Historical Validation of Integrated Transport–Land Use Model System

Eric J. Miller, Bilal Farooq, Franco Chingcuanco, and David Wang

The Integrated Land Use, Transportation, Environment (ILUTE) model system is an agent-based microsimulation model for the greater Toronto–Hamilton, Ontario, Canada, area. The model system uses disaggregate models of spatial socioeconomic processes to evolve the state of the greater Toronto–Hamilton area from a known base case to a predicted end state in 1-year time steps. ILUTE has reached a state of operational implementation in which historical validation runs are being undertaken. The model runs start with 100% of the population of people, families, households, and dwelling units in the greater Toronto area that was synthesized for the year 1986. Twenty-year historical simulations (1986 to 2006) have been run, with model outputs being compared with Canadian census data and Transportation Tomorrow Survey data for 1991, 1996, 2001, and 2006. This paper presents recent findings from these historical validation tests and emphasizes the system's modeling of the demographic evolution of the population and the region's housing market.

The Integrated Land Use, Transportation, Environment (ILUTE) model system is an agent-based microsimulation model that dynamically evolves urban spatial form, demographics, travel behavior, and environmental impacts over time for the greater Toronto–Hamilton, Ontario, Canada, area. ILUTE has been under development for some time (*1–5*) and has reached the point at which it is being tested within a 20-year historical time period (1986 to 2006). The primary purposes of this paper are to (*a*) provide an update on the current state of ILUTE and (*b*) present the most recent historical test results.

The next section of the paper provides a high-level description of ILUTE, along with references to more detailed documentation of the model system. The primary focus of this paper is on two key components that are undergoing extensive testing: demographics and the housing market. These are discussed in some detail in the paper. The final section provides a brief summary of the paper and a discussion of ongoing and future work.

DESCRIPTION OF ILUTE

ILUTE is a comprehensive, integrated model system designed to project the evolution of demographics, land use, and travel within an urban region over time. It is an object- and agent-based microsimulation system and a time-driven simulation model in which the system state is evolved from a known base case to some future end state one time step at a time. The system state is defined according to the individual people, households, dwelling units, firms, and so on that collectively define the urban region being modeled. That is, the evolutionary engine operates on lists of people, households, and so on, simulating the behavior of each of these agents over time. Figure 1 summarizes key elements of the current implementation.

The model system is initialized with a set of agents or objects that is synthesized from base year census data. This set consists of 100% of the population of people, families, households, and dwelling units that has been constructed for each census tract in the study area for 1986 with a modified iterative proportional fitting procedure (*6, 7*) that does the following:

- Simultaneously generates these four objects in a fully consistent manner,
- Permits a large number of attributes to be included in the synthesis,
- Is computationally efficient,
- Makes full use of multiple multivariate tables of observed data, and
- Can be extended to include additional elements.

For testing purposes, the 100% population can be used, or, to speed up run times, a subset randomly drawn from the full population can be used, with all other model elements and processes being appropriately scaled.

The current implementation models all processes using a standard 1-year time step. ILUTE, however, permits individual processes to occur at finer time steps down to a 1-month resolution level, if it is so desired.

Resident population demographics are updated in each time step. The update includes in- and out-migration processes, which are significant in the greater Toronto area, which has been growing (and is projected to continue to grow) by approximately 100,000 people per year.

The labor market component evolves the labor force over time according to

- Entry and exit of people to and from the labor market,
- Mobility of workers within the labor market from one job to another,
- Allocation of workers actively seeking employment to jobs currently available in the market, and
- Worker wages and salaries by occupation, industry, and location.

The housing market component similarly evolves the residential locations of households over time. It includes the endogenous

E. J. Miller, Department of Civil Engineering and Cities Centre, University of Toronto, 455 Spadina Avenue, Toronto, Ontario M5S 2G8, Canada. B. Farooq, F. Chingcuanco, and D. Wang, Division of Engineering Science, Department of Civil Engineering, 35 Saint George Street, University of Toronto, Toronto, Ontario M5S 1A4, Canada. Corresponding author: E. J. Miller, miller@ecf.utoronto.ca.

Transportation Research Record: Journal of the Transportation Research Board, No. 2255, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 91–99.
DOI: 10.3141/2255-10

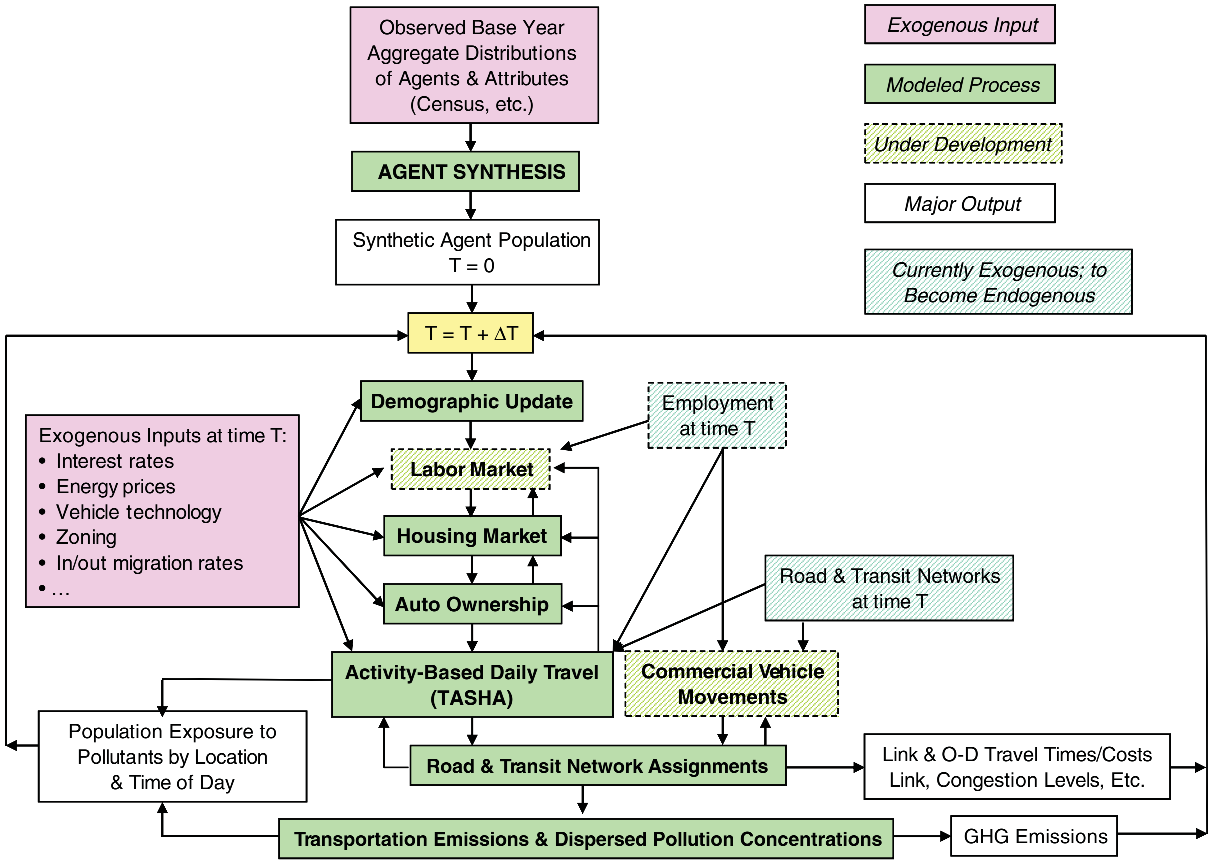

FIGURE 1 High-level flowchart of ILUTE processes (O-D = origin–destination; GHG = greenhouse gas).

supply of housing by type and location, as well as the endogenous determination of sales prices and rents.

Household auto ownership is dynamically evolved by using the models of household vehicle transactions and vehicle type or vintage choice developed by Mohammadian and Miller (*8–10*).

Once household demographics, labor market characteristics, residential location, and auto ownership levels have been determined, the activity and travel patterns for each person within each household for a typical weekday are estimated by using the agent-based Travel and Activity Scheduler for Household Agents (TASHA) microsimulation model developed by the ILUTE team. Full documentation for TASHA is provided elsewhere (*11–15*). TASHA is designed so that it readily interfaces with a variety of network assignment models. It can currently be used with either EMME or MATSim (*16*). The advantages of using a microsimulation model such as MATSim relative to an aggregate model such as EMME include the following:

- A microsimulation model has the ability to retain an agent-based representation throughout the modeling process; that is, the identity of individual agents and their travel behavior are retained in MATSim but are lost in procedures such as EMME, which aggregate individual trips into origin–destination flow tables.
- MATSim (and other dynamic assignment procedures) deals explicitly with network dynamics and provides an explicit temporal representation, in contrast to the static representation used in conventional static methods such as EMME.
- For full 24-h network modeling, the authors have found that running MATSim is at least as computationally efficient as running 24 one-hour static assignments in EMME and that MATSim provides a much higher level of behavioral fidelity and enhanced representation of network performance (*16*).

Considerable work in recent years has focused on development of an environmental modeling component within ILUTE (*17–19*). As illustrated in Figure 1, this work involves modeling of both link- and zone-based vehicle emissions. The dynamic, disaggregate nature of TASHA and MATSim permits both the running and the stationary emissions of each vehicle to be dynamically computed. These emissions become inputs into an atmospheric dispersion model (in this case, CALPUFF) so that pollutant concentrations can be computed over time and space. At the same time, TASHA generates a dynamic population of where each person is over time and space. Placement of people and concentrations together at each location in each time period allows peoples' exposures to pollutants over time to be computed.

It is the intent to implement some form of firmographic model within ILUTE, perhaps in the spirit of the work of Maoh (*20*) or Moeckel (*21*). This has not yet been accomplished, and so for the current testing of an historical model system, employment levels observed by occupation and industry for each census track in the study area are exogenous inputs to the simulation. Similarly, a much longer term project is to implement a microsimulation-based commercial vehicle movement model within ILUTE (*22*). Finally, another long-term project is to endogenously evolve the routine components of the road and transit network (e.g., streets and bus routes) over time in response to land use development so that changes in these important components of the network do not need to be anticipated by the modeler and predefined as exogenous inputs to a given simulation run.

Implicit in Figure 1 is that ILUTE is a disequilibrium model. A basic assumption is that urban areas are open, dissipative, path-dependent systems that are never in equilibrium but, rather, that are continuously responding to the constantly various endogenous and exogenous forces that drive the evolution of the urban system state and that do not permit that system state to ever stabilize to an equilibrium. Although this approach is behaviorally sound, it does mean that classic equilibrium-based consumer welfare measures cannot be computed. A means of overcoming this weakness in the approach is a matter of ongoing research.

Within individual model components, both rule-based and utility-maximizing models are used, depending on the process being modeled. Assumptions concerning within-component equilibrium, stabilization, and optimization also vary from one process to another. In general, the authors' preference is for myopic processes in which individual agents seek to maximize their utility within individual decisions (e.g., what mode of travel to take to work) but not globally across multiple decisions (e.g., overall optimization of daily activity patterns). Similarly, the authors' preference is for modeling of market transactions that leave both individual buyers and individuals sellers satisfied with their exchange of a good or service but that do not involve the imposition of strict global equilibrium constraints. Assumptions, however, do vary from one model component to another, depending on both behavioral concerns and practical considerations of the available modeling methods, computational efficiency, and so forth.

Spatial markets play a central role in ILUTE, in that it is through market demand–supply interactions that all spatial processes of interest within ILUTE occur. All markets in ILUTE involve a demand process, a supply process, and a market-clearing process that mediates between demand and supply by determining the exchange of goods and services between consumers and producers and the prices at which these exchanges occur. All such market processes are modeled at the level of the individual agent (buyer, seller) and individual transactions between buyers and sellers.

No agent is continuously active in any given market. Households do not search for new residential locations on a daily basis, workers do not continuously switch jobs, and so forth. Rather, market participation is characterized by protracted periods of inactivity. At any point in time, however, an agent may decide to become active in a market, in response to a wide variety of push–pull factors. Once the agent is active in a market, the agent engages in a search process, looking for options to improve his or her current situation. The agent remains active in the market either until a satisfactory new alternative is found and successfully obtained or until the agent decides that an improved alternative relative to the status quo cannot be feasibly obtained within the current market and so decides to remain in the initial state.

Supply-side processes within ILUTE are currently generally modeled in a more aggregate fashion (e.g., the development industry produces a certain number of new dwellings by type and location during each year of the simulation). The outputs from these processes, however, are a list of, for example, new individual dwellings and jobs (and their associated individual attributes), which are then matched with demanders on a one-to-one basis.

Two generic market-clearing processes are currently used in ILUTE: (*a*) a variable-price process in which prices are endogenously determined on a transaction-by-transaction basis within each market-clearing episode by use of an auction-type process (*23*) and (*b*) a fixed-price process in which prices are fixed within each market-clearing episode and are then globally updated between market-clearing episodes in response to general demand–supply characteristics. This process also applies to cases in which prices do not exist but a market-like matching of agents is required (*24*). Thus, prices are endogenous within the market in both processes; what differs is the way in which prices are determined by the market interactions.

The owner-occupied housing market is an important example of the variable-price, auction-based process. Several fixed-price market processes exist within ILUTE. These currently consist of

- Rental housing market, in which rents are fixed either by policy (rent control, assisted housing) or through an aggregate market adjustment process (*25*);
- Labor market, in which it is assumed that workers are, in the short run, salary takers, with salaries adjusting over time in response to aggregate market adjustments (*26*); and
- Marriage market, in which single males and females are matched to form married couples and for which no price exists but which can otherwise be modeled in a fashion similar to that of other fixed-price markets (see below).

Much more extensive documentation of the ILUTE system as a whole can be found in a 10-volume series of technical reports that can be downloaded from http://www.ecf.utoronto.ca/~miller/ILUTE.zip.

The next two sections of the paper present model validation results for two key components of the ILUTE system: demographics (including the marriage market model) and the owner-occupied housing market. The Canadian census is used as the primary source of observed data for validation of the ILUTE outputs. In Canada, the census is undertaken every 5 years. All ILUTE model runs start in 1986 with an initial population synthesized from 1986 census data (*6, 7*). ILUTE outputs for 1991, 1996, 2001, and 2006 are then compared with observed census tabulations. In addition, published data on annual housing starts from the Canada Mortgage and Housing Corporation and data on annual housing sales prices from the Toronto Real Estate Board are also used. Data from both the Canada Mortgage and Housing Corporation and the Toronto Real Estate Board are quite aggregate in nature, limiting the spatial level of detail at which comparisons can be made. Although 20-year simulation runs (1986 to 2006) are made, because of limitations to the length of this paper, only selected results (typically for 2001, 15 years into the simulation runs) are shown.

DEMOGRAPHIC MODEL AND SELECTED TEST RESULTS

The demographic updating component evolves the person, family, and household agents and their associated attributes over time. Families are explicitly maintained within the model system so that family relationships and interactions can be tracked over time and used to help explain family-related behaviors.

A household is defined as one or more people living within the same dwelling unit. Hence, a one-to-one mapping between households and occupied dwelling units occurs. A household can consist of any of the following combinations of people and families:

- Single person;
- Multiperson, nonfamily;
- Single family;

- Multifamily;
- Single family with individual (i.e., nonfamily) people; and
- Multifamily with individual people.

Demographics are updated each year. A bottom–up approach is used. By that approach, the demographic changes in a region emerge through the sequential updating of each person, family, and household in the region. In-migration events introduce new people, families, and households into the study region. Out-migration is also handled as part of the demographic processes. Each demographic event uses simple transition probabilities, conditioned on a person's current state, to determine a change in a demographic attribute. Cross tabulations, derived from empirical data, are used to compute these conditional probabilities. Monte Carlo simulation is used to determine the outcomes of all demographic events. Further details concerning demographic updating procedures can be found elsewhere (*27, 28*).

Figure 2 compares the greater Toronto–Hamilton area age distributions by year predicted with an initial run with 100,000 households of ILUTE and census data. Note that the 1986 distribution represents the synthesized input distribution used to initialize the ILUTE run. In general, the generated distribution tracks the census distributions well, especially given that the predicted distribution is the net outcome of numerous processes—births, deaths, in-migration, and out-migration—in addition to the aging process per se.

Overall predicted and observed births, deaths, and out-migrations are shown by year in Figure 3. ILUTE does a good job of predicting births and deaths. In particular, it captures the declining birth rate in the region due to an aging population well. It does, however, need to improve its predictions of out-migrations. The out-migration model is currently hampered by the lack of good local data on out-migration rates by household or family type for the region. In-migrations are an exogenous input to the model, and so comparisons between predicted and observed values are of little value.

Of particular interest within this paper is the marriage market, which matches prospective husbands and wives together within a utility maximization framework both as an example of an important demographic process and as an example of a fixed-price market process. The problem can be defined as a maximum weighted bipartite matching problem. Full details of the marriage market model can be found elsewhere (*27, 28*). Table 1 presents results from the initial run with data for 100,000 households. Table 1 compares the age distributions of married couples in 2001 (15 years into the simulation) observed in the census and predicted by ILUTE. In general, the predicted results correspond well with the observed values.

Similarly, Figure 4 compares the observed (2001 census) and predicted differences in income for married couples. The model tends to overpredict matches with very small income differences; some adjustment of the matching algorithm utility parameters

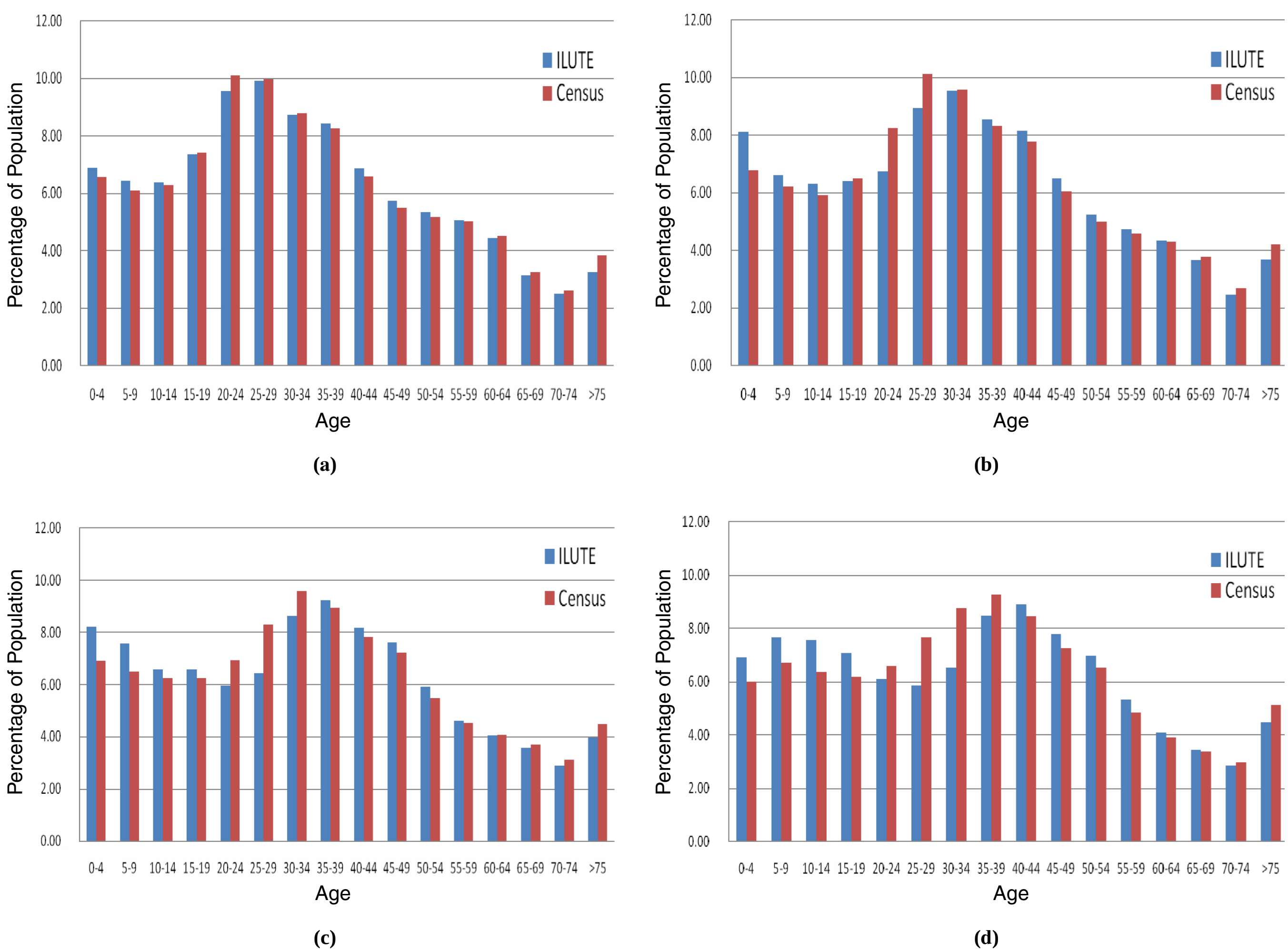

FIGURE 2 Predicted and observed greater Toronto–Hamilton area age distributions: (*a*) 1986, (*b*) 1991, (*c*) 1996, and (*d*) 2001.

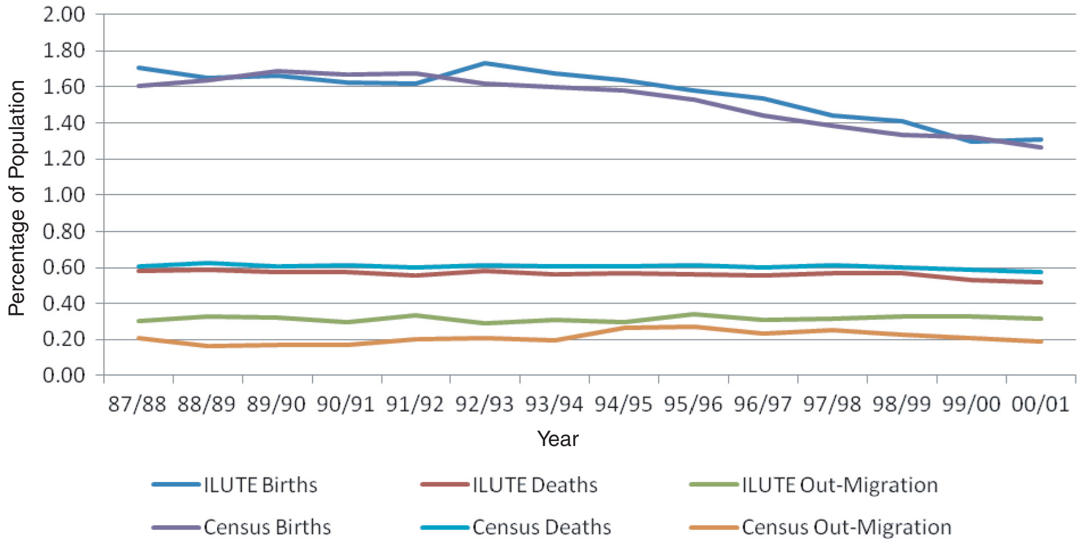

FIGURE 3 Predicted and observed births, deaths, and out-migrations by year.

will be required in subsequent runs. Otherwise, however, a good correspondence between the observed and the predicted values is obtained.

OWNER-OCCUPIED HOUSING MARKET AND SELECTED TEST RESULTS

Figure 5 elaborates the owner-occupied housing market model in ILUTE and shows that at any point in time a list of active demanders of housing and a list of active dwelling units available to be purchased exist. Demanders and suppliers come together within the market, and exchanges occur when a supplier agrees to sell a dwelling unit to a household at a mutually agreed-upon price. Thus, three types of agents exist within this market process: households; dwelling owners; and a market agent that is a virtual agent used within the simulation model to keep track of vacancies and prices, manage the lists of active demanders and suppliers, and manage the buying and selling market-clearing process. Three key points about this process should be noted:

- Prices are endogenously determined through the bid–auction (*29*) process of buyers and sellers interacting and coming to mutually agreeable prices for the exchange of the dwelling. These market prices

TABLE 1 Observed and Predicted Age Distributions for Married Couples, 2001

Age of Female (years)	Percentage of Couples by Age of Male: 18–24	25–34	35–44	45–54	55–64	65–74	75–84	85 and older
Census 2001 Married Couples								
18–24	0.28	1.00	0.14	0.03	0.00	0.00	0.00	0.00
25–34	0.18	10.94	7.10	0.39	0.06	0.00	0.00	0.00
35–44	0.02	1.57	19.11	7.84	0.55	0.08	0.00	0.00
45–54	0.01	0.08	1.59	15.21	6.19	0.46	0.03	0.00
55–64	0.00	0.01	0.05	0.95	8.58	4.40	0.24	0.02
65–74	0.00	0.00	0.01	0.04	0.51	5.98	2.39	0.08
75–84	0.00	0.00	0.00	0.00	0.03	0.43	2.56	0.51
85 and older	0.00	0.00	0.00	0.00	0.00	0.01	0.11	0.24
ILUTE 2001 Married Couples								
18–24	1.21	0.71	0.17	0.00	0.00	0.01	0.00	0.00
25–34	0.05	11.40	3.78	1.00	0.03	0.03	0.00	0.00
35–44	0.02	0.97	18.74	8.73	2.38	0.12	0.03	0.00
45–54	0.00	0.40	4.62	12.28	6.32	1.69	0.07	0.00
55–64	0.00	0.01	0.72	3.44	5.96	3.33	0.61	0.02
65–74	0.00	0.01	0.02	0.40	1.83	3.60	1.54	0.23
75–84	0.00	0.00	0.00	0.01	0.10	1.02	1.25	0.47
85 and older	0.00	0.00	0.00	0.00	0.01	0.05	0.28	0.32

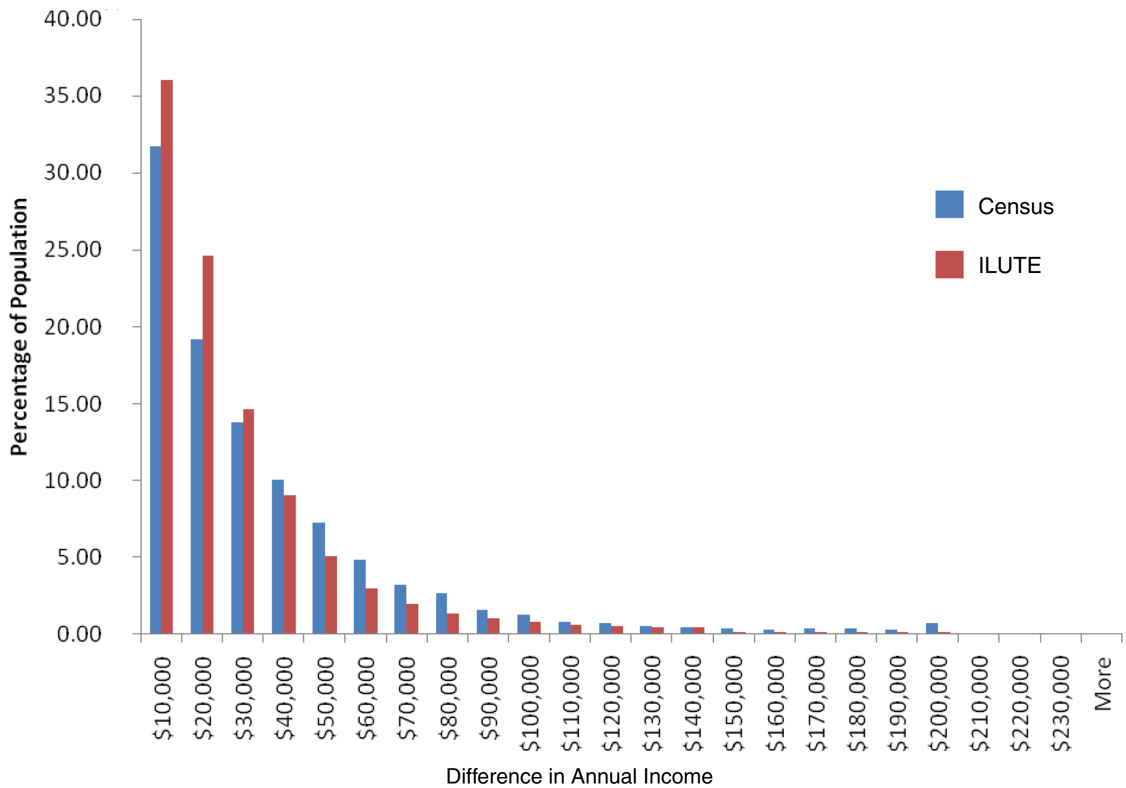

FIGURE 4 Observed and predicted income differences for married couples, 2001.

can influence decisions by agents in subsequent periods to become active in the market.

- The supply of housing comes from two distinct processes. The first process is the construction of new housing by developers and builders. The second process (and the quantitatively more important process at any one instant) is the decision of owner occupants to become active in the housing market. This decision results in the household becoming active both as a demander for a new dwelling unit and as a supplier of its old dwelling unit, which becomes active in the market on the supply side at the same time that the household becomes active on the demand side.
- Until a household sells its current dwelling, it has the option of exiting from the housing market and staying in its current dwelling; that is, it need not sell if it does not wish to. Similarly, owners of vacant dwellings do not need to sell in any given period if they deem it economically unattractive to do so.

From the last point, although the term "market clearing" is used, no behavioral need or mechanism within ILUTE forces the market to completely clear or equilibrate within any one time period. Dwellings can remain vacant from one time period to another, and households can continue to be active (or drop out without transacting) from one

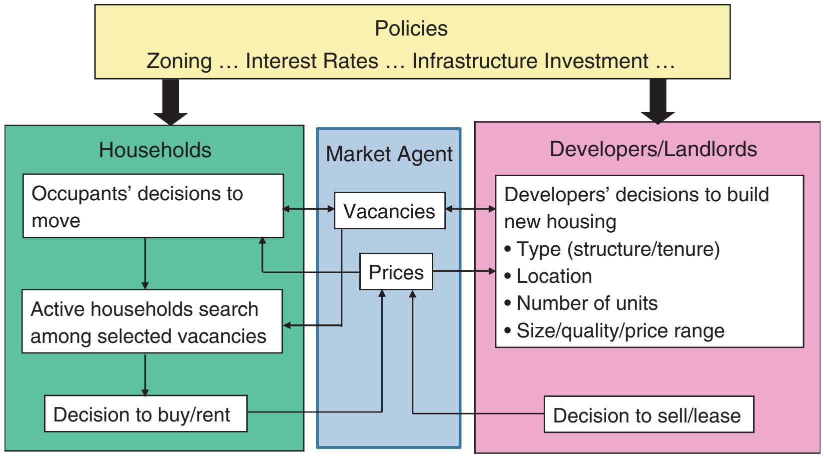

FIGURE 5 Simulation of owner-occupied housing demand, supply, and market clearing.

time period to another as they deem fit. It is expected that in times of excess supply prices will tend to fall (or at least not increase) and rates of provision of new supply will tend to fall, whereas in times of excess demand the converse will be true (with appropriate response lag times in both cases). However, no reason exists to insist that demand match supply at any point in time or that prices systematically adjust so that the market equilibrates or stabilizes in any formal sense. In particular, in ILUTE it is assumed that each buyer and seller in the market is myopic, in that

- Buyers are not aware of the actions of other buyers and have detailed information only concerning dwellings that are in their choice set,
- Suppliers are not aware of the actions of other sellers and have detailed information only concerning the buyers that are in their prospect set, and
- Dwellings are auctioned one at a time, so prices are myopically determined one sale at a time and not by a global balancing process.

Given these assumptions, in ILUTE dwellings are sold one at a time by randomly selecting an active dwelling, determining its sales price (while holding the prices of all other active dwellings fixed for the moment), and then randomly selecting the household from within this dwelling's prospect set that will purchase the dwelling at the sales price. Once this dwelling has been sold to the selected household, the following updating steps are taken:

- The household is moved to its new location and returned to the passive state in the housing market.
- The dwelling is removed from the list of active dwellings in the housing market.
- The choice sets of all households in the dwelling's prospect set are updated through deletion of the sold dwelling from the choice sets. The location choice probabilities are updated accordingly. The unsuccessful households can also decide to exit the housing market by becoming passive in the dwelling at their current location, providing that they have not yet sold this dwelling.

More detailed discussions of the ILUTE owner-occupied housing market model are presented elsewhere (*23*).

Testing of the housing market model is still in a preliminary stage. Figure 6 compares total predicted and observed new housing by year from an early model run. In general, ILUTE underpredicts the supply of new housing, but the overall shape of the trend curve is quite good.

Figure 7 plots the distribution of asking prices in the greater Toronto–Hamilton area in 2001 averaged over 10 runs with 10% of the sample. All prices are in 2001 Canadian dollars (when 1 Canadian dollar was approximately equal to 0.66 U.S. dollars). Observed asking prices for 2001 were not available, but average transaction prices were. The average Toronto Real Estate Board transaction price for 2001 is $222,000, whereas the ILUTE average asking price is $380,000. As will be discussed further below, ILUTE transaction prices are higher than observed transaction prices. Given the asking prices shown in Figure 7, the current asking price model is initializing the market with prices that are too high. This trend leads to transaction prices that are also too high. A next step in the model development process will be to recalibrate the asking price model so that lower, more representative asking prices are generated.

Table 2 summarizes the mean and standard deviation of predicted transaction prices, categorized by dwelling structure type, compared with average values from the Toronto Real Estate Board in 2001. It should be noted that the Toronto Real Estate Board values are averages by Toronto Real Estate Board zone, with these zones being geographically large. Thus, a considerable amount of variance has been squeezed out of the data from the Toronto Real Estate Board. In all cases, ILUTE overpredicts average transaction prices relative to the observed average values of the Toronto Real Estate Board (delta in Table 2), although all the averages of the Toronto Real Estate Board fall within 1 standard deviation of the ILUTE averages. Furthermore, the predicted averages for three of the four dwelling types are within $50,000 of the observed averages. Prices for detached dwellings (which constitute a significant majority of the transacted dwellings), however, are clearly significantly overpredicted. Again, the most logical source of this error is the asking price model, which needs to be revisited in subsequent testing.

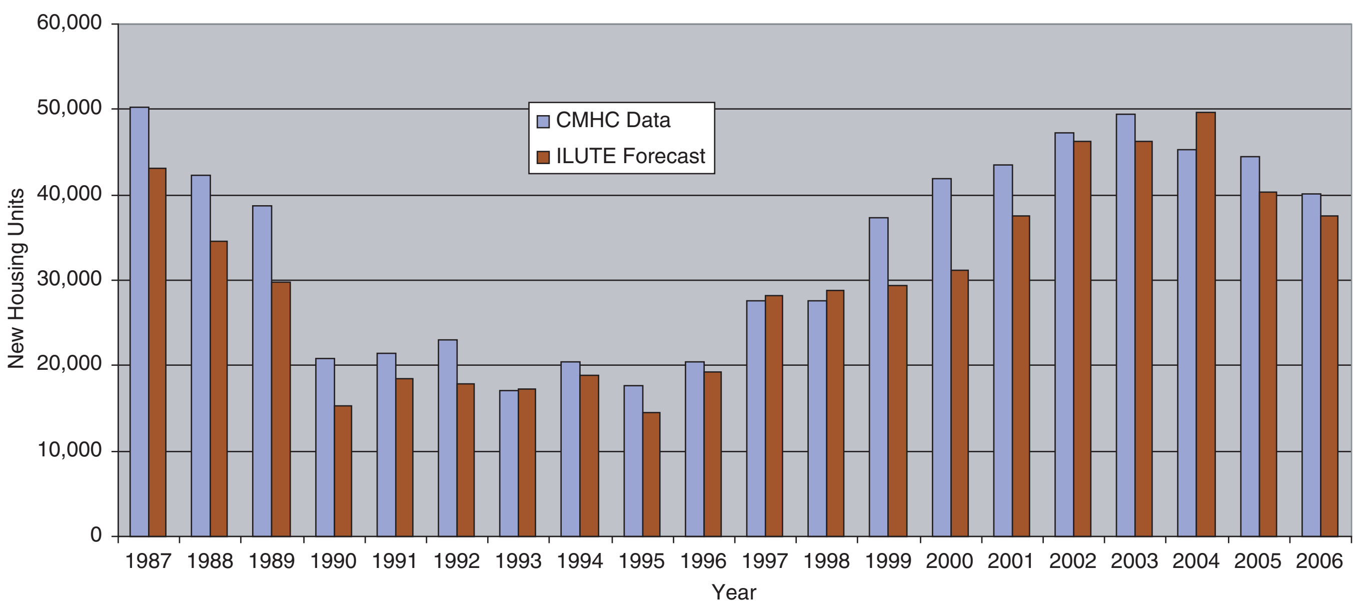

FIGURE 6 Predicted and observed greater Toronto–Hamilton area supply of new housing (CHMC = Canada Mortgage and Housing Corporation). (Source: CHMC.)

