What-Ifs, If-Whats and Maybes: Sketch of Ubiquitous Collaborative Decision Support Technology

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Abstract Since its introduction, geographic information science has witnessed a tremendous growth and can build on enormous achievements (e.g. Cheng et al. 2012). Current geographic information systems and the decision support systems and models that have been accompanying these systems have a strong 'geography' identity, typical of the era in which geographic information system were introduced. Systems are mostly based on spatial entities (mostly grids or polygons). To the extent that commercial and open source geographic information systems have been enriched with models, a similar strong geographic flavor can be discerned. Most models of spatial choice behavior are related to the aggregate spatial interaction models, models of land use change are often based on cellular automata. The question then becomes whether dominant spatial decision support systems, fundamentally based on aggregate spatial interaction, cellular automata and similar models, are suitable for adequately predicting consumer response. We content that in light of the increasing complexity of the decision making process and increasing personalization of decisions and lifestyles, these systems and their underlying models have increasingly become inadequate and obsolete. The field should shift to the development of more integral microscopic models of choice behavior, allowing more integral policy performance assessments. Moreover, mobile computing should allow and stimulate the development of real-time information and decision support systems that support the management of urban functions and include persuasive computing. Uncertainty analysis should play an integral role in these developments.

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1 Introduction: Shifting Contexts

Since its introduction, geographic information science has witnessed a tremendous growth and can build on enormous achievements (e.g. Cheng et al. 2012). Scholars from a variety of disciplines and backgrounds have become involved in this area of research and development, and made significant contributions to the field. The number and more importantly the quality of international journals in geographic information science have experienced wealthy growth and steady improvement. International conferences, including CUPUM, have continued their success in attracting leading scholars in the field, presenting their latest research findings and reflecting on existing areas of research to formulate evolving research agendas. The application of geographic information systems and associated decision and planning support systems has shown profound evidence of international dissemination and valorization (e.g. Geertman and Stillwell 2009).

This is not to say that all tools, models and integrated decision support systems have found ample application (Vonk et al. 2005, 2007a, b; Te Brömmelstroet and Schrijnen 2010). It is probably fair to argue that in many parts of the world geographical information systems with their mapping opportunities have gradually replaced conventional maps and databases. Information science has entered many private and public firms and organizations. It has affected daily work in a positive way, increasing productivity, although issues of synchronization, the existence of different data formats and software platforms remain (e.g. De Paoli and Miscione 2011). The application success of decision support systems shows considerably more variability. In some fields of application, such as transportation planning, the use of forecasting and impact assessment models is relatively common. Other fields, such as retail planning, have shown significant fluctuation (e.g. Huang and Levison 2011; Shen et al. 2011; Rasouli and Timmermans 2013), while the use of decision support systems in other domains is still virtually lacking (e.g. Johnson and Sieber 2011). Regional and international differences prevail.

In general, the acceptance of new technology depends on perceived needs, awareness of the technology and the extent to which the technology successfully addresses the needs (e.g. Bailey et al. 2011; Slotterback 2011; Rae and Wong 2012). In that context, it is relevant to memorize that geographic information systems and the decision support systems and models that have been accompanying these systems have a strong ‘geography’ identity, typical of the era in which geographic information system were introduced. Systems are mostly based on spatial entities (mostly grids or polygons). To the extent that commercial and open source geographic information systems have been enriched with models, a similar strong geographic flavor can be discerned (e.g. Voudouris 2011). Most models of spatial choice behavior are related to the aggregate spatial interaction models (e.g. Silveira and Dentinho 2010), models of land use change are often based on cellular automata. In particular, the number of applications of cellular automata model is staggering (e.g. Furtado et al. 2012; García et al. 2011, 2012; Long et al. 2012; Mahiny and Clarke 2012; Norte Pinto and Pais Antