of residence, job, vehicle ownership and travel pattern. This methodology has received little attention in the transportation and land use literature, but has some features worth further consideration in this domain. Bayesian networks, sometimes called probabilistic causal networks, or decision networks, represent a research area on expert systems within the broader literature of artificial intelligence. Unlike neural networks, which emphasize predictive power but shed little light on causal structure, Bayesian networks are graphical models that represent a probabilistic causal structure.

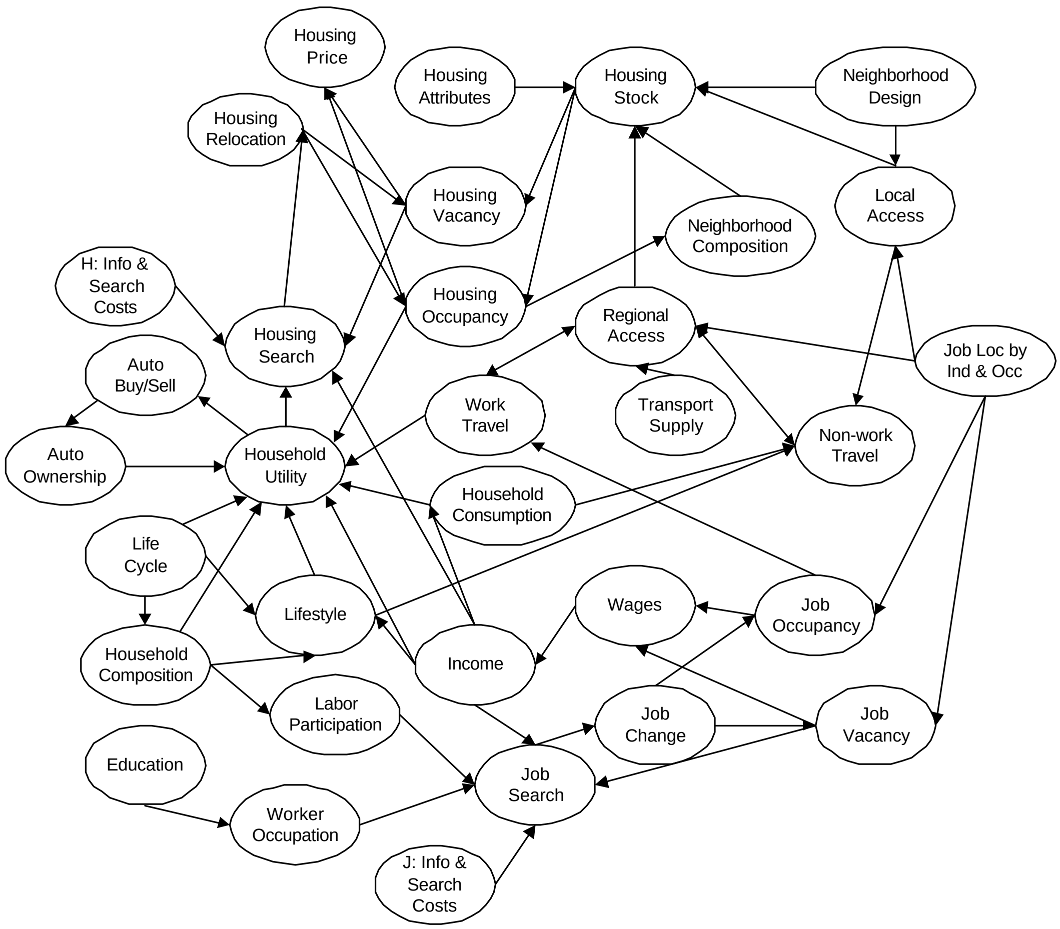
By combining causal and probabilistic elements, the approach facilitates combination of prior knowledge of causal structure, and data (for an introduction to this methodology, see Jensen, 1996; Heckerman, 1996). Methods have now been developed to learn not only parameters for a given causal structure, but also to learn or refine causal structure from data (Heckerman, 1996). A related development is Bayesian Model Averaging (BMA), which deals with problems in which a range of model structures that are theoretically or empirically equivalent are combined into a more robust model (Raftery, 1995).

Bayesian networks may provide an avenue to hybridizing several promising aspects of the preceding frameworks. They can efficiently represent high dimensional choice problems, such as the cluster of household choices described in this paper, without resorting to a restrictive hierarchical treatment as is done in both nested logit modeling and decision trees. They are probabilistic, like RUM models, but can more readily incorporate aspects such as learning, adaptation, and incomplete information. They could potentially be used as a decision framework within a multi-agent simulation environment, in which households interact in housing and labor markets, with housing suppliers and employers.

Bayesian networks are the subject of active research in computer science and statistics, and are being applied empirically to fairly large-scale problems. Software to support inference and the learning of probabilities and structures is developing rapidly. Some efforts are directed towards the development of embedded, modular software components using object-oriented methods that could make large-scale simulation systems using this approach substantially more feasible (Koller and Pfeffer, 1997).

The diagram in Figure 1 is a potential Bayesian network encompassing many of the aspect of household choice discussed in this paper. It represents the choices as nodes, as well as the variables that influence those choices. To make this potential model more tractable, a causal network should be constructed as a Directed Acyclic Graph that can be traced in one direction, avoiding circularity.

Figure 1: Bayesian Network of Housing, Labor, Vehicle and Travel Choices



6 A Research Agenda

The preceding discussion suggests that there is substantial need for development of models that integrate household choices of residence, job, vehicle ownership and daily activity and travel patterns. It recognizes numerous challenges that warrant further research, identifies several alternative frameworks and explores their potential for addressing these challenges. Clearly, research will proceed on multiple fronts, but for illustrative purposes, this section attempts to ground the discussion further by outlining a research agenda to evolve an existing model system to more completely address some of these challenges.

One interpretation of the preceding discussion leads to the development of a framework that attempts to integrate household decision making into a probabilistic choice model representing imperfect information, interdependence of choices across household members, strategic planning to achieve lifestyle preferences over short and long-term time frames, learning from experience, adaptation of choice behavior, explicit search processes for housing and jobs, constraints on time and budget, and the interaction of households and workers in imperfect housing and labor markets characterized by dynamic disequilibrium. Certainly no such framework has been operationalized, and it is an open question whether it is practically attainable given the limitations of current theory, available data, and modeling technology. Nevertheless, it is worth developing a clearer understanding of how this framework could be pursued, and what the impediments are to doing so.

Of the operational urban modeling systems that deal with residential and workplace location, we can identify only two that adopt a dynamic disequilibrium approach, in contrast to the traditional cross-sectional equilibrium approaches. These are Delta (Simmonds, 1999), and UrbanSim (Waddell, 2000), both of which use a discrete-choice modeling approach. There are other modeling efforts using discrete choice modeling that are equilibrium-oriented, such as the MetroSim (Anas, 1994), and 5-LUT (Martinez, 1992), that could potentially be extended in the directions we have proposed, but the disequilibrium approach proposed is more consistent with the first two of these approaches. The early work by Kain and Apgar (1985) in developing the HUDS model anticipates several elements we have proposed, including dynamic disequilibrium in a housing market microsimulation model, but it is no longer operational. There are also microsimulation models of land use and transportation interaction, such as IRPUD (Wegener, 1985) and MASTER (Mackett, 1990), or of housing markets (Oskamp, 1997), that could form plausible starting points for such a venture. We focus now on the feasibility of extending one model system, UrbanSim, to implement the proposed framework.

UrbanSim was conceived as a disaggregate simulation model of urban real estate markets, to use in connection with travel models to simulate the effects of transportation and land use policies on urban travel and land use patterns (Waddell, 2000). It uses microsimulation of individual households to predict residential moves and housing choices, and simulates real estate development at a spatially detailed level. The initial version of the model used traffic analysis zones for location choice and land parcels for simulating development, but in the current version both location choice and development are simulated using small grid cells (currently 150 by 150 meter). The mobility and location choices are simulated using multinomial logit models, as are the probabilities of real estate development and redevelopment within a cell. Samples of alternatives are drawn to create the choice set for households considering location choice, and they choose the highest utility alternative available. Development choices by landowners or developers are simulated, and the probability of development is based on expected profit and risk. The model has been applied in Eugene-Springfield, Oregon; Honolulu, Hawaii; Salt Lake City, Utah; and is being applied now in Seattle, Washington and other metropolitan areas. UrbanSim is implemented in Java as Open Software and is freely available on the Internet (http://urbansim.org).

Given the construction of UrbanSim as a dynamic microsimulation in annual time steps, the feasibility of implementing the proposed modeling framework appears plausible. A software architecture for implementing and evolving spatially-explicit simulation model components (Noth *et. al.*, 2000) makes the integration of the new model components, such as activity-based travel models, relatively straightforward. These new model components need to be specified and coded using the UrbanSim Application Programming Interface, which specifies model ordering and interdependencies with other model components.

Changes in the software architecture will be needed to fully accommodate some of the features found in multi-agent modeling, but the UrbanSim architecture already contains many of the necessary features. The ability to use a high-resolution grid and spatial queries, for example, provides a useful tool for implementing spatial search and filtering operations to simulate agent-environment interactions. The granularity of interactions required for agent-interaction, however, requires development of extremely efficient methods of implicit invocation and communication. These extensions, and a high-level model specification language, are the subject of current development of the UrbanSim software architecture (Noth, 2001).

The proposed integrated treatment of household choices of residence, job, vehicle ownership and daily activity and travel patterns would replace the current residential mobility and location components of UrbanSim. The decision to search for an alternative residential location, or to change labor market status or job, could be triggered by a change in life cycle characteristics such as the birth of a child, by economic conditions such as a change in transportation or housing costs, or by a duration hazard. Whether these choice dimensions could or should be integrated as a fully simultaneous choice process, as would be the case if they were structured as a nested logit model, or alternatively connected in a looser structure that allows a range of interdependent choice structures to be used, along the lines of Bayesian Model Averaging, remains an open question. The potential for using Bayesian networks to hybridize and extend some of the better features of Random Utility Maximization and decision heuristic approaches remains to be further examined. Substantial exploration and testing of alternative approaches to integrating these choice processes and dimensions will be needed before much can be said definitively about their relative merits and costs. Thus it is fitting to end this paper with a call for further research on these questions, and to suggest that collaborative and multidisciplinary efforts be promoted as vehicles to enrich research and reduce disciplinary and proprietary impediments to progress.

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