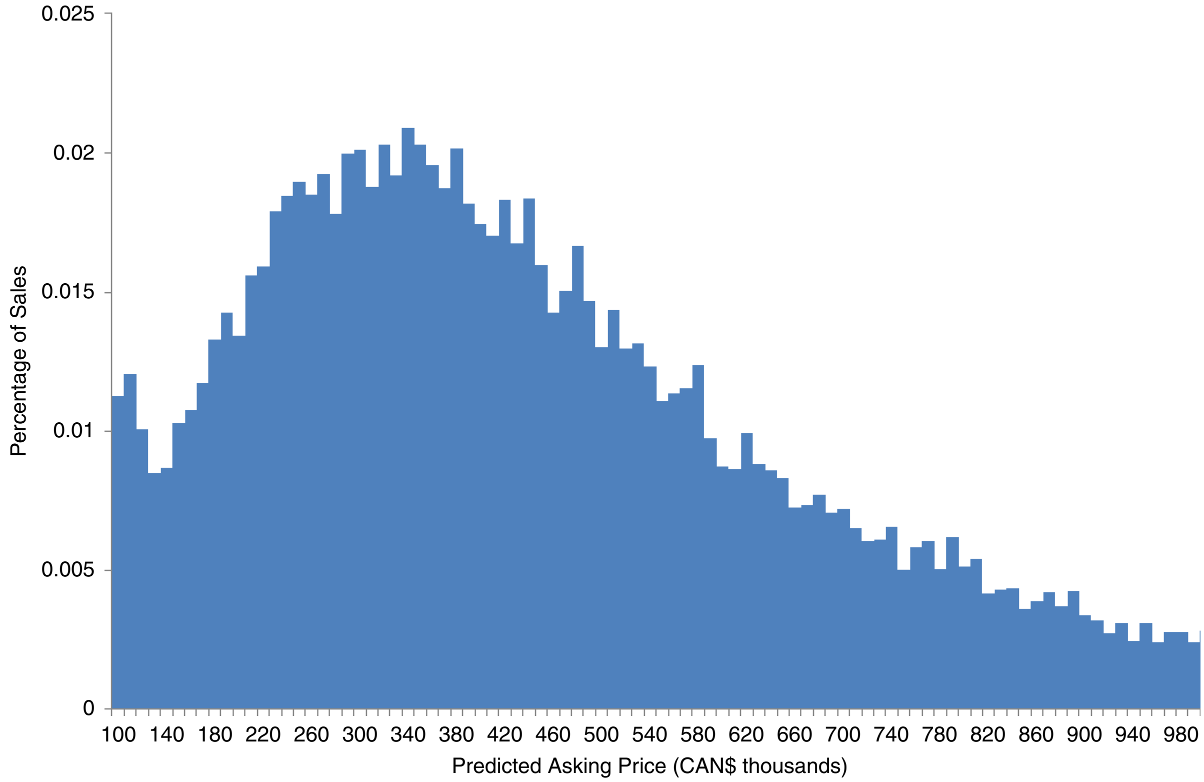

FIGURE 7 Predicted asking prices for housing, 2001.

SUMMARY AND FURTHER WORK

This paper has summarized the current state of the ILUTE agent-based microsimulation integrated urban model system. In addition, the paper has focused on the demographic and housing market components of the model system, which are two of the key components that are undergoing extensive testing. This testing consists of running 20-year historical simulations (1986 to 2006) so that model outputs can be compared with observed data for this time period.

Much work remains to be done. For the demographic model, improvements in both the in-migration and out-migration models are possible, providing that improved historical data for the Toronto region can be obtained. The marriage market model also requires further testing and calibration.

For the owner-occupied housing market model, the asking price model, particularly for detached dwellings, urgently requires improvement. The new dwelling supply model also requires further calibration. Once this model has been improved, further detailed testing of temporal mobility rates, transaction prices, and the spatial distribution of location choices is required for the owner-occupied housing market model.

Several components of ILUTE are still under development. Rental housing market and labor market models will be implemented within the model system shortly. More medium-term activities will include implementation of a firmographic model and improved feedback from the transportation (TASHA-MATSim) model subsystem and the location choice processes modeled.

In addition to these components, a general concern that cuts across all of the ILUTE spatial choice models is choice set modeling. As has often been described in the literature (*30, 31*), choice set modeling is too often the weak link in integrated urban models. ILUTE is no exception in this regard. A major forthcoming research thrust by the ILUTE group will be to develop improved spatial choice models for residential and commercial location, labor, and travel choice set determinations. One recent attempt to do this has been described by Elgar and colleagues (*32*), but much remains to be done to generalize and operationalize these findings.

TABLE 2 Predicted and Observed Transaction Prices by Dwelling Structure Type, 2001

	ILUTE			
Dwelling Type	Average	SD	TREB Average	Delta
Detached	480,000	200,000	307,000	173,000
Semidetached	280,000	130,000	230,000	50,000
Attached	260,000	110,000	212,000	48,000
Apartment	226,000	96,400	182,000	44,000
Total	392,000	180,000	222,000	170,000

NOTE: SD = standard deviation; TREB = Toronto Real Estate Board.

REFERENCES

1. Miller, E. J., and P. A. Salvini. Design and Evolution of ILUTE Dynamic Microsimulation Framework. Presented at 77th Annual Meeting of the Transportation Research Board, Washington, D.C., 1998.
2. Miller, E. J., and P. A. Salvini. The Integrated Land Use, Transportation, Environment (ILUTE) Microsimulation Modelling System: Description and Current Status. In *The Leading Edge in Travel Behaviour Research* (D. Hensher, ed.), Pergamon, Amsterdam, Netherlands, 2001, pp. 711–724.

