A Retrospect and Prospect of Urban Models: Reflections after Interviewing Michael Batty

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Abstract Based on an interview with Prof. Michael Batty, a leading scholar in urban modeling, this paper reviews the history of urban models, comments on their present developments and pictures their prospects. The first section briefly overviews the family tree of urban models and then looks further into the causes for their failure in planning application in the first upsurge of related research in the 1960s and 1970s. The second section summarizes the current development of urban models, which can be counted as the second upsurge of related research. It is estimated that more research attention will be paid to building dynamic, disaggregate, micro and problem-oriented models, with a combination of top-down and bottom-up modeling methods. This can be more capable of tackling the growing urban complexity and uncertainty. Meanwhile, the "big data era" also poses more opportunities for the development of urban models. The last section introduces three new trends in the theoretical, educational and research development of urban models, which compose the idea of "new science of cities" from Michael Batty, the start-up of quantitative urban research education and the establishment of Beijing City Lab.

Keywords urban model; quantitative urban research; big data; Beijing City Lab; China

In a retrospect of the development of urban science, one can find that it has experienced a shift from qualitative to quantitative research. It started from simple descriptions of urban phenomena, then moved to summarizations of these phenomena, then to understandings of the relationships within urban system, and finally to a systematic view of urban development. Influenced by such a development trajectory, urban modeling, which is a mathematical expression of urban phenomena based on the abstraction and conceptualization of urban system, has emerged as an expanding branch of urban science. Urban models have now become an important tool for understanding, managing and planning the urban system. They can be applied to support the formulation and assessment of urban policy and planning.

Urban modeling is receiving growing research attention in China, with China's urban planning transforming from mass-construction in the past two to three decades to more sophisticated management. In order to better inform Chinese scholars of the history and possible future of urban modeling research, the authors interviewed Prof. Michael Batty, the director of CASA (Center of Advanced Spatial Analysis) at UCL (University College London) and a leading scholar in this field. The paper does not intend to present a comprehensive overview of urban models, but put forward a few reflections on their development trajectory, types, application performance, future development, and related education, so as to raise Chinese scholars" interest and further in this field.

1. The early stage of urban modeling research

1.1 Static model as the main type

The urban modeling research started from the beginning of the 20th century. At its primary stage in the 1950s, researchers developed several models from an urban form perspective, e.g., the Concentric Ring Model of land use by Ernest Watson Burgess, the Central Place Theory by Walter Christaller, the Sector Model of land use by Homer Hoyt, the Multiple-Nuclei Land Use Model by Chauncy Harris and Edward Ullman, etc. In the late 1950s, the invention and promotion of the computer brought new opportunities to urban models, which led to the first boom of research in this field in the 1960s and 1970s. Typical models developed in this period include the Spatial Interaction Model and the Land Use Transportation Interaction Model (LUTI), represented by the Lowry Model (Lowry, 1964) and the Alonso Model (Muth, 1961; Alonso, 1964; Mills, 1967), which were then introduced to urban planning to assess urban development policies. Later on, the integration of spatial economics and the LUTI model framework gave birth to Spatial Equilibrium Models. However, most applied urban models still belonged to the category of static models up till then. It was not until the 1990s that dynamic models, such as the Agent-based Modeling (ABM), Cellular Automata (CA), and Spatial Unequilibrium Model, began to dominate, driven by the upgrade of computer hardware, artificial intelligence, and GIS.

When it comes to the nations of researchers at that time, the US was taking the lead. The University of Pennsylvania (U Penn) was recognized as the home of urban models, marked by William Alonso and the Penn-Jersey Model by Britton Harris. The UK was a bit later, with about five or six research groups in the field including the University of Reading, the University of Cambridge, the University of Leeds, and CASA at UCL. Reading started relevant research in the early 1970s, followed by Cambridge and Leeds in the late 1970s, which have been the biggest groups in the UK since then. However, their emphases are diverse: the Cambridge group is more involved in developing the MEPLAN model, while the Leeds group is more involved in spatial analysis. Besides, CASA has also grown into a highly capable group in quantitative spatial analysis and urban modeling after about twenty years" development. Moreover, there are also researchers and institutes working in the field scattered all around the world, e.g., the Venezuelan company Modelistica that developed the TRANUS model based on the spatial input-output model (de la Barra, 1989).

Regarding the objects of modeling, early urban models laid more emphasis on transport than land use, because both the US and the UK had a strong transport sector engaged in transport planning and engineering. This was different from the strong physical planning and urban design orientation in China. This kind of transport orientation approach in the two countries also led to several strong transport research groups, such as the one at the University of California, Berkeley that produced CUF and CUF-2 for the San Francisco Bay Area (Landis, 1994, 1998) and the one at the Imperial College London. This was also the case in the continental Europe.

1.2 Uncertainty as the major challenge

The first golden age of quantitative urban study came in the 1960s and the 1970s, when urban models were aimed to predict the consequences of different combinations of public actions. Public actions include urban renewal, taxation, transportation facilities, water, sewer, and other utilities, zoning, building code enforcement, mortgage and other credit availability, antidiscrimination efforts, employment opportunities, and so forth (Lee, 1968). However, the enthusiasm in this topic was then dampened by urban social theories such as New Marxism, because the models failed to solve practical problems and to get extensive application.

According to Prof. Micheal Batty, the main reason was that the best predictions of the models, such as long term structural change, were not among the interests of policy makers. Instead, they were particularly interested in urban renewal, housing problems, etc. These were key issues for urban policy making but the most difficult to articulate in models. For example, the housing market is a mixed market of private and public actors, with a vast contrast in the size and scale between the supply and demand side, and a great lag in suppliers' reaction to market changes. Consequently, there are a lot of distortions in the housing market, making it much more difficult to simulate than truly commercial markets such as the retail market. Although early urban models did take such issues into consideration, they failed to grasp the underlying logic of those markets.

When one digs deeper, the failure also laid in the lack of a valid theoretical basis at that time. As a result, urban models were criticized for being too simplistic compared with the urban issues that they were dealing with, although they had been fairly complicated. In New York, for example, there were a variety of models targeted at emergency services like the fire, police and ambulance services in the 1970s, to decide the allocation of facilities and man power. However, their poor performance in turn aggravated the problems by misleading the allocation of emergency services away from where crises really took place. In this particular instance, the lack of urban theories led to two weaknesses of the models. On one hand, the actual way that the firefighters and the policemen responded to emergencies was not taken into account, e.g., fire fighters might be absent from work. On the other hand, the models did not get to the basis of the patterns of emergencies, e.g. the breaking out of fires was not just to do with the facts of buildings like buildings age, but also behavioral factors.

The problem can be further attributed to the incapacity of urban theories to deal with uncertainty. In other words, researchers did not have access to enough information on the underlying behavioral patterns of the model agents, which might appear to act rationally but probably in a much more complex framework. Moreover, the issue of uncertainty is also a key concern of planning theory (Christensen, 1985; Allmendinger, 2001; Yu, 2004; He et al., 2012), noted by the quote that uncertainty is the only certainty there is. Therefore, it is the interest of both planning theory and urban modeling to understand and tackle the uncertainty of urban development.

2. The latest progress of urban modeling research

2.1 Sophistication as the main development direction

At the current stage, most urban models are dynamic models, which can be further grouped by their theoretical basis. The model groups include the Gravity Model and the Entropy Maximizing Model based on the spatial interaction theory; the Alonso Model, Discrete Choice Model, Spatial Input-Output Model and Regression Model based on economic theories; the Cellular Automata (CA), Agent-based Modeling (ABM); and Microsimulation Model (MSM) based on the complexity science (Long, 2013). In addition, there are a few models that cannot be entirely grouped because they are built quite separately from the bottom-up perspective, although they do tend to have aspects in them that are similar in part to other models. They tend not to have recognizable names or acronyms like MEPLAN or SLEUTH (a model based on cellular automata, Clarke et al., 1997). Moreover, they are just one-off in most cases, such as the Beijing Urban Development Model (BUDEM, Long et al., 2010), instead of being developed into software packages and applied to various cities. The BUDEM for example is customized to reflect the development characteristics of Beijing. Furthermore, there is another cluster of models, which emerged not from this particular tradition, but from GIS, e.g., the SLEUTH model. These models are different in that they mainly deal with land development without dealing with the transportation sector, although some of them do interface with travel demand models.

