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The case for microsimulation frameworks for integrated urban models

Eric Miller
University of Toronto
miller@ecf.utoronto.ca

Abstract: The primary objective of this paper is to "make the case" for adoption of microsimulation frameworks for development of integrated urban models. Similar to the case of activity-based travel models, microsimulation in integrated urban models enables such models to deal better with: heterogeneity and non-linearity in behavior; identification of the detailed spatial and socioeconomic distribution of impacts, benefits and costs; tracing complex interactions across agents and over time; providing support for modelling memory, learning and adaptation among agents; computational efficiency; and emergent behavior. The paper discusses strengths, weaknesses and challenges in microsimulating urban regions, including the extent to which microsimulation models are still subject to Lee's famous "seven sins of large-scale modelling," as well as the extent to which they may help alleviate or reduce these sins in operational models. The paper concludes with a very brief discussion of future prospects for such models.

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1 Introduction

An integrated urban model (aka "integrated land use — transport model") is actually a complex model system in which both transportation and land use ("urban form," "urban activity system") co-evolve over time. Figure 1 provides a very high-level conceptual representation of such systems.

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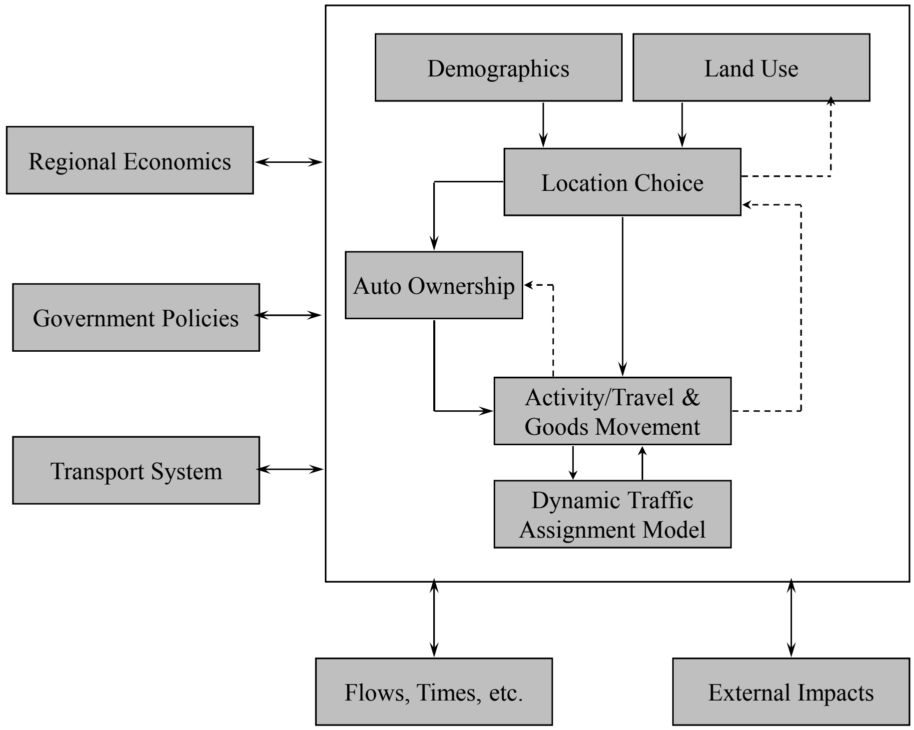

Figure 1: An Idealized Integrated Urban Model System

(Source: Adapted from Miller, et al. (1998)

While individual model systems vary in terms of the nature and extent of their implementation of Figure 1, it is argued (Miller, Kriger, & Hunt, 1998) that a "complete" integrated model should include models of:

- Development of urban land and the supply of building stock by type (residential, office, etc.).
- Location decisions of households (residential location) and firms (job locations), given building stock supply, as outcomes of real estate market processes.
- Demographic evolution of the resident population.
- Firmographic evolution of business establishments and jobs.
- Place of residence — place of work linkages, as the outcome of a labor market process.
- Place of residence — place of school linkages, as the outcome of an "education market" process.
- Household auto ownership.
- Person daily multi-modal travel, as the outcome of an activity-based approach.
- Daily multi-modal movement of goods and services.
- Simulation of all daily flows through the multi-modal transportation networks.
- Calculation of a wide range of system impacts, including travel costs, emissions, greenhouse gases, etc.

Clearly three major types of processes are at play in such an integrated model system:

- The decisions of individual agents (persons, households, firms, etc.) as they execute their day-to-day activity patterns.
- Collaboration among agents to achieve mutual benefits (household members sharing resources and activities; social network interactions; etc.).
- Market demand-supply processes within which agents interact, compete with one another for scarce resources, and exchange goods and services.

The conceptual and policy analysis case for integrated urban modelling is strong (Wegener, 1995; Miller, 2017): travel demand and the cost-effectiveness of alternative transportation systems and system components (road, transit, active) directly depend on urban form (population, employment and other activity distributions and densities), while the development of the built form and the location choices of households, firms, etc. within this built form clearly depends (among other factors) on the accessibility provided by the transportation system as it differentially connects points in space with varying levels of service.

If integrated urban models can be constructed that provide robust estimates of the net impacts of both land use and transportation policies on the evolution of urban form, transportation system performance, etc., then the value to urban design, planning, infrastructure investment, etc. is obvious. In particular, they should provide the ability to capture the feedback loops between transportation, land use, macro urban economic development, etc. so that a more complete and realistic understanding of the likely intended and unintended consequences of various policies can be assessed. One very critical example of this need is the question of high-order transit (largely rail, but also BRT) infrastructure investment on land development and land values. The large capital and operating costs of new rail infrastructure is often difficult to justify economically unless positive land development/value impacts accrue. In the absence of an operationally validated integrated urban model, however, credible, evidence-based "business cases" for major transit investment are often difficult to make, and the policy debate often degenerates into ideological, ill-informed political squabbles.

Integrated urban models historically have been quite aggregate in both their spatial and socio-economic representations (Miller et al., 1998), reflecting historical limitations in both data and computing power. As both of these constraints have eased over time, some models have become more disaggregated, especially spatially, and, to a lesser extent, demographically. With increasing disaggregation, microsimulation becomes a natural, but not necessarily inevitable, option for model system design.

Similarly, integrated urban models historically have generally not attempted to address the full suite of processes listed above, often focusing on housing market (principally demand-side) processes, and often treating labor market, demographic and building supply processes relatively simplistically, if at all. As data and computing capacities have improved and as policy needs have evolved, the need and potential for more comprehensive model systems has emerged over time. Again, the question arises concerning the extent to which microsimulation is an attractive approach for dealing with increasingly complex representations of urban processes.

It might be argued that the data and computational requirements of a microsimulation approach are not needed, that "simpler", more aggregate traditional approaches are sufficient for the purpose at hand. Similarly, it might be argued that simpler, more aggregate and "parsimonious" models are sufficient for addressing urban policy questions, and that more comprehensive model systems are not necessary. While microsimulation methods are slowly entering transportation and urban modelling practice, progress is generally slow, presumably reflecting both the conservative, risk-averse nature of many planning agencies, as well as their lack of technical familiarity with the approach. The primary purpose of this paper is to argue for explicit commitment to a microsimulation paradigm for constructing integrated urban models. In particular, the paper argues that microsimulation need not be more data-hungry or computationally intensive than other modelling approaches, while providing a far more behaviorally sound and policy-sensitive modelling framework.

Section 2 of the paper briefly introduces the microsimulation approach and illustrates its use in both travel demand models and integrated urban models. In so doing it builds "the case" for the microsimulation approach. Section 3 then addresses a number of potential issues with microsimulation models that might limit their usefulness or even feasibility. Section 4 concludes the paper with a brief look ahead with respect to the evolution of integrated urban models.

2 Microsimulation

2.1 Definition

In the introduction to the *Handbook of Microsimulation Modelling*, Cathal O'Donoghuel defines microsimulation as "a simulation based tool with a micro unit of analysis that can be used for ex-ante analysis. It is a micro based methodology, utilizing micro units of analysis such as individuals, households, firms and farms, using surveys or administrative datasets. It is a simulation based methodology utilizing computer programs to simulate public policy, economic or social changes on the micro population of interest" (O'Donoghuel, 2014). The concept of microsimulation is virtually as old as practical digital computing, dating back at least to the seminal work of Orcutt in the late 1950s (Orcutt, 1957, 1960). As computing power has increased, particularly over the past twenty years, microsimulation has seen widespread use across the spectrum of socio-economic modelling applications (O'Donoghuel, 2014), including transportation and land-use modelling.

The case for microsimulation modelling of travel demand is well understood and well discussed in the literature (Bonsall, 1982; Mackett, 1990; Goulias & Kitamura, 1992, 1996; Miller, 1996, 2014; Miller & Salvini, 2002). Microsimulation is now the de facto standard in best-practice travel demand models (Castiglione, Bradley, & Gliebe, 2015).

Microsimulation also has a long history in the integrated modelling field, dating back, at least, to the early work of Stuart Chapin (Chapin & Weiss, 1968), Roger Mackett (1985) and Miller, Noehammer, and Ross (1987). Michael Wegener and his colleagues have, perhaps, been the most successful in developing several generations of operational land-use microsimulation models (Strauch, et al., 2005; Moeckel, Schwarze, Spiekermann, & Wegener, 2007; Spiekermann & Wegener, 2007; Wagner & Wegener, 2007; Wegener, 2011a). Michael Batty's team at University College London is using cellular automata simulations to explore basic processes underlying urban systems (Batty, 2005, 2013). The University of Toronto ILUTE team has successfully demonstrated the ability to microsimulate urban demographic evolution (Chingcuanco & Miller, 2018), housing markets (Farooq & Miller, 2012; Rosenfield, Chingcuanco, & Miller, 2013; Farooq, Miller, Chingcuanco, & Giroux-Cook, 2013) and travel behavior (Miller & Roorda, 2003; Roorda, Carrasco, & Miller, 2009) over extended periods of time in a computationally efficient manner (Miller, Farooq, Chingcuanco, & Wang, 2011). And more conventional land-use model systems such as MUSSA (Martinez & Donoso, 2010), PECAS (Hunt & Abraham, 2005; Abraham & Hunt, 2007) and UrbanSim (Waddell, Borning, Noth, Freier, & Becke, 2003; Waddell, 2011) have become increasingly disaggregate over time, incorporating more microsimulation elements as they evolve.

Based on Miller (2003), brief, but hopefully compelling arguments for microsimulation, are presented in the following sub-sections.

2.2 Heterogeneity and non-linearity in behavior:

Human decision-making behavior is generally both heterogeneous (different people have different preferences, past experiences, etc., and so may make different decisions when confronted with a given choice) and non-linear (their "stimulus-response functions" are non-linear). It is well understood in travel demand modelling that the combination of heterogeneity and non-linearity means that aggregate models that attempt to predict aggregate (macro) behavior as a function of aggregate explanatory variables can exhibit significant aggregation bias. A microsimulation approach, in which the behavior of individual agents is directly modelled as a function of their specific attributes, decision context and preferences, in principle provides a far better approach to modelling travel behavior. In the microsimulation approach, the aggregate/macro outcomes (total ridership on a new subway line, overall reduction in greenhouse gases, etc.) that are generally of policy interest are the emergent outcome of decisions of the individual agents in the system.

Housing and labor markets are also clearly very heterogeneous and highly differentiated spatially. Cross-classification of households, dwelling types, jobs, etc. to deal with this heterogeneity quickly becomes computationally burdensome. List-based approaches are computationally more efficient, as well as facilitate the use of behaviorally sound disaggregate choice models. Housing and labor market processes, in turn, depend upon demographic processes of household formation and evolution, and other socio-economic processes, which need to be modelled at the micro (person by person, household by household) level for both computational efficiency and behavioral fidelity reasons.

2.3 Distribution of impacts, benefits and costs:

The distribution of impacts, benefits and costs across the population is of considerable policy interest for equity considerations, among other (e.g., political) reasons. A microsimulation approach allows these impacts to be measured at the level of each individual or household, allowing a detailed examination of policy impacts across socio-economic groups, spatial locations, etc. This rich detailing of system behavior and impacts should greatly enhance policy debate.

In particular, major equity issues exist in land-use modelling, including affordable housing, access to services, environmental justice and other impacts that are highly differentiated across space and socio-economic groups. Understanding the spatial distribution at a very fine grain of development and land value impacts of transportation investments (e.g., around metro stations), zoning decisions, etc. is of critical policy importance.

2.4 Tracing complex interactions

Many decisions are complex in that they may involve any or all of:

- The choice of a "bundle" of actions (e.g., activity type, destination and travel mode).
- Interconnections between one decision and another (I may drive to work since I need the car to go shopping after work; if I move to this suburban location I will need to buy a car).
- Interactions among agents (ridesharing, participation in joint activities, etc.)

These and similar complex behaviors and interactions can only be modelled at the disaggregate level of the individual agent.

The urban region is a large system of systems: housing, labor, schools, auto ownership, social networks, travel, etc. Each of these systems is complex and heterogeneous in its own right; the interaction between these systems adds further complexity. Agents simultaneously exist and act within multiple systems and their actions "flow" within and between these systems. Microsimulation allows individual agents to be tracked from one system and decision context to another, thereby permitting the transmission of information and the ramifications of decisions in one system to another. As noted in Section 1, integrated urban models must deal with the behaviors of individual agents, their collaborative interactions through their social networks and their competitive interactions within a variety of spatial and economic markets. Microsimulation is essential for dealing with the first two of these problems. Markets can be modelled in a variety of ways, including microsimulation, which has been shown to be able to model housing and other markets robustly and efficiently (Rosenfield et al., 2013).

2.5 Support for the modelling of history, memory, learning and adaptation ("decision dynamics")

Similarly, modelling of behavioral dynamics — how one decision in time affects the next; how agents learn and adapt over time — is only possible within an agent-by-agent microsimulation approach within which individual experiences can be "remembered" and behavior can evolve over time in response to the agents' experiences. Such models of learning and adaptation are in their infancy in the travel modelling field (Psarra, Arentze, & Timmermans, 2016) and have not yet seen practical application, due both to a general lack of suitable time-series data to develop such models and to practical problems in how to model travel behavior dynamics within an arbitrary "day in the life" which is the typical travel demand model use case.

Unlike current travel models, however, integrated urban models are explicitly dynamic in that they step through time one year at a time (and potentially at finer time steps, say, month by month). This permits memory to build up and current decisions to be based on past experience (as well as possibly expectations about the future based on extrapolation of past trends). Microsimulation provides the framework within which memory of past events can be stored and (possibly) tastes and preferences can evolve over time. It also supports inertia and disequilibrium in markets and other processes. That is, aggregate models inevitably require assumptions that markets are always in equilibrium and that agents are always optimizing their behavior. But housing markets, for example, typically display considerable inertias and associated disequilibria (e.g., I may stay in my current dwelling even if it is not currently "optimal" in some way). Further, because integrated models operate over time periods of decades, they create an environment within which more dynamic models of travel behavior are also conceivable. Such models could possibly include learning and/or adaptation, since the agents are continuously tracked over many years of behavior within the model system.

2.6 Computational efficiency

While the explicit modelling of millions of agents sounds (and can be) computationally intensive, it can also be the most efficient means of dealing with the heterogeneity in agent behavior discussed above. Conventional aggregate models deal with heterogeneity (in occupation, income, age, auto ownership, household structure, etc.) by cross-classifying persons (and/or households) into homogeneous categories and then applying travel choice calculations to the persons in each category. The result of this approach is typically dozens (or more) of categories of trip-maker that must be considered for every travel decision. This typically results in hundreds of millions of choice model calculations to model the behavior of a few million agents. Carefully designed microsimulation models can greatly reduce computation times by constructing a list of each agent in the system (and its individual attributes) and modelling its behavior directly.

2.7 Emergent behavior

Models should be capable of "surprising" us with unexpected results that emerge out of the combination of processes, constraints, etc. at play within the system. Microsimulation gives permits agents to interact to generate emergent aggregate outcomes. This is important for at least two reasons. First, cities are clearly self-adapting and self-organizing complex systems within which the urban built form and the spatial-temporal socio-economic activity system evolves over time. A realistic model of urban spatial processes must be capable of generating emergent behavior if it is to be a truly useful tool for policy analysis. That is, it must be able to (at least occasionally) surprise us with unexpected outcomes that have not been "hard-wired" into the model's code. For example, a model which predicts (under appropriate circumstances) the gentrification of a previously "run down" neighborhood without having the gentrification process explicitly specified within its set of coded behaviors presumably is a very powerful and useful policy analysis tool. Models which do not capture such self-organization are unlikely to be overly behavioral in nature and hence unreliable for policy analysis, which explicitly needs to understand how behavior will change in the face of the policy under consideration.

Second, we live in a world in which the status quo/"business as usual" is not sustainable. We need to find alternative paths into the future that improve upon current trends. Again, models which are not able to find emergent paths away from these current trends are not particularly useful policy analysis tools.

2.8 Support for other disaggregate models

Finally, disaggregate travel demand models have been available for use since the 1970s. It is arguable that they still are not generally employed to their full advantage since they too typically lack the disaggregated socio-economic and other contextual inputs that they require to be maximally effective. An integrated urban microsimulation model should be able to provide the individual agent attributes needed to properly specify and use disaggregate travel models to their full advantage.

2.9 Microsimulation and "the science of cities"

In the emerging "science of cities" literature we are increasing seeing how cities apparently obey scale laws at the macro level (Bettencourt, Lobo, Helbing, Kuhnert, & West, 2007; Batty, 2008; Bettencourt & West, 2010). Explanation of these macro properties (as well as other elements of urban macro performance under investigation with the "city science" literature) inevitably will require understanding how micro-level interactions result in these emergent macro outcomes (Bettencourt, 2013). Microsimulation-based integrated models provide the computational virtual laboratory for these explorations (Batty 2005, 2013). In particular, Downey (2012) argues that complexity theory is providing an alternative scientific paradigm that is intrinsically heterogeneous, non-linear, discrete, and stochastic in its "world-view" and, hence, inevitably simulation, rather than analytically, based.

2.10 Summary: So what?

The late Ryuichi Kitamura reportedly used to terrorize his graduate students by always asking them at the end of a presentation of their recent research results a very simple question: "So what?" i.e., what is the practical importance of these findings? The discussion in the previous sub-sections has focused on the potential generic advantages of the microsimulation framework for improved modelling of the spatial-temporal socio-economic processes of interest within integrated urban models. Implicit in this discussion is that the benefits of this approach for practical policy analysis are self-evident. To get beyond this assumption and to at least begin to answer Prof. Kitamura's "so what" question, one can note a long list of policy questions that can benefit from analysis through a microsimulation lens. These include:

- *Housing market analysis:* Equity accumulation, residency length, lifecycle stage, lags, leads and "triggering events" in residential mobility decision-making and household composition evolution, among other factors and processes affecting housing location/relocation decision-making all benefit from (or may even only be feasible) within an agent-based microsimulation framework.
- *Labor market analysis:* Labor force entry, exit and mobility depend on household-level interactions and dynamics, as well as individual attributes and employment history. Work commuting

patterns evolve through sequences of individual worker residential and employment location decisions over time, not through a macro market equilibration process.

- *Demographic modelling:* University of Toronto demographer David Foot famously said that "demographics is two-thirds of everything" (Foot, 1996). While aggregate demographic models are very common, as noted above, disaggregate person- and household-level models are essential for supporting state-of-the-art activity/travel models and are also essential to support housing and labor market simulations. As demonstrated by Chingcuanco & Miller (2018), large-scale urban demographic simulations are a practical proposition.
- *Building supply modelling:* Most current land-use models (e.g., UrbanSim and PECAS) work at very disaggregate spatial scales of the individual parcel in their modelling of building supply; i.e., the models attempt to determine optimal land development decisions at a very micro scale in response to the existing local micros built environment, zoning, other neighborhood factors, etc.
- *Emissions and energy modelling:* Microsimulation modelling provides much more accurate estimates of vehicle emissions and energy use since it is able to capture driving cycle dynamics, hot/cold start regimes and hot soak emissions estimates (Hatzopoulou, Hao, & Miller, 2011; Hao, Hatzopoulou, & Miller, 2010). More aggregate models of residential and office building energy use are possible, but the potential to interface disaggregate activity/travel models with building energy models provides the potential for much more dynamic time-of-day modelling of energy usage (e.g., "the lights are on and the heat — or air conditioning — is on" when people are at home).

3 Microsimulation in integrated urban models

3.1 Introduction

As noted in the previous section, experimentation with microsimulation-based integrated urban models has a long history in the academic literature. Such models, however, are still not common in operational practice. As also noted above, this may reflect conservatism within planning agencies with respect to adopting new methods, past failures of such modelling efforts, and/or a lack of interest model-based planning. This section explores through the microsimulation lens some classic objections to integrated urban models as represented by Lee's classic "seven sins of large-scale models" (Section 3.2), as well as some other important considerations (Section 3.3).

3.2 Microsimulation and Lee's "seven sins"

Integrated urban microsimulation, of course, is not without its pitfalls and weaknesses. As with all large-scale models, it is potentially heir to Lee's "seven sins of large-scale modelling" (Lee, 1973). As Miller (2009) argues, however, considerable progress in behavioral theory, modelling methods, data and computing power over the past decades means that such models are a much more practical proposition than they were when Lee first wrote his devastating critique of the first generation of land-use models. In particular, it is arguable that it is precisely because of the computational feasibility of microsimulating millions of agents that large-scale urban models can potentially circumvent at least five of Lee's seven sins:

- *Hypercomprehensiveness:* Microsimulation well designed within an agent/object-oriented approach provides the means to deal with complex systems and systems of systems in operationally practical ways. Also, the counter-argument to the complaint of hyper-comprehensiveness is that partial models run the risk of ignoring important feedbacks between processes and systems of systems interactions. It is critical that these interactions and feedbacks be understood if either transportation or land-use policies are to be effective and not "surprise" us with unexpected and unintended consequences. A simulation framework is the only one which can explore these issues.

- *Grossness:* Microsimulation permits models to be constructed at the fine spatial and socio-economic scales necessary to capture heterogeneous, non-linear behaviors.
- *Wrongheadedness and Mechanicalness:* Microsimulation permits behaviorally robust models to be formulated and implemented at the level at which behavior actually occurs: the individual agent.
- *Complicatedness.* It is important to distinguish between complexity and complicatedness. Microsimulation often allows complex behavior to be modelled using simple models. It often simplifies the model relative to aggregate models which require more complex specifications to deal with the underlying behavioral heterogeneity. Large urban models inevitably will be complicated to some degree in their algorithmic and data structures, and certainly parsimony in model construction is always a virtue. But well-designed microsimulation models can be more transparent and understandable than at least some more aggregate formulations.

The data requirements of large-scale urban microsimulation models (Lee's sixth sin of "hungriness") are, of course, large, but generally no larger than any other approach to urban modelling. And, in today's era of detailed GIS-based datasets concerning land cover, built form, assessment data, etc., as well as increasingly prevalent "big data" sets of various forms, data availability for model development and application, although still a practical concern, is no longer the "deal breaker" that it might once have been for such models.

The final of Lee's seven sins is the cost of building a large urban simulation model ("expensiveness"). Again, a microsimulation approach need not be any more expensive to develop than a more conventional model. But the complaint of expensiveness is, in itself, a curious one. Given that urban transportation investment decisions involve billions of dollars in capital and operating costs over the lifetime of the investment, that urban real estate markets similarly involve billions of dollars — and are one of the primary sources of wealth in our societies (Kennedy, 2011), and that our economic and social welfare depends on well-designed urban built forms and transportation networks, it would seem well worthwhile to spend an extremely small fraction of such sums on building tools that would improve our decision-making concerning these massive investments. The question is not whether such models are expensive or not, but rather, first, is whether they are cost-effective, and, second, can we afford not to build and use them?