3. Miller, E. J., J. D. Hunt, J. E. Abraham, and P. A. Salvini. Microsimulating Urban Systems. Geosimulation: Object-Based Modeling of Urban Phenomena. *Computers, Environment and Urban Systems,* Special Issue, Vol. 28, 2004, pp. 9–44.
4. Salvini, P. A., and E. J. Miller. ILUTE: An Operational Prototype of a Comprehensive Microsimulation Model of Urban Systems. *Networks and Spatial Economics,* Vol. 5, 2005, pp. 217–234.
5. Miller, E. J. *Development of an Operational Integrated Urban Model System,* Vol. I. Project final report. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
6. Pritchard, D. R., and E. J. Miller. *Synthesizing Base Year Agents. Development of an Operational Integrated Urban Model System,* Vol. III. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
7. Pritchard, D. R., and E. J. Miller. Advances in Agent Population Synthesis and Application in an Integrated Land Use/Transportation Model. *Transportation,* forthcoming.
8. Mohammadian, A., and E. J. Miller. Estimating the Expected Price of Vehicles in a Transportation Microsimulation Modeling System. *Journal of Transportation,* Vol. 128, No. 6, 2002, pp. 537–541.
9. Mohammadian, A., and E. J. Miller. Empirical Investigation of Household Vehicle Type Choice Decisions. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1854,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 99–106.
10. Mohammadian, A., and E. J. Miller. Dynamic Modeling of Household Automobile Transactions. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1831,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 98–105.
11. Miller, E. J., and M. J. Roorda. Prototype Model of Household Activity–Travel Scheduling. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1831,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 114–121.
12. Miller, E. J., M. J. Roorda, C. A. Kennedy, A. S. Shalaby, and H. MacLean. *Activity-Based, Multi-Modal Modelling of Travel Behaviour for Urban Design.* Final project report. Transport Canada Transportation Planning and Modal Integration Initiatives, Joint Program in Transportation, University of Toronto, Toronto, Ontario, Canada, 2006.
13. Roorda, M. J., E. J. Miller, and N. Kruchten. Incorporating Within-Household Interactions into Mode Choice Model with Genetic Algorithm for Parameter Estimation. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1985,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 171–179.
14. Roorda, M. J., E. J. Miller, and K. M. N. Habib. Validation of TASHA: A 24-Hour Activity Scheduling Microsimulation Model. *Transportation Research Part A,* Vol. 42, 2008, pp. 360–375.
15. Miller, E. J., J. A. Carrasco, K. M. N. Habib, and M. J. Roorda. *Activity Travel Modelling. Development of an Operational Integrated Urban Model System,* Vol. VII. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
16. Gao, W., M. Balmer, and E. J. Miller. Comparison of MATSim and EMME/2 on Greater Toronto and Hamilton Area Network, Canada. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2197,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 118–128.
17. Hatzopoulou, M., E. J. Miller, and B. F. L. Santos. Integrating Vehicle Emission Modeling with Activity-Based Travel Demand Modeling: Case Study of the Greater Toronto, Canada, Area. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2011,* Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 29–39.
18. Hatzopoulou, M., and E. J. Miller. *Environmental Modelling. Development of an Operational Integrated Urban Model System,* Vol. VIII. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
19. Hao, J. Y., M. Hatzopoulou, and E. J. Miller. Integrating an Activity-Based Travel Demand Model with Dynamic Traffic Assignment and Emission Models: Implementation in the Greater Toronto, Canada, Area. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2176,* Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 1–13.
20. Maoh, H. F. *The Location of Business Establishments in the City of Hamilton, Canada: A Micro-Analytical Model Approach.* PhD thesis. McMaster University, Hamilton, Ontario, Canada, 2005.
21. Moeckel, R. Microsimulation of Firm Location Decisions. *Proc., 9th International Conference on Computers in Urban Planning and Urban Management.* UCL Centre for Advanced Spatial Analysis, London, 2005.
22. Roorda, M. J., R. A. Cavalcante, S. McCabe, and H. Kwan. *A Conceptual Framework for Modelling Goods Movement and the Regional Economy. Development of an Operational Integrated Urban Model System,* Vol. IX. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
23. Farooq, B., E. J. Miller, and M. A. Habib. A Microsimulation Housing Market Clearing Model. Presented at 12th International Conference on Travel Behaviour Research, Jaipur, India, 2009.
24. Farooq, B., F. Chingcuanco, and E. J. Miller. Microsimulating Price-Taker Markets. Presented at 57th North American Regional Science Association International Conference, Denver, Colo., 2010.
25. Giroux-Cook, M., and E. J. Miller. Development and Implementation of a Microsimulation Model for the Rental Sector. Presented at 57th North American Regional Science Association International Conference, Denver, Colo., 2010.
26. Hain, M. *Labour Market Model of the Greater Toronto and Hamilton Area for Integration Within the Integrated Land Use, Transportation, Environment Modelling System.* MASc thesis. Department of Civil Engineering, University of Toronto, Toronto, Ontario, Canada, 2010.
27. Miller, E. J., F. Chingcuanco, B. Farooq, K. M. N. Habib, and M. A. Habib. *Demographic and Labour Market. Development of an Operational Integrated Urban Model System,* Vol. IV. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.
28. Chingcuanco, F. ILUTE Demographic Updating Module: Current Operational Status. Working paper. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2010.
29. Martínez, F., and P. Donoso. MUSSA: A Land Use Equilibrium Model with Location Externalities, Planning Regulations and Pricing Policies. Presented at 7th International Conference on Computers in Urban Planning and Urban Management, Honolulu, Hawaii, 2001.
30. Timmermans, H. The Saga of Integrated Land Use-Transport Modeling: How Many More Dreams Before We Wake up? Keynote paper presented at 10th International Conference on Travel Behavior Research, Lucerne, Switzerland, 2003.
31. Miller, E. J. Integrated Urban Models: Theoretical Prospects. Invited resource paper. In *The Expanding Sphere of Travel Behaviour Research: Selected Papers from the 11th International Conference on Travel Behaviour Research* (R. Kitamura, T. Yoshii, and T. Yamamoto, eds.), Emerald, Bingley, United Kingdom, 2009, pp. 351–384.
32. Elgar, I., E. J. Miller, and B. Farooq. *Modelling Firm Mobility and Location Choice. Development of an Operational Integrated Urban Model System,* Vol. VI. Urban Transportation Research and Advancement Center, University of Toronto, Toronto, Ontario, Canada, 2008.

The Transportation Demand Forecasting Committee peer-reviewed this paper.