Throughout the whole development process, urban models have presented a shift from aggregation to disaggregation, and from top-down to bottom-up approaches. Researchers started fifty years ago with aggregate models like the Lowry Model, the Alonso Model, and the early versions of the UrbanSim models (a spatial inequilibrium model based on the LUTI model framework, MSM, ABM, and discrete choice, Waddell, 2002). Researchers then began to break down the population and introduce a bit of dynamics into those static models, which brought them to disaggregation. In parallel, transport models have followed the same trend. They have now been developed from the original aggregate trip distribution models into highly-disaggregate agent-based models of transportation systems where individual travelers or families are modeled separately, inspired by the discrete choice models or the so-called disaggregate demand models in economics. Such models like the TRANSIMS (Smith et al., 1995) and the MATSim (Balmer et al., 2008) have been a huge departure from the aggregate models like the MEPLAN which simulated in zones of 3000 – 4000 households.

It can be concluded from the review that sophistication, which refers to dynamic, discrete, micro, and bottom-up approaches, will be the main development direction of urban models. Correspondingly, the integration of urban models with the planning practice will also be detailed from macro- to micro- to meso-scale planning. For example, top-down spatial equilibrium models like MEPLAN, TRANUS, and PECAS (Hunt and Abraham, 2005) were mainly applied to assess the impacts of large-scale planning policies (Wan and Jin, 2014), while later models like UrbanSim are applied on smaller scales.

2.2 Four trends in modeling methods

In order to provide planning support on various urban issues in an age of growing complexity, according to Micheal Batty, urban models are presenting four trends in their modeling methods. The first is to build integrated models which contain both aggregate and disaggregate, or macro and micro features. In this case, macro models can be manipulated to generate zonal scale simulations, which can be further allocated in a finer scale by micro models. For instance, in the BUDEM (Long et al., 2010), the annual urban land growth in Beijing is first simulated exogenously and then allocated according to the development suitability of each land cell decided by its location, planning constraints and neighboring status.

The second is to develop particular aspects of models for particular problems, i.e. problem-oriented models, or one-off models. Such a strategy is facilitated by the large pool of modeling tools produced through decades of modeling research, from which one can draw and package the most useful bits of models to solve specific problems. In addition to the BUDEM, there are also models of this type developed in Japan, Europe, and North America, even with software packages in some cases. However, such a trend does not necessarily mean the requiem of big comprehensive models, but expansion on all fronts in the field of urban modeling, which will give birth to more problem-oriented models, as well as more comprehensive models. In the context of China, this trend can also contribute to providing planning support as the urban planning and management of China is growing more and more sophisticated. For instance, LISA (Lab of Interdisciplinary Spatial Analysis) in Cambridge is developing an ABM model for the spatial distribution of the creative industry in Jiading District, Shanghai.

The third is to tackle the growing complexity of urban systems. Since models by their very nature and definition are simple, if the systems turn out to be too complex, they would have to break urban systems down into several aspects to be embodied in more than one model, e.g., specific models on infrastructure construction, housing supply, urban renewal, etc., or models at different level of sophistication. Moreover, the enhancement of data quality, the expansion of model types, and the progress of ICT (Information and Communication Technology) are all contributing to tackling complexity. For example, the progress of ICT poses new opportunities to experiment in cities in a limited area and very short term by providing various kinds of information and information devices that enable people to respond quickly to stimulus. People can for example be informed of and respond to congestions or underground breakdowns via smart phones. By this means, researchers are able to quickly figure out the latest trends and their impacts. Another example is the idea of using crowd-sourcing to generate new datasets which are not accessible by traditional surveys or too expensive to acquire. The OpenStreetMap (OSM) data contributed by users through handheld GPS sets, aerial and satellite photos or personal memory is a good example. A recent application is a research by Long and Liu (2013) that identified the land use type and development intensity of each block in 297 Chinese cities based on OpenStreetMap and Point of Interest data. Meanwhile, the ability to predict is under extreme scrutiny. It is quite clear that people cannot predict the exact future, but can predict conditionally, which is what prediction means in social systems.

