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HANDBOOK OF TRANSPORTATION ENGINEERING

Chapter XX. TRANSPORTATION AND LAND USE

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INTRODUCTION

The calculations and recommendations of transportation engineers and planners regularly recognize the fundamental role that land use conditions play in the theatre of transportation. An obvious example is the profession's heavy reliance on trip generation rates, with regular reference to the Institute of Transportation Engineer's *Trip Generation* manual (ITE 2008) for over 150 land use types, with rates affected by development size and site location within urban regions.

As a derived demand, travel ensures that persons can engage in various activities at multiple sites, while packages and products reach their intended distributors and end users. Whether they be homes or businesses, parks or croplands, the more separated in space these activity sites are, the longer the travel distances. Accompanying these distances comes a shift to faster modes, an infeasibility of non-motorized modes, a greater need for high-speed freeways and jet airplanes. Within a given transportation system, greater distances due to larger populations or less intensely developed land will result in greater demands on system components and a higher likelihood of congested travel conditions, over land, over water, and in the air. It is important that community planners and system designers recognize such relationships, while pursuing plans that enhance land use-transportation interactions.

Many will agree that the U.S. transportation profession has for far too long emphasized mobility enhancements for the motoring public (e.g., new highways and higher speeds), rather than a more balanced view of accessibility improvements, reflecting transport options in concert with land use patterns (Bartholomew 2007, Litman 2003 and 2007, Handy 1994). This is no doubt due to challenges in effectively managing both land use and transport, with state departments of transport pursuing major network improvements and city officers permitting land owners' improvements to existing parcels. Transportation engineers and planners should seek to recognize how their decisions can impact access to jobs, schools, services, and other key destinations via a variety of modes, along with longer-term land use changes. In reality, various highway improvements can degrade access for local travelers, including walk and bike modes, and quality of life for local residents and shop owners, while improving travel times for through travelers. Such myopic planning led to America's Freeway Revolts of the 1960s and 1970s. (Mohl 2004) European models of transportation planning and land use management look very different. (See, e.g., Knoflacher [2007] and Pucher et al. [2010].) Many Americans have become fans of the principles embodied in concepts of Smart Growth, New Urbanism, Neotraditional Design, Traditional Neighborhood Development, and Transit-Oriented Developed (TOD), as ways to moderate reliance on personal vehicles while curbing other ills of relatively standard U.S. design and development practices (see, e.g., Litman 2010, Evans et al. 2007, Handy 2005, Duany et al. 2000, Calthorpe 1993).

Travel is a complex phenomenon; and travelers trade off alternative destinations and routes, much as they do modes, vehicle ownership levels, and their own home (and work and school) locations. Thus, regions with double the density of activity sites (proxied by work and population densities) generally will not experience half the amount of travel distance or travel-related energy consumption, even though transit and carpooling may become more viable alternatives[1]. Works by Newman and Kenworthy (1996, 1999, 2006), Holtzclaw (1991, 1994), and Holtzclaw et al. (2002) are regularly cited on this score: One may expect an elasticity of regional vehicle miles traveled (VMT) with respect to regional density of about -25 to -30%. In other words, as density doubles, energy use and VMT tend to fall by 25 to 30%. Or, as density halves, energy use and VMT have been estimated to rise by over 30% – even after controlling for certain demographic attributes like income and household size (Holtzclaw et al. 2002). Nevertheless, a wide variety of other attributes – including parking costs, land use balance, infrastructure provision, demographics, and even topography – can be critical. All are at play in the land use-transport connection, and density in isolation is no panacea for congestion and many other transportation problems.

Just as land use decisions help shape travel choices and traffic conditions, network investment decisions and transportation policies play some role in location choices and land development decisions, along with property values and other variables of interest to a variety of stakeholders. This chapter begins by summarizing typical categories of land use and then moves on to discussions of how such land uses affect travel-related choices, how transport improvements and policies impact land use patterns, how integrated land use-transportation models work, and how a variety of other meaningful topics relate to this complicated yet critical arena for demand forecasting, policymaking, and system design and management.

LAND USE CATEGORIES

The term "land use" carries at least three distinct implications: land cover, use type, and intensity. The first refers to land coverage (such as forested, barren, developed, wetlands, and shrubland), or land use/land cover. It is widely used in the field of geography, where biodiversity and ecosystem conservation are key and remote sensing technologies are regularly used to enable large-scale geospatial data retrieval and classification. Of course, land cover change can be attributed to human exploration and activity, with ties to transportation system coverage and capacity (see, e.g., Laurance et al. 2001, Walker 2004). The second dimension of land emphasizes developed land, in urban and exurban areas, and is often further classified into categories that are pertinent to individual studies. These include residential vs. non-residential, commercial, industrial, civic, educational and transportation uses. Such details are useful for city and regional planning purposes, but do not serve as direct inputs to travel demand models, which rely instead on land use intensity details (in tandem with job and household type information).

With the increasing popularity of geographic information systems (GIS), a variety of spatial data sets now exist, for transportation engineering and planning use. For example, appraisal districts, which are responsible for appraising real, taxable property, are increasingly linking their data to a GIS layers for parcel-level data. The tax-related codes provide a meaningful measure of land use classification. Table 1 shows a typical coding system and broad categories often suitable for land use studies and neighborhood characterizations. (See, e.g., Zhou and Kockelman 2008a and 2009a.)

Table 1. Land Use Categories

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[1] Reduced trip chaining, greater activity participation rates, travel to more preferred destinations, and more uniformly distributed (rather than poly-nucleated) activity sites may emerge in denser environments.

Classification	*Description*
Large-lot Single-family	Single-family homes on lots greater than 10 acres
Single-family	Single-family detached, two-family attached
Mobile Homes	Mobile homes
Multi-family	Three- and Four-plex, apartments and condos, group quarters, retirement facilities
Commercial	Retail and general merchandise, apparel and accessories, furniture and home furnishings, grocery and food sales, eating and drinking, auto related, entertainment, personal services, lodgings, building services
Office	Administrative offices, financial services (banks), medical offices, research and development
Industrial	Manufacturing, warehousing, equipment sales and service, recycling and scrap, animal handling
Civic	Semi-institutional housing, hospital, government services, educational facilities, meeting and assembly facilities, cemeteries, day care facilities
Mining	Resource extraction, quarries
Open Space	Parks, recreational facilities, golf courses, preserves and protected areas, water drainage areas and detention ponds
Utilities	Utility services, radio towers, communication service facilities, water/wastewater facilities
Undeveloped/Rural	Rural uses, vacant land, land under construction
Water	Inundated areas, such as lakes and rivers
Transportation	Railroad facilities, transportation terminal, aviation facilities, parking facilities, right-of-way and traffic islands

Note: Table details come from City of Austin's Land Use Survey Methodology (2000).

When lacking detailed spatial data on actual land use types, one can turn to zonal employment and household density measures to represent local land use conditions. Such density measures can also be used to generate area-type categories. For example, the Texas Department of Transportation (TxDOT) classifies central business district (CBD) zones as those having 8 or more person-equivalents[2] per gross acre, urban areas as having 3 or more person-equivalents per gross acre, suburban as 1 or more, and rural as anything less dense.

Such categories, while coarse, are regularly found to be statistically and practically significant in models of travel behavior, property value, and other variables of interest, particularly when alternative attributes of urban form (and/or demographic and firmographic information) are lacking. Nevertheless, it is best to retain, and control for, the continuous underlying measures of density that generate such categories (as well as the type of jobs and households or persons they reflect). In addition, a simple distance-to-CBD variable (Euclidean or network-based) tends to be highly practically significant in a variety of contexts, serving as a solid surrogate for regional accessibility (particularly in monocentric regions). Where feasible, measures characterizing the

[2] Equivalent population is simply zone population plus zone employment times the region's persons-per-job ratio.

diversity, mixing, and balance of land uses (based on parcel-level data, but computed at a more spatially aggregate level, like a 600-meter radius circle or traffic analysis zone) can also prove quite meaningful in prediction.

Of course, network-based attributes, such as the share of intersections that are four-way, average block size, and distance to nearest principal arterial, can be helpful in prediction – not just of travel behavior, but also land use conditions and land use change. When used in tandem, land use and travel cost or other types of access variables can provide accessibility measures, both local and regional, to different types of activities and actors (see, e.g., Srour et al. 2002). And these are often key to prediction, as described below.

LAND USE EFFECTS ON TRAVEL DEMAND

Land use choices essentially determine activity site locations, and thus opportunities for trip origins and destinations. From trip generation and attraction decisions come travel distances, and these tie into each travel mode's feasibility and cost, with the automobile dominating choice for longer intra-regional trips within most developed countries.

Low-density land use patterns have been cited as an important source of roadway congestion, energy depletion, air pollution, and greenhouse gas (GHG) emissions (see, e.g., Dunphy and Fisher [1996], Newman and Kenworthy [2006] and Ewing et al. [2008]); and many investigations have concluded that vehicle ownership levels, shares of motorized trips, and household VMT depend on various features of urban form in both practically (and statistically) significant ways. (See, e.g., Fang [2008], Holtzclaw et al. [2002], Ewing and Cervero [2001 and 2010] and Cervero and Kockelman [1997].)

As an example, Musti and Kockelman's (2009) regressions of vehicle ownership levels on demographic and land use attributes at the level of traffic analysis zones (TAZs) in Austin, Texas signal a striking -30% elasticity with respect to local employment density, ceteris paribus, suggesting that jobs density (or the attributes for which it proxies, such as regional access, central location, and land use balance) can play a key role in energy and VMT savings, per capita. Moreover, as distance to the CBD falls in such regressions, vehicle ownership falls further, providing a type of "double dividend" (since many jobs tend to be centrally located). Since VMT per vehicle owned is relatively stable, regardless of vehicle ownership level (averaging 9,000 to 10,000 miles per year, in the U.S., according to National Household Travel Survey data [Kockelman et al. 2009]), much of the VMT and energy savings that can come from land use changes probably stem from vehicle ownership decisions.

Of course, there are other ways to moderate congestion, energy, air quality, and climate change concerns, without altering land use patterns (which can be slow to take hold, though arguably more enduring and beneficial in other respects[3]). Among these are congestion pricing, gas taxes, fuel-economy regulations, vehicle purchase feebates, full- and mild hybridization of vehicles, pre-heating catalytic converters, and so forth (see, e.g., Kockelman et al. 2009). And, of course, land use conditions are not the only factor impacting travelers' choices. Demographics tend to

[3] The building stock generally enjoys lifetimes that exceed those of vehicles and many policies, and more compact development can lead to savings on infrastructure and other public expenditures (such as school bussing) while enabling more healthful mode choices (such as walking). (See, e.g., Burchell et al. 2002.)

offer much greater predictive power (see, e.g., Bento et al. 2005 and Schimek 1996)[4].Over the past two decades, a great deal of literature has emerged concerning the relationship between the physical features of urban landscapes and traveler behavior. Ewing and Cervero's (2001, 2010) comprehensive reviews of such studies essentially conclude that regional-level accessibility is a key predictor of per-capita VMT, while travelers' vehicle ownership levels and mode choices are most affected by neighborhood-level land use patterns. As Boarnet and Crane (2001) note, behavioral processes at play are complex, and studies that use different data sets and geographic scales and focus on different aspects of travel behavior draw something distinctive conclusions. In general, early work has used more aggregate statistics, while later work has benefited from access to more disaggregate data and richer controls on demographics, neighborhood attributes (both at the origin and destination), travel costs (across alternatives), and other factors.

To disentangle the relationship of travel behavior and the built environment, researchers have relied on quasi-experimental designs (e.g., pairing matched neighborhoods, as in Cervero and Gorham [1995], Khattak and Rodriguez [2005], and Shay and Khattak [2005]), cross-sectional data and regression techniques (see, e.g., Kockelman [1997], Cervero and Kockelman [1997], Crane and Crepeau [1998] and Salon [2006]), and analysis of longitudinal data (see, e.g., Krizek [2003]). When comparing travel behavior in matched neighborhoods, households in neo-traditional and transit-oriented neighborhoods engage in fewer automobile trips, less VMT, and more work trips by transit, as compared to counterparts living in more conventional neighborhoods. Thanks to a reliance on longitudinal data (of 6,144 moving households' travel choice changes), Krizek's (2003) findings in this vein appear most compelling.

Among all potential control variables, priced parking and higher regional accessibility appear to provoke the greatest reductions in personal-vehicle use (see, e.g., Kockelman [1997], TRCP [2004], Ewing and Cervero [2001], and Kockelman et al. [2009]). The associations are felt to be strong enough and the literature robust enough that the U.S. Environment Protection Agency relies on average estimates provided by Ewing and Cervero's (2001) extensive review to inform its Smart Growth Index Model, a tool used by transportation planners in U.S. regions seeking emissions credits for various land use actions (U.S. EPA 2002, Kuzmyak et al. 2008).

In their international review of city data, Newman and Kenworthy's (2006) argue that 14 jobs or persons per acre can serve as a very meaningful threshold density, for per-capita transport energy use. Above this density they notice a sharp increase in walk, bike, and transit use. They also recognize that it is unrealistic for cities to simply add a rail line through the center and expect significant distance and mode shifts. Nevertheless, they do suggest that auto-oriented cities can and should be restructured as smaller, transit-oriented cities, to save energy and travel. Of course, different cities around the world enjoy very different histories, cultures, incomes, and transport systems. Moreover, the notion of regional density relationships holding at a local level is problematic. In reality, density is just one of many factors at play. Density is highly correlated (and causally associated) with a variety of other features. (See, e.g., Kuzmyak et al.'s [2003] and Litman's [2010] factor descriptions and literature summaries, and Ewing and Cervero's [2010] meta-analysis of impacts.)

[4] Of course, it is difficult, if not impossible, for planners, engineers and others to appreciably affect demographics (like income, household sizes, and the age and presence of children).

The Impact of Self Selection

In light of all of the empirical estimates, one wonders to what extent self-selection is at play in location and travel decisions. In other words, are one's home location and destination choices purposefully supportive of travel choices that one wishes to pursue, regardless of location? While much of the work supports, to some degree, a meaningful role for urban form, controlling for attitudes, to approximately correct for self-selection bias (due to residential sorting), diminishes the estimated influence of the built environment (Mokhtarian and Cao 2008). This highlights the importance of the self-selection issue. Of course, attitudes are typically difficult to measure, and may be largely shaped by one's location. Unfortunately, highly controlled experimental designs (like moving randomly selected household to different sites for some period of time and measuring their travel distances) are infeasible.

Researchers have had to rely on special econometric techniques to appreciate the magnitude of self-selection effects. Zhou and Kockelman (2008b) used Heckman's latent index model (Heckman 1979, Heckman and Vytlaci 1999, and Heckman, Tobias and Vytlaci 2001) to investigate daily VMT by households surveyed in Austin, Texas. In their study, the daily VMT of the average household living in an urban or CBD zone (i.e., at densities of at least 3 person-equivalents per gross acre) is 47.5 miles per day, as compared to 71.0 miles per day for households living below this density threshold. Their results suggest that at least half the differences in VMT observed between ostensibly equivalent households living in more urban versus less urban neighborhoods is due to the location itself, while self-selection of such locations (by households that wish to meet special travel needs and/or preferences) accounts for the remainder.

In general, better control of relevant attributes (e.g., income, household size, the presence and age of children, occupation and education of working adults) diminishes estimates of self-selection effects (since location preferences are regularly associated with socio-economic and other characteristics). Bhat and Guo (2004) discuss such issues, while controlling for a variety of standard demographic and neighborhood factors in their Oakland, California (Alameda County) data set. Their specification allowed for error-term correlation between location and vehicle ownership choices, to reduce self-selection effects; and results still showed significant built environment effects.

TRANSPORT'S EFFECTS ON LAND USE

Transportation system improvements can affect regional economies and land development through increased mobility of persons and goods, along with improved access to customers, suppliers, labor and amenities. Land values are regularly used as a proxy for the access benefits (e.g., implicit value of travel time savings) that come with system improvements, and different types of improvement can have very different impacts on these values. Moreover, impacts can vary noticeably across land use types and across regions. (See, e.g., TRB 1995, and ten Siethoff and Kockelman 2002.) In general, transit projects tend to have positive effects on both residential and commercial property values (e.g., Weinstein and Clower 1999, Cervero and Duncan 2002, Armstrong and Rodríguez 2006, and Hess and Almeida 2007), while highway projects offer more variable effects (e.g., tenSiethoff and Kockelman 2002, Mikelbank 2004, and Iacono and Levinson 2009). Concerns relating to air pollution, noise, safety and other issues can dampen valuation of residential properties near highway corridors, while added visibility and enhanced access cause commercial property valuations to rise.

As an example, Weinstein and Clower (1999) found that property values within one-quarter mile of Dallas' light rail stations increased about 3% more than those in control neighborhoods (i.e., those with similar neighborhood characteristics) over a 4-year period (2 years before and 2 years after station opening). And Armstrong and Rodriguez (2006) found properties in cities with a commuter rail station to be valued as much as 10% higher than their counterparts. Cervero and Duncan (2002) estimated such differences for commercial land values to be on the order of 120% within 0.25 miles of a commuter rail station in California's San Jose area.

Mikelbank (2004) used spatially correlated hedonic models and found that highway projects have negative impacts on housing values during the pre-construction and construction phases. TenSiethoff and Kockelman (2002) estimated the negative impacts of highway-upgrade construction to be -$0.50 per square foot of structure per year using tax assessment values along U.S. 183, a corridor in Austin, Texas. They also estimated a sizable benefit of being within one-half mile of the corridor, at about $50,000 per acre of land and $3 per square foot of structure. In contrast, Iacono and Levinson (2009) generally did not find statistically significant impacts of new-highway construction or improvement projects on property value changes in three Minnesota case studies.

The impacts of transportation on land use are also evident in the land development process and location preference of households and firms, with commute times, highway access, and airport access playing important roles (see, e.g., Zhou and Kockelman 2008a, 2009b; Bina and Kockelman 2009; Bina et al. 2006; Van Ommeren et al. 1999; Rouwendal and Meijer 2001; Clark et al. 2003; Tillema et al. 2006; and De Bok and Bliemer 2006). Specific locations within a network (e.g., corner parcels) and transport project timing are also important considerations for developers (tenSiethoff and Kockelman 2002).

In terms of residential preferences, Bina and Kockelman (2009) estimated home prices of recent buyers in Austin, Texas to fall by $8,000 with every mile (further) from the CBD, and by $4,700 for every minute in added (one-way) commute time (ceteris paribus[5]). They also found that higher-income households are more willing to pay for centrality, which is not surprising given value of time effects.. Similarly, Bina et al. (2006) estimated apartment rents in Austin to fall $20 per month with every mile of added distance to the CBD and by $24 for every added commute minute. Interestingly, commute time to work ranked second, right after apartment price, in terms of attribute importance (as evaluated by survey respondents on a scale of 1 to 5). Other access attributes ranked fifth, sixth, and eighth in the lineup of 15 apartment-choice considerations. Nevertheless, access was less of a factor in recent home buyer decisions (Bina and Kockelman 2009), and home owners comprise roughly two-thirds of the U.S. housing market (according to the 2000 Census of Population).

In general, the effects of land use on transport choices appears to be more direct and strong than the reverse. This is due, in large part, to the important roles of trip generation and attraction, whose spatial distribution largely determines distances traveled between activity sites (see, e.g., Zhao and Kockelman 2002). Nevertheless, the role of transport decisions on land use patterns seems quite evident in many data sets and modeled processes. As a result, many regions throughout the world seek to forecast both land use and transport futures, in tandem.

[5] Control variables include variables like home or apartment size, age of dwelling, number of bedrooms, lot size, and bus-stop density.

LAND USE MODELING

Due to significant environmental, traffic and other impacts of urbanization, federal and local regulation (e.g., the U.S. Clean Air Act Amendments of 1990 and Intermodal Surface Transportation Efficiency Act of 1991) effectively require that transportation planning plans and programs account for the interaction and feedbacks between transport and land use (Lyons 1995). And passage of the U.S. Safe, Accountable, Flexible, and Efficient Transportation Equity Act (SAFETEA-LU) in 2003 emphasized the coordination between transportation and land use planning at the state and metropolitan area levels (CEE 2008). Such legislation directly and indirectly encourages the development and application of land use models that tie to models of travel demand. The State of Oregon has been pursuing such integrated modeling efforts in earnest for many years, as a result of its urban growth boundary requirements (based on 1970s legislation), and the State of California now has a law (Senate Bill 375) to reduce GHGs by limiting urban sprawl, with integrated land use-transport modeling a key tool for policy comparisons.

Land use models (LUMs) seek to predict a region's future spatial distribution of households and employment. Though not nearly as complex as the human systems they seek to mimic, such model systems are very complicated. The forces that drive land use change range from regional climate to topography, public policies to human preferences, and social structures to transportation infrastructure; and these factors interact in intricate ways.

Theories of land use can be traced to von Thünen's (1826) concept of agricultural rents and travel costs around a market center, followed by Wingo's (1961) and Alonso's (1964) urban examples. These early models treat land as homogeneous and continuous, and recognize only one employment center. They also neglect latent taste heterogeneity. Thanks to increasing computational power and theoretical advances, many operational LUMs have been developed, with most applying at spatially aggregate levels (such as traffic analysis zones [TAZs]). Key theoretical constructs underlying the majority of LUMs include gravity allocation, cellular automata, spatial input-output, general equilibrium, and discrete response simulation.

Land Use Model Specifications

Multiple researchers have summarized and compared such models (PBQ&D 1999, U.S. EPA 2000, Wegener 2004, Dowling et al. 2005, and Iacono et al. 2008). The general consensus is that many limitations remain and the appropriateness and usefulness of any tool varies by context. For example, gravity models tend to use regional totals to adjust forecasts across all zones, and have been found to perform less well with disaggregate zone systems and/or sparse zone activity levels (PBQ&D 1999). Zhou et al. (2009) found that reasonable forecasts emerged only after imposing a variety of hard-coded rules (e.g., restricting excessive growth and declines in population and jobs at the zone level), suggesting that local knowledge and expert opinion may be needed to manually adjust gravity model forecasts. They also found that household and employment allocations were relatively insensitive to land use consumption levels, and standard equations may suffer from over-specification.

Cellular automata (CA) models are a class of artificial intelligence (AI) methods, with SLEUTH (Slope, Land use, Exclusion, Urban extent, Transportation and Hill shade) being the most widely applied (e.g., Clarke et al. 1997, Silva and Clarke 2002, and Syphard et al. 2005). It represents a dynamic system in which discrete cellular states are updated according to a cell's own state, as well as that of its neighbors. While CA models may mimic many aspects of the dynamic and complex land use systems, they generally lack behavioral foundations to explain the process. Moreover, they emphasize land-cover type, not land use intensity, so post-processing is needed to generate employment and household count patterns (which are, of course, critical to travel demand modeling).

Spatial input-output models are used to anticipate the economic and related interactions of employment and household sectors across zones, using discrete choice models for mode and input-origin choices. Production and demand functions consider transport disutility between zones, and people (and generally freight) move from one location to another in order to equilibrate supply and demand. Representative models include TRANUS (e.g., Johnston and de la Barra 2000), PECAS (e.g., Hunt and Abraham 2003), and RUBMRIO (e.g., Kockelman et al. 2004). Trade-based spatial input-output models are most suitable for larger spatial units (e.g., countries, regions, states and/or nations), so spatial resolution can be poor. Good trade and production data are also difficult to come by. It is worth noting that PECAS now includes a disaggregate sub-model for space development, to anticipate developer actions at the level of parcels or grid cells (see, e.g., PECAS 2007, and Hunt et al. 2008). This advance results in a hybrid of spatial input-output (for activity allocation) and microsimulation.

General equilibrium models rely on a modeling framework that balances demand for built space and the supply of real estate. They generally require analytical solutions to obtain results equilibrate real estate markets at zonal levels. MUSSA for Santiago, Chile (e.g., Martínez and Donoso 2001, 2006, and Martinez and Henriquez 2007), now embedded in Cube-Land commercial software, and MetroScope for Portland, Oregon (Conder 2007) are two such models. In addition to household and firm behavioral data, information on the supply side of built space is essential to calibrating and applying such models. However, such data are generally quite difficult to obtain, resulting in often heroic, yet necessary, assumptions. Such models are built on the notion of balancing supply and demand for land and/or space at the level of zones, and rents are generally endogenously determined. Information on monetary metrics allows modelers to study the impacts of economic incentives (and disincentives) on land development, land use patterns, and agent welfare.

Random utility maximization for discrete choices (McFadden 1978) is the basis for most microsimulation models. While utility maximization is a reasonably defensible behavioral principle, numerous factors affect individual household and firm decisions, and these factors interact in complicated ways, generally demanding some form of dynamic dis-equilibration. For such reasons, opportunities for model improvement always exist. Two operational microsimulation models are Waddell’s UrbanSim (e.g., Waddell 2002, Waddell et al. 2003, Waddell and Ulfarsson 2004, and Borning et al. 2007) and Gregor’s LUSDR (Land Use Scenario DevelopeR). UrbanSim simulates location choices of individual households and jobs, while anticipating new development on the basis of such models, but prices are not explicitly derived from the interaction of supply and demand. LUSDR emphasizes very fast model runs and the stochastic nature of results, seeking a balance between model completeness and practicality (Gregor 2007). Zhou and Kockelman (2009b) recently simulated market bidding and clearance for Austin, Texas parcels and their associated buildings, in harmony with developers’ (random profit-maximizing) decisions, demonstrating how microsimulation models may soon evolve in such a way that they are even more disaggregate and realistic in nature.

Land Use Model Applications

Of course, the objective for transportation planners and engineers is a realistic model that successfully integrates, and accurately forecasts, both transportation and land use changes (Miller et al. 1999). And many relevant variables will always lie outside the model components. Preferences evolve in uncertain ways, along with incomes, household sizes, transport and building technologies, energy prices, loan rates, and other factors of interest. A single forecast, assuming that development trends observed over the calibration period will continue and no new policies are imposed, is generally not of great value. Land use-transport models can better serve communities and their policymakers through multiple-scenario analyses, preferably with various uncertainties explicitly recognized and quantified. (See, for example, Sevcikova et al. 2007, Zhao and Kockelman 2002, Gregor 2007, Lemp and Kockelman 2009, Duthie et al. 2009, Krishnamurthy and Kockelman 2003, and Pradhan and Kockelman 2002.)

As one example, Zhou et al. (2009) forecasted year-2030 land use and travel conditions across the Austin-Round Rock metropolitan statistical area, by integrating a gravity-based land use model (G-LUM) with a standard travel demand model (TDM). Three scenarios were investigated, including a business-as-usual (BAU) scenario (i.e., development trends observed over the five-year calibration were assumed to continue, and no new policies were imposed), a congestion pricing-plus-carbon tax scenario (i.e., marginal delay costs were applied on all congested freeway segments in the network, and carbon tax of 4.55 ¢/mile was applied to all network links), and an urban growth boundary (UGB) scenario (where all new development was restricted to a zones with 2 or more job-equivalents per acre, plus their adjacent zones), centered on existing population centers). Documentation associated with Putman's ITLUP® model was used to design three sub-model components, for residential location assignments (by household type, in RESLOC), job assignments (by category, in EMPLOC), and zone-level land consumption estimates (by use type, in LUDENSITY), as illustrated in Figure 1.

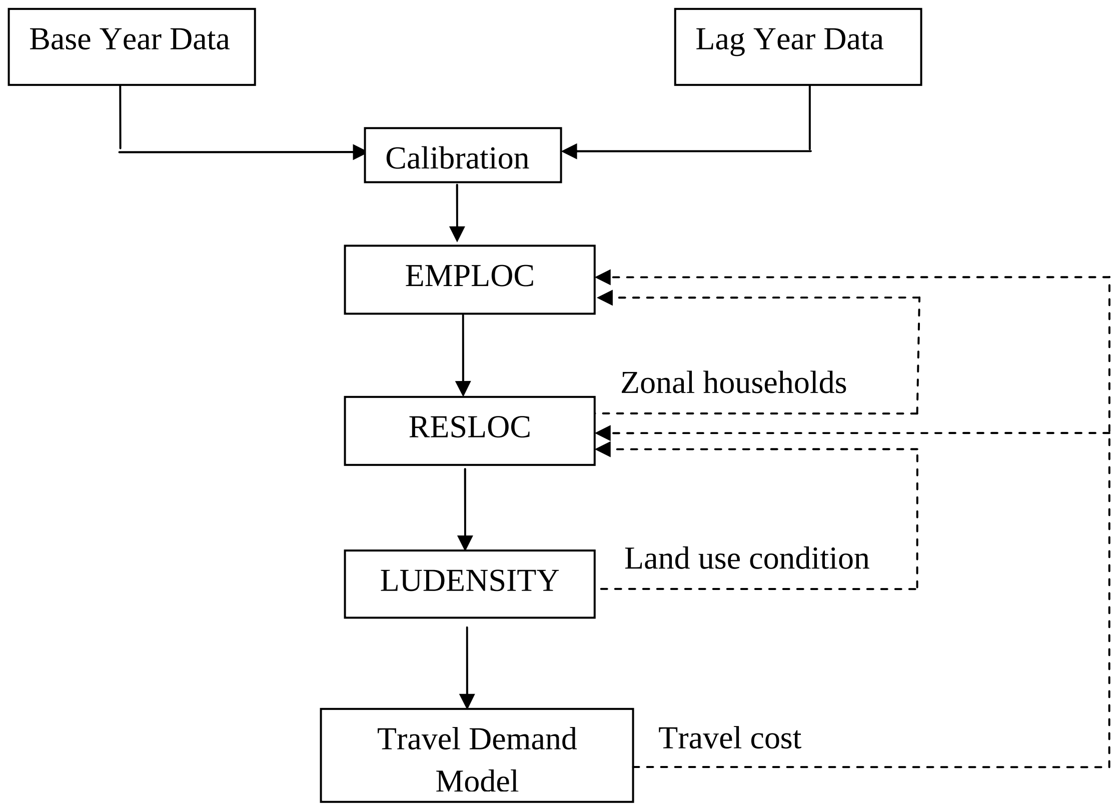

FIGURE 1. Gravity-Based Land Use Model Example, in Concert with a Travel Demand Model (from Zhou et al. 2009)

Note: Dashed lines represent one-period (t-1) lagged feedback of information. Each period is 5 years.

Year-2030 predictions were summarized in terms of vehicle-miles traveled (VMT), traffic flows, volume-to-capacity ratios, speeds, and downtown accessibility indices (to households and employment), as described at length in Zhou et al. (2009b). Of particular interest is the fact that the road pricing pricing (roughly 5¢/mile on most links) had almost no discernable effect on land use predictions, yet resulted in the same predicted reduction in regional VMT (roughly -15%) as the UGB policy (which also greatly impacted land use patterns).

Tirumalachetty and Kockelman's (2010) design and five-scenario application of a detailed microsimulation model (Figure 2) to the same Texas region resulted in GHG emissions estimates that were lowest under this same style of UGB policy. Their VMT and GHG estimates were lower under this UGB policy than estimates based on a $3-per-gallon gas tax increase coupled with road tolls of 10 cents per vehicle-mile. In other words, certain land use policies may be expected to have significant land use and transport effects, even when traditional land use models are used, and even when compared to considerable road tolling strategies.

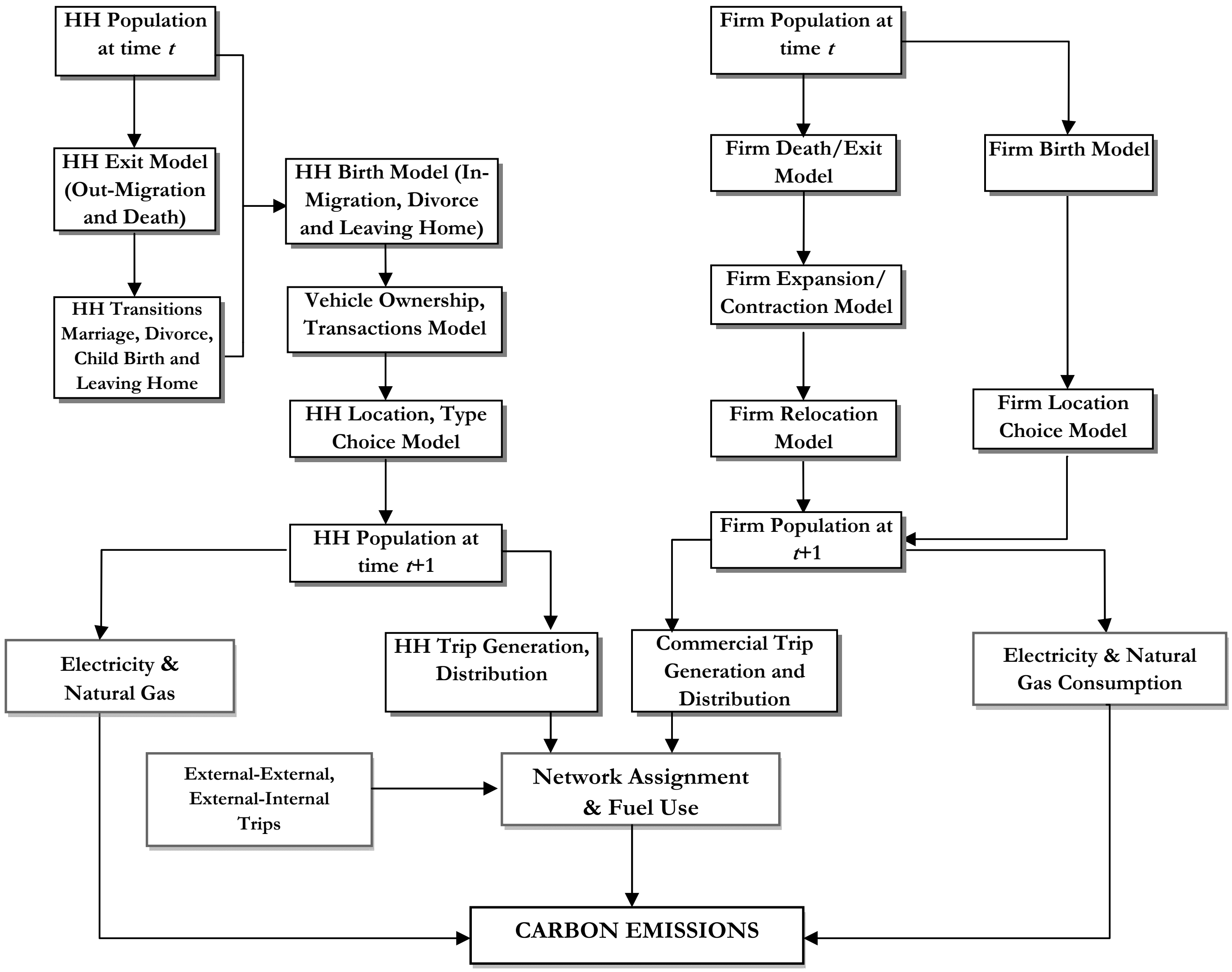

FIGURE 2. Example Microsimulation Model Framework (from Tirumalachetty and Kockelman 2010)

OTHER TOPICS

Beyond the potential and perceived relationships between land use and transport, and their integrated modeling using mathematical algorithms, other topics are worthy of discussion in a chapter on land use and transport. For example, one wonders whether higher densities or more accessible neighborhoods produce significant local congestion. Kuzmyak et al. (2008) described Cox's (2003) argument that higher densities mean much higher traffic densities and congestion levels, since VMT per capita does not fall as fast as density rises. They recognized that, in reality, the VMT savings are so significant (using Cox's own numbers), and mode shifts so likely, at higher densities, that one cannot assume overall congestion will be worse. In fact, traveler delays are estimated to be noticeably higher in places like Dallas and Atlanta than in high-density locations like New York City and Boston, year after year, based on Schrank and Lomax's (2009) *Urban Mobility Report* for U.S. regions.