Perhaps the most important of Lee's critiques, which he repeated in his 1994 revisit of the field (Lee, 1994), and which was also echoed a decade later by Timmermans (2003), is the lack of sound theory in the land-use models of his day — that they were neither good engineering (since they were of little practical use) nor good science (since they lacked sound theory). This remains a compelling concern in current integrated urban models, many of which arguably remain relatively ad hoc in nature. A microsimulation approach does not directly solve this problem, since microsimulation is not a model per se, but rather is a computational structure for the implementation of models of system behavior. It does, however, represent an approach for addressing these issues in that, if properly designed, it can provide a sound "engineering" of the problem in terms of providing a flexible, computationally efficient modelling platform for the implementation of theoretically sound models.

3.3 Other issues

In addition to the inevitable issues of data and theory, key concerns exist in designing an integrated urban microsimulation model. The first of these is avoiding endless disaggregation. There is a temptation to model at finer and finer levels of socio-economic and/or spatial detail. Part of the art of microsimulation is to disaggregate where disaggregation is needed and feasible, and to keep the model simpler and more aggregate where it is not. Parsimonious models are always a virtue. Data and theory do have their limits in any practical application, as does the need to account for heterogeneity and non-linearity. In any application there occurs a point where further disaggregation is likely to generate more "noise than signal" and it is at this point that detailed modelling should end and simpler, more statistical models become appropriate (Wegener, 2011b).

Integrated urban microsimulation models are very large Monte Carlo simulators. The statistical validity of the outputs of such models is an on-going concern. That is, the output of one run of the model system is one path into the future. Ideally, the model system should be run many times for a given set of inputs in order to generate a distribution of outcomes and their probabilities of occurrence. This is rarely done, given the associated computational burden and complexity of trying to interpret the results. Nevertheless the statistical properties and robustness of results generated by integrated urban microsimulation models needs to be investigated in greater detail than has generally been the case to date.

Finally, even ignoring the possible need for replications of model runs, computation times of large microsimulation models are a continuing concern. Parallel and distributed (cluster/cloud) computing and careful attention to program efficiency help considerably in this regard, as does continuously increasing computational power. Experimentation with "sampling", in which agents and systems are "scaled down" so that, for example, only 10% of a population is explicitly modelled, is another approach to reduce computing times. The accuracy of such "scaled" outputs is, however, questionable in many applications (can one really model 10% of a housing market and get "correct" results?), and much more investigation of this issue is needed.

4 Final comments

While integrated urban microsimulation models are not yet commonplace, especially in operational practice, a very strong case exists for their more widespread use. Continuing advances in computer power, large disaggregate datasets, econometric methods for parameter estimation, and behavioral theory make microsimulation an increasingly feasible and attractive proposition (Miller, 2009). In particular, increasingly powerful and efficient software for integrated microsimulation modelling, such as MATSim (Horni, Nagel, & Axhausen, 2016), ILUTE (Miller et al., 2011), SILO (Moeckel, 2017), among others, is providing a computational framework for the development and application of such models. Over the past 10-15 years we have seen microsimulation methods become the dominant, state of the art approach to urban travel demand modelling, and it is reasonable to expect that this trend will extend into integrated urban models as well.

Perhaps the greatest obstacle to the development of the next generation of integrated urban models is not technical but cultural. Integrated urban modelling has always struggled to attract the resources and support within metropolitan planning agencies that it arguably warrants. Many reasons for this exist, including, it must be recognized, past failures of many such models. But urban regions are growing rapidly across the globe, and how we design our cities, their urban form and their transportation systems will go a long way towards defining at least the physical conditions for urban prosperity, quality of life, social equity and political stability. These are first-order challenges that we must address successfully. It is argued that integrated urban models have an important role to play in achieving these goals. And, it is further argued, that these models will need to take on a microsimulation form if they are going to deal successfully with the complexities of the systems and their behaviors that need to be modelled.

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