The fourth is to build several models from slightly different perspectives on the same problem to look at the range of results instead of just one model, which is one of the most feasible approaches in tackling uncertainty. This approach comes from macroeconomics, in which the economy of a country is modeled by several different econometric models to generate a basket of results to discuss. Nevertheless, it has never been carried out in urban research for mainly two reasons: firstly, because a bigger arsenal of tools is needed; second, it could still be very expensive although models are now much easier to build. Therefore, such an approach would probably be first applied to large-scale policies such as a master plan, regional plan, transportation infrastructure construction, etc.

2.3 Urban modeling in the era of big data

Prompted by the progress of ICT, the emergence of big data has now enabled urban researchers to identify individual behaviors from various data sources such as sensor networks, social networks, RFID, call detail records, etc. Relevant research that has already been undertaken includes new models of movement and location, risk analysis of development path, new models and systems for mobility behavior discovery, new tools for governance of mobility demands, etc. (Batty, 2012). The availability of data poses both new opportunities and challenges for urban spatial analysis and modeling, which has now become a hotspot of research.

Urban modeling research is presenting several new trends in the era of big data. First, it is becoming more multidisciplinary than ever, by integrating the traditional expertise in the field with new knowledge from computer science, GIS, time geography, etc. Secondly, it is becoming more fragmented, as it focuses on certain aspects of the urban system instead of the system as a whole (Batty, 2012). Because marked by their volume and velocity, big data is particularly suitable for specialized analysis, while the traditional data are less abundant but more well-rounded. Third, the model is getting closer to data, or data itself is the model, as mentioned by Micheal Batty. In this case, interesting results can be produced by simple statistical analysis. Fourth, the focus of research is shifting from simulation and prediction to present evaluation, because the more sophisticated a model is, the less suitable it is for long term prediction, which is the very nature of sophisticated models.

Furthermore, it is promising that there will be much more trends to identify if big data are collected over a longer period of time like five or ten years. Researchers will be able to identify long term trends emerging from a series of short term ones, which is a research paradigm shift. For example, from journey-to-work data, one can identify routine behaviors and use them as unique identifiers of individuals, and see whether individuals shift their routine patterns over a month, or half a year. For another example provided by Micheal Batty, from credit card data recorded over twenty or thirty years' period, one can see how people's lifestyle is embodied in their purchases, e.g. people consume less and differently as they get older. However, much remains to be explored about what long term big data could bring to urban quantitative research and planning decision making.

In fact, the shift towards more data intensive modeling has already been embedded in the development of GIS. GIS is basically inputting data into a spatial information system and displaying the data in various ways, so that a lot of GISs and GIS-based techniques are very close to the data, which is a prelude to the trend of data modeling mentioned in the last section. However, when speaking about data modeling, it is not sure whether big data will sing another requiem of urban models after Lee's famous work. Nevertheless, it is too premature for a look back before another wave of model applications, which has only just begun.

2.4 Professional culture as the main obstacle to model application

Urban models have not yet been massively applied in planning practice, although academia has made lots of progress in urban modeling in the past decades, and a growing number of local governments and funding bodies are getting interested. There are mainly three reasons.

First, different national cultures develop different styles of thinking about urban models. Micheal Batty thinks that there is a much stronger sense of "technological optimism" in the US than in other countries like the UK, although that has been changing a little bit because of the negative impacts of new technologies. As a result, there was such a strong optimism on the side of planners and policy makers in the 1960s and 1970s that most American cities had built their own models. Of course they were later found out not to be as useful as suggested. In the UK, there was much less optimism that these tools would be useful anyway, so there have been much less applications there. The majority of which are the work of the David Simmonds Consultancy in London and the rest of southeast England, the work of one or two transport consultancies, and the application of MEPLAN. Nevertheless, the attitudes in the UK has also been changing because of the long influence of computer technologies. In terms of China, since most planners were trained as designers, they tend to be uncomfortable with modeling and letting the design process be informed by model results. According to the authors' experience, Chinese planners' major doubts over urban models lie in the validity of model mechanisms and parameters, as well as the suitability of models from developed countries for Chinese cities, but they are getting familiar with models.

Second, professional culture is also hindering urban models from being accepted by planner and policy makers, who lack relevant training and a real sort of feel for these approaches. Moreover, policy makers are probably not very happy about models because models conflict with their role of letting cities develop more spontaneously, as they are committed to organize and optimize. According to Michael Batty, it is a difficulty for many policy makers to be told about what they should not do. Hence, there was a saying that models are part of the problem, not part of the solution in the 1960s and 1970s; in other words, models contained within them various things that planners and policy makers wanted to change.

Third, many ideas of system analysis and system development in urban modeling were transplanted from the military and defense related fields in the 1960s, which was not an easy transition. It is quite common that techniques and tools were not well adapted to the urban system, causing problems like data problems, computation problems, financing and funding problems, etc.

Due to the above problems, the first golden age of urban modeling faded away in the late 1970s. It was not until the 1990s, perhaps even more in the 2000s, that researchers got in a situation where data availability and computational power was no longer a major issue for modeling. Meanwhile, the miniaturization and large outreach of computer technology has also prompted the development of GIS, which can serve as a platform for preprocessing and post processing spatial information. All these factors are now giving a new impetus to modeling and leading to a so-called "second golden age". Moreover, the smart-city movement is running in parallel to this new interest in modeling, but quite different in many ways. Smart cities are dealing with short time spans like a couple of days or peak hours, whereas urban models are about the dynamics over a much longer time span like six months, five years, or longer. Nevertheless, as a set of tools and techniques to understand cities, urban models also overlap with certain aspects of the smart city such as on very fine-scale pedestrian and vehicle movements, very detailed transport system disruptions, etc. Therefore, certain types of operation and research models are being developed in the smart city movement by IBM, CISCO, etc. In such a "second golden age", it is a must for researchers to learn from the past on how to improve model application to avoid similar problems.

3. The future of urban modeling

3.1 The emergence of the new science of cities

Echoing this second boom of urban modeling, Michael Batty has recently published a new book on quantitative urban research, named The new science of cities (Batty, 2015). Nonetheless, as he mentioned in the book, there is not just one new science, but many new sciences of the city. It is labelled as the "new science" because many of the techniques and tools involved in the science are relatively new, compared to the older sciences such as urban economics, social physics, transportation-type theories, etc., which were loosely called the "regional science." The older sciences were based on a much more static, cross-sectional, and systematic view of cities, while the newer science is based on the idea of evolving cities and a complexity theory. To some extent, the new science can be defined as an urban science that is related to the complexity theory and makes use of all the new tools and techniques produced over the last twenty to twenty-five years. In addition, there are many other dimensions in which the new science can be characterized, such as disaggregation, bottom-up thinking, evolution and so on. To conclude, the emergence of this new science indicates that in the past decades academia has made considerable progress in its urban complexity research.

In his new science, Batty takes the urban complexity and the network theory as two new perspectives to study the city, which switch the emphasis of urban science from location to networks, flows, and the dynamics of change. The CASA, which Batty directs, is exploring a lot of ideas and methods that relate to the morphology and the connectivity of cities, e.g. short-term dynamics under bifurcations and perturbations, static models in a dynamic framework to generate rapid changes, etc. Some of these models represent more of the old science, but the dynamics of them represent more of the new.

The long term mission of the new science would be to achieve a better understanding of what is happening in cities on a database basis. For example, one could construct a daily-updated 3D city model from remote sensing data acquired on a daily basis to observe how the city would be changing over periods of time as an accumulation of micro-changes, which is also a type of big data. As another example, one could construct a model of traffic flow updated on a daily or weekly basis to reflect people's real time movements. In other words, the intelligence function of the city can be established in more details. Such a shift already exists in bits and pieces, e.g. traffic control centers of aircrafts that capture data on an hourly basis to keep the system running, but now needs to be extended to the land use system. Moreover, more tools and methods are needed to extract useful information from the database, which also already exist in bits and pieces. It relies on the new science to join the pieces up, which would make planning more rational and effective.