Another topic worthy of mention is access management. Management of property access, for safety, congestion and other reasons, is an important component of transportation engineers' toolkits, as zoning, setbacks, and other methods for moderating land use-transport interactions fall under the purview of local city planners, rather than regional or super-regional transportation staff. The U.S. Transportation Research Board's *Access Management Manual* (TRB 2003) provides recommended practices for agencies struggling with the issues of preserving flow and protecting travelers while adequately serving property owners' interests. In general, access regulations (e.g., where and how to design driveways, relative to intersection locations and adjacent property site layouts) impact the layout, intensity, and type of business or residential property that can be sited along such corridors. In other words, something as basic as driveway (and parking lot) design can have a significant, though highly localized, land use impact.

Of course, air quality, GHG emissions, energy, noise exposure and other impacts also come to mind when contemplating the land use-transportation relationship, as alluded to earlier. Developed regions entail highly complex human interactions, over space and time, and land use and transport are key facets of these dynamic systems. Transportation engineers have major roles to play in balancing competing needs and interests, of diverse and dependent ecosystems, as they try to anticipate system responses to their proposed designs and policies. The significant literature relating to and modeling capabilities for land use-transport interactions provide ample opportunity for educated and enlightened decisions, as we navigate the paths that lie ahead.

REFERENCES

Alonso, W. 1964. *Location and Land Use*. Cambridge: Harvard University Press.

Armstrong, R. J., and Rodríguez, D. A. 2006. An Evaluation of the Accessibility Benefits of Commuter Rail in Eastern Massachusetts Using Spatial Hedonic Price Functions. *Transportation* 33, 21-43.

Bartholomew, K. 2007. The Machine, The Garden And The City: Towards An Access-Efficient Transportation Planning System. *The Environmental Law Reporter* 37 (8) 10593-10614.

Bhat, C. and Guo, J. 2004. "A Mixed Spatially Correlated Logit Model: Formulation and Application to Residential Choice Modeling," *Transportation Research Part B*, 38, 147–168.

Bento, A., Cropper, M., Mobarak, A., and K Vinha, K. 2005. The Effects of Urban Spatial Structure on Travel Demand in the United States. *The Review of Economics and Statistics* 87 (3), 466-478.

Bina, M., and Kockelman, K. 2009. Location Choice vis-a-vis Transportation: The Case of Recent Home Buyers. Chapter 28 in *The Expanding Sphere of Travel Behaviour Research*, Kitamura, R. and T. Yoshii (Eds.). Emerald Publishing, 597-619.

Bina., M., Kockelman, K., and Warburg, V. 2006. Location Choice vis-à-vis Transportation: The Case of Apartment Dwellers. *Transportation Research Record* No. 1977, 93-102.

Boarnet, M., and Crane, R. 2001. *Travel by Design: The Influence of Urban Form on Travel*. Oxford University Press, United Kingdom.

Borning, A., Waddell, P., and Förster, R. 2007. UrbanSim: Using Simulation to Inform Public Deliberation and Decision-Making. In Traunmueller, R. et al. Eds., *Digital Government: Advanced Research and Case Studies*. New York: Springer-Verlag.

Burchell, R., Lowenstein, G., Dolphin, W., Galley, C., Downs, A., Seskin, S., GrayStill, K., and Moore, T. 2002. *The Costs of Sprawl – 2000*. Transit Cooperative Research Program (TCRP) Report 74. Transportation Research Board, Washington, D.C. Available at http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_74-a.pdf.

Calthorpe, P. 1993. *The Next American Metropolis: Ecology, Community, and the American Dream*. Princeton Architectural Press.

Center for Environmental Excellence (CEE), 2008. American Association of State Highway and Transportation Officials (AASHTO). Retrieved in December 2008, http://environment.transportation.org/environmental_issues/land_use_sg/#bookmarkPolicyandGuidance.

Cervero, R. and Duncan, M. 2002, Transit's value-added: Effects of Light and Commuter Rail Services on Commercial Land Values. *Transportation Research Record* No. 1805, 8-15.

Cervero, R., and Kockelman, K., 1997. Travel Demand and the Three Ds: Density, Diversity, and Design. *Transportation Research Part D: Transport and Environment* 2 (2), 199–219.

Cervero, R., and Gorham, R., 1995. Commuting in Transit versus Automobile Neighborhoods. *Journal of the American Planning Association* 61 (2), 210–226.

City of Austin. 2000. Land Use Survey Methodology. Available at http://www.ci.austin.tx.us/landuse/survey.htm

Clark, W.A.V., Huang, Y., and Withers, S. 2003. Does Commuting Distance Matter? Commuting Tolerance and Residential Change. *Regional Science and Urban Economics* 33, 199-221.

Clarke, K. C., Hoppen, S., and Gaydos, L. 1997. A Self-Modifying Cellular Automaton Model of Historical Urbanization in the San Francisco Bay area. *Environment and Planning B: Planning and Design* 24, 247-261.

Conder, S., 2007. Metroscope 3.0 Specifications as Implemented at Portland Metro. (Received from Sonny Conder in November 2008.)

Cox, W. 2003. How Higher Density Makes Traffic Worse. *Public Purpose* 57 (May). Available at http://www.publicpurpose.com/pp57-density.htm.

Crane, R., and Crepeau, R., 1998. Does Neighborhood Design Influence Travel? a Behavioral Analysis of Travel Diary and GIS Data. *Transportation Research D*, 3(4), 225–238.
DeBok, M., and Bliemer, M. 2006. Infrastructure and Firm Dynamics: Calibration of Microsimulation Model for Firms in the Netherlands. *Transportation Research Record 1977*, 132-44.

Dowling, R., Ireson, R., Skabardonis, A., Gillen, D., and Stopher, P. 2005. National Cooperative Highway Research Program NCHRP. Report 535: *Predicting Air Quality Effects of Traffic-Flow Improvements: Final Report and User's Guide*. Transportation Research Board, Washington, D.C.

Duany, A., Plater-Zyberk, E., and Speck, J. 2000. *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. North Point Press.

Dunphy R.T., Fisher K. 1996. Transportation, Congestion, and Density: New Insights. *Transportation Research Record* 1552: 89–96.

Duthie, J., Voruganti, A., Kockelman, K., and Waller, S.T., 2009. Uncertainty Analysis and its Impacts on Decision-Making in an Integrated Transportation and Gravity-based Land Use Model. Forthcoming in *Journal of Urban Planning and Development*.

Evans, J.E., Pratt, R.H., and Kuzmyak, J.R. 2007. Transit Oriented Development. Chapter 17 in TCRP *Traveler Response to Transportation System Changes*. Transportation Cooperative Highway Research Program (TCRP) Report 95. Transportation Research Board, Washington D.C.

Ewing, R., and Cervero, R. 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1780, 187–114.

Ewing, R., and Cervero, R. 2010. Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association* (forthcoming).

Ewing, R., Bartholomew, K., Winkelman, S., Walters, J., and Anderson, G. 2008. Urban Development and Climate Change. *Journal of Urbanism* 1(3), 201-216.

Fang, H. A. 2008. A Discrete-Continuous Model of Households' Vehicle Choice and Usage, With an Application to the Effects of Residential Density. *Transportation Research B* 42 (9), 736-758

Gregor, B. 2007. Land Use Scenario Developer: Practical Land Use Model Using a Stochastic Microsimulation Framework. *Transportation Research Record*, No. 2003, 93-102.

Handy, S. 1994. Highway Blues: Nothing a Little Accessibility Can't Cure. *Access* 5, 3-7.

Handy, S. 2005. Smart growth and the transportation-land use connection: What does the research tell us? *International Regional Science Review* 28 (2): 146-167.

Heckman, J.J. 1979. Sample Selection Bias as a Specification Error. *Econometrica*, 47 (1), 153–162.

Heckman, J.J., and Vytlaci, E.J. 1999. Local Instrumental Variables and Latent Variable Models for Identifying and Bounding Treatment Effects. *Proceedings of the National Academy of Sciences* 96, 4730–4734.

Heckman, J.J., Tobias, J.L., and Vytlaci, E.J., 2001. Four Parameters of Interest in the Evaluation of Social Programs. *Southern Economic Journal*, 68 (2), 210–223.

Hess, D.B. and Almeida, T.M., 2007. Impact of proximity to light rail rapid transit on station-area property values in Buffalo, New York. *Urban Studies*, 44 (5-6), 1041-1068.

Holtzclaw, J., Clear, R., Dittmar, H., Goldstein, D., and Haas, P.,2002. Location efficiency: Neighborhood and Socio-Economic Characteristics Determine Auto Ownership and use – studies in Chicago, Los Angeles, and San Francisco. *Transportation Planning and Technology* 25(1), 1-27.

Hunt J. D., Abraham, J. E., de Silva, D., Zhong, M., Bridges, J., and Mysko, J., 2008. Developing and Applying a Parcel-level Simulation of Developer Actions in Baltimore. *Proceedings of the Transportation Research Board 87th Annual Meeting*, Washington, DC.

Hunt J. D., and Abraham, J. E., 2003. Design and Application of the PECAS Land Use Modeling System. Presented at *the 8th Computers in Urban Planning and Urban Management Conference*, Sendai, Japan.

Iacono, M. and Levinson, D., 2009. The Economic Impact of Upgrading Roads: Draft Final Report. http://nexus.umn.edu/Projects/EIUR/EIUR.pdf.

Iacono, M., Levinson, D., and El-Geneidy, A., 2008. Models of Transportation and Land Use Change: A Guide to the Territory. J*ournal of Planning Literature*. 22(4), 323-340.

Institute of Transportation Engineers (ITE). 2008. *Trip Generation*, 8th Edition. Washington, D.C.

Johnston, R. A., and de la Barra, T., 2000. Comprehensive Regional Modeling for Long-range Planning: Linking Integrated Urban Models and Geographic Information Systems. *Transportation Research Part A: Policy and Practice*, 34 (2), 125-136.

Khattak, A.J., and Rodriguez, D., 2005. Travel Behavior in Neo-Traditional Neighborhood Developments: a Case Study in USA. *Transportation Research Part A*, 39, 481–500.

Knoflacher, H. 2007. Success and failures in urban transport planning in Europe: Understanding the transport system. *Sahana* 32 (4): 293-307.

Kockelman, K., 1997. The Effects of Location Elements on Home Purchase Prices and Rents: Evidence from the San Francisco Bay Area. *Transportation Research Record* No. 1606, 40-50.

Kockelman, K., Jin, M., Zhao, Y., and Ruiz-Juri, N. 2004. Tracking Land Use, Transport, and Industrial Production using Random-utility-based Multizonal Input-Output Models: applications for Texas trade. *Journal of Transport Geography* 13 (3), 275-286.

Kockelman, K., Bomberg, M., Thompson, M. and Whitehead, C. 2009. GHG Emissions Control Options: Opportunities for Conservation. Paper commissioned by the National Academy of Sciences' Committee for the Study on the Relationships Among Development Patterns, VMT, and Energy Conservation, resulting in Special Report 298. Washington, D.C. Available at http://onlinepubs.trb.org/Onlinepubs/sr/sr298kockelman.pdf.

Krishnamurthy, S., and Kockelman, K. 2003. Propagation of Uncertainty in Transportation-Land Use Models: An Investigation of DRAM-EMPAL and UTPP Predictions in Austin, Texas. *Transportation Research Record* No. 1831, 219-229.

Krizek, K. J. 2003. Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter? *Journal of the American Planning Association*. 69(3), 265-281.

Kuzmyak, J.R., Pratt, R., Douglas, G.B., and Spielberg, F. 2003. Land Use and Site Design. Chapter 15 in TCRP *Traveler Response to Transportation System Changes*. Transportation Cooperative Highway Research Program (TCRP) Report 95. Transportation Research Board, Washington D.C.

Kuzmyak, J., PolyTech Corporation, and Caliper Corporation. 2008. Land Use and Traffic Congestion Study, Task 2 Report: Literature Review. Arizona DOT Research Project No. 619.
Lemp, J., and Kockelman, K. 2009. Understanding & Accommodating Risk & Uncertainty in Toll Road Projects: A Review of the Literature. *Transportation Research Record No. 2132*, 106-112.

Laurance,W. F., M. A. Cochrane, S. Bergen, P. M. Fearnside, P. Delamônica, C. Barber, S. D'Angelo, and T. Fernandes. 2001. The Future of the Brazilian Amazon. *Science* 291: 438-39.

Litman, T. 2003. Measuring Transportation: Traffic, Mobility and Accessibility. *ITE Journal* 73 (10): 28-32.

Litman, T. 2007. Evaluating Accessibility for Transportation Planning. Victoria Transport Policy Institute. Available at http://www.vtpi.org/access.pdf.

Litman, T. 2010. Land Use Impacts on Transport: How Land Use Factors Affect Travel Behavior. Victoria Transport Policy Institute. Available at http://www.vtpi.org/landtravel.pdf.

Lyons, W. M., 1995. Policy innovations of the US Intermodal Surface Transportation Efficiency Act and Clean Air Act Amendments. *Transportation* 22, 217-240.

Martinez, F. J., and Donoso, P. 2001. MUSSA: A Land Use Equilibrium Model with Location Externalities, Planning Regulations and Pricing Policies. Presented at the 7th International Conference on Computers in Urban Planning and Urban Management (CUPUM 2001), Hawaii.

Martinez, F. J., and Donoso, P. 2006. MUSSA II: A Land Use Equilibrium Model Based on Constrained Idiosyncratic Behavior of all Agents in an Auction Market. Proceeding of the Transportation Research Board 86th Annual Meeting, Washington, D.C.

Martinez, F. J., and Henriquez, R. 2007. A Random Bidding and Supply Land Use Equilibrium Model. *Transportation Research Part B,* 41, 632-651.

McFadden, D. 1978. Modeling the Choice of Residential Location. In Karlquist, A. et al. Eds., *Spatial Interaction Theory and Residential Location*. Amsterdam: North-Holland.

Mikelbank B. A. 2004. Spatial Analysis of the Relationship between Housing Values and Investments in Transportation Infrastructure, *The Annals of Regional Science,* 38, 705-726.

Miller, E. J., Kriger, D. S., and Hunt, J. D. 1999. *TCRP Report 48: Integrated Urban Models for Simulation of Transit and Land Use Polices: Guidelines for Implementation and Use*. Transportation Research Board, National Research Council, Washington, D.C.

Mohl, R.A. 2004. Stop the Road: Freeway Revolts in American Cities. *Journal of Urban History* 30 (5): 674-70.

Mokhtarian, P.L., and Cao, X. 2008, Examining the Impacts of Residential Self-Selection on Travel Behavior: A Focus on Methodologies. *Transportation Research Part B* 42, 204–228.

Musti, S., and Kockelman, K. 2009. Evolution of the Household Vehicle Fleet: Anticipating Fleet Composition and PHEV Adoption in Austin, Texas. Proceedings of the 12th Conference of the International Association for Travel Behaviour Research (IATBR), in Jaipur, India. Available at http://www.ce.utexas.edu/prof/kockelman/public_html/TRB10VehicleChoice.pdf.

Newman, P. and Kenworthy, J. 1999. Costs of Automobile Dependence: Global Survey of Cities. *Transportation Research Record* 1670, 17-26.

Parsons Brinckerhoff Quade and Douglas (PBQ&D) 1999. National Cooperative Highway Research Program NCHRP. Report 423A: *Land-Use Impacts of Transportation: A Guidebook.* Transportation Research Board, Washington, D.C.

PECAS. 2007. *Theoretical Formulation: System Documentation Technical Memorandum 1*. Received from John Abraham in March 2008.

Pradhan, A., and Kockelman, K. 2002. Uncertainty Propagation in an Integrated Land Use-Transport Modeling Framework: Output Variation via UrbanSim. *Transportation Research Record* 1805, 128-135.

Pucher, J., Dill, J., and Handy, S. 2010. Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine* 48 (2).

Putman, S. H. *Integrated Urban Models 2: New Research and Applications of Optimization and Dynamics*. Pion Press, London, 1991.

Rouwendal, J., and Meijer, E., 2001. Preferences for Housing, Jobs, and Commuting: A Mixed Logit Analysis. *Journal of Regional Science* 41, 475-505.

Salon, D., 2006. Cars and the City: An Investigation of Transportation and Residential Location Choices in New York City. Dissertation for Doctorate in Agricultural and Resource Economics, The University of California at Davis.

Schrank, D., and Lomax, T. 2009. Annual Urban Mobility Report. Texas A&M University, Texas Transportation Institute.

Schimek, P. 1996. Household Motor Vehicle Ownership and Use: How much Does Residential Density Matter? *Transportation Research Record* 1552, 120-125.

Sevcikova, H., Raftery, A., and Waddell, P. 2007. Assessing Uncertainty in Urban Simulations using Bayesian Melding. *Transportation Research, Part B* 41 (6), 652-669.

Shay, E., and Khattak, A.J., 2005. Automobile Ownership and Use in Neotraditional and Conventional Neighborhoods. *Transportation Research Record: Journal of the Transportation Research Board*, 1902, 18–25.

Silva, E. A., and Clarke, K. C., 2002. Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal. *Computers, Environment and Urban System*, 26, 525-552.

Syphard, A. D., Clarke, K. C., and Franklin, J.2005. Using a cellular automaton model to forecast the effects of urban growth on habitat pattern in Southern California. *Ecological Complexity*, 2, 185-203.

Srour, I., Kockelman, K., and Dunn, T. 2002. Accessibility Indices: A Connection to Residential Land Prices and Location Choice. *Transportation Research Record 1805*, 25-34.

ten Siethoff, B. and Kockelman, K. 2002. Property values and highway expansions: an investigation of timing, size, location, and use effects. *Transportation Research Record 1812*, 191-200.

Tillema, T., Ettema, D., and Van Wee, B. 2006. Road pricing and (re)location decisions of households. Proceedings of the 85th Annual Meeting of the Transportation Research Board, Washington D.C.

Tirumalachetty, S., and Kockelman, K. 2010. Forecasting Greenhouse Gas Emissions from Urban Regions: Microsimulation of Land Use and Transport Patterns in Austin, Texas. Proceedings of the 89th Annual Meeting of the Transportation Research Board and forthcoming in *Transportation Research Record*.

TRANUS, 2008. TRANUS English. Modelistica. Retrieved in December 2008. http://www.modelistica.com/tranus_english.htm.

Transportation Research Board (TRB). 1995. Expanding Metropolitan Highways. Special Report Number 245. Washington, DC: National Academy Press.

Transportation Research Board (TRB). 2003. *Access Management Manual*. Washington, DC: National Academy Press.

U.S. Environmental Protection Agency (U.S. EPA). 2000. *Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns*, Report EPA 600-R-00-098. Washington, D.C.

U.S. Environmental Protection Agency (U.S. EPA). 2002. Smart Growth Index (SGI) Model, U.S. Environmental Protection Agency. Available at www.epa.gov/livablecommunities/topics/sg_index.htm.

Van Ommeren, J., Rietveld, P., and Nijkamp, P. 1999. Job Moving, Residential Moving, and Commuting: A Search Perspective. *Journal of Urban Economics*, 46, 230-253.

Waddell P., and Ulfarsson, G. F. 2004. Introduction to Urban Simulation: Design and Development of Operational Models. In Haynes, K., Stopher, P., Button, K., and Hensher, D. Eds., *Handbook in Transport Volume 5: Transport Geography and Spatial Systems*. Oxford: Pergamon Press.

Waddell, P. 2002. UrbanSim: Modeling Urban Development for Land Use, Transportation and Environmental Planning. *Journal of the American Planning Association*, 68 (3), 297-314.

Waddell, P., Borning, A., Noth, M., Freier, N., Becke, M., and Ulfarsson, G. 2003. Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. *Networks and Spatial Economics*, 3 (1), 43-67.

Walker, R. 2004. Theorizing Land-cover and Land-use Change: The Case of Tropical Deforestation. *International Regional Science Review* 27: 247–270.

Wegener, M. 2004. Overview of Land-use Transport Models, in David A. Hensher and Kenneth Button (Eds.): *Transport Geography and Spatial Systems*. Handbook 5 of the *Handbook in Transport*. Pergamon/Elsevier Science, Kidlington, UK.

Weinstein, B. L. and Clower, T. L. 1999. The Initial Economic Impacts of the DART LRT System. Center for Economic Development and Research, University of North Texas. http://www.unt.edu/cedr/dart.pdf

Wingo, L., 1961. *Transportation and Urban Land Use*. Baltimore: Johns Hopkins University Press.

Zhao, Yong and Kockelman, K. 2002. "The Propagation of Uncertainty through Travel Demand Models: An Exploratory Analysis." *Annals of Regional Science* 36 (1), 145-163.

Zhou, B., and Kockelman. K. 2008a. Neighborhood Impacts on Land Use Change: A Multinomial Logit Model of Spatial Relationships, *Annals of Regional Science* 42 (2), 321-340.

Zhou, B., and Kockelman, K. 2008b. Self-Selection in Home Choice: Use of Treatment Effects in Evaluating the Relationship between the Built Environment and Travel Behavior, *Transportation Research Record* No. 2077, 54-61.

Zhou, B., and Kockelman, K. 2009a. Predicting the Distribution of Households and Employment: A Seemingly Unrelated Regression Model with Two Spatial Processes, *Journal of Transport Geography* 17, 369-376.

Zhou, B., and Kockelman, K. 2009b. Land Use Change through Microsimulation of Market Dynamics: An agent-based Model of Land Development and Locator Bidding in Austin, Texas. Presented at the 56th North American Meetings of the Regional Science Association International, in San Francisco, California.

Zhou, B., Kockelman, K., and Lemp, J. 2009. Applications of Integrated Transport and Gravity-Based Land Use Models for Policy Analysis. *Transportation Research Record* 2133, 123-132.