3.2 The start-up of related education

In terms of the UK, there was a gradual shift in urban planning from an architectural approach towards more of a social science approach in the 1970s, so most planning schools in the UK are neither quantitative-based nor urban design-based, but instead engaged in economic and development studies. Michael Batty thinks that it would take quite a few years to adjust the education system to get planners more exposed to quantitative methods, complemented by other relevant changes taking place in parallel. First, there needs to be a change in the planning faculty to include more expertise in quantitative urban research. However, more importantly, quantitative urban research does not necessarily have to be conducted by people with a planning background but can also be done by those from backgrounds that are more scientifically orientated. Consequently, the change will come more from the prior education of people coming into planning. Second, the change will also come from different agencies involved in planning, including a lots of big firms and government agencies doing the job from different perspectives. For example, IBM has now launched their planning division; and big engineering companies like ARUP have also recruited a lot of quantitative planners. Their employees are not necessarily professional planners in the traditional sense. In fact, a lot of professional planners are now switching into the development control system instead of the strategic planning.

The Bartlett School of Planning at UCL has recently launched a new Master's program in urban analytics and smart city, which is more a kind of feeder course for the PhD Courses taught include urban theories, modeling methods (ABM, CA, etc.), computer visualization, programming, GIS, smart cities, etc., which is a pioneer in quantitative-related education in urban studies.

3.3 An experiment of Research 2.0

The establishment of Beijing City Lab (BCL, http://www.beijingcitylab.com, http://longy.jimdo.com) is dedicated to develop quantitative urban studies for Chinese cities, while design and qualitative urban studies are still the mainstream in urban planning and studies in China. BCL, founded by Dr. Ying Long in October 2013 is a research community for studying, but not limited to, China's capital Beijing. The Lab focuses on employing interdisciplinary methods to quantify urban dynamics, generating new insights for urban planning and governance, and ultimately producing the science of cities required for sustainable urban development. The lab's current mix of planners, architects, geographers, economists, and policy analysts lends unique research strength. The lab has one managing director, six associate directors, 11 honorary directors, 24 research fellows, and 38 junior and student members as of May 2014. A considerable number of studies that BCL has conducted are for Beijing, and it is turning its focus from Beijing to the whole China in the last three months. In this regard, the "Beijing" in the lab name represents the base of BCL, like the Beijing Charter proposed in 1999.

The research interest of BCL falls into the pool of quantitative urban studies, rather then being limited to planning a support system or new technologies for planning, which has already been extensively explored in China in last decades. Quantitative approaches are deployed by BCL for spatial analysis, statistics, modeling and forecast as to better understanding the past, present and future of cities. The research outcomes of BCL are expected to be applied not only in planning compilation and evaluation but more broadly, in urban policy making and evaluation.

As a two-year city lab, BCL has great potential for studies on Chinese cities, and it is benchmarking itself with the best city labs in the world, like the MIT Senseable City Laboratory, UCL's CASA or the Singapore-ETH Future Cities Laboratory. The difference between BCL and these other city labs, is that BCL is not affiliated with any academic entities thus making it lack enough financial support. However we admit the merit of its open character which attracts many researchers and students to follow and join in. As one of the honorary members of BCL, Michael Batty comments on BCL that BCL with full English pages has significant contribution to broadcasting Chinese urban studies to the research community in the rest of the world. The web-based and open research network also marks its important role in Chinese quantitative studies in the near future.

4. Conclusion

After decades of development, the urban model, which stems from system thinking and integrates computer science, economics, geography, etc., has far exceeded its original paradigm. It has been gradually shifting from spatial, temporal, and activities aggregation to spatial, temporal, and activities disaggregation (Batty, 2013). Thus, changing from a macro perspective to a micro or individual perspective. It has always been a major challenge for urban models to tackle the complexity and uncertainty of the urban system no matter this being in the first golden age in the 1960s and 1970s or at present in this second golden age. However, that is also the motivation for planners and policy makers to turn to models, because it is where traditional planning does not give good performance. Therefore, the complexity and uncertainty issue poses both challenges and opportunities. Despite that urban models have not been extensively applied in planning practice by far, it is promising that they would attract more research attention from various fields and be developed into helpful tools for urban planning and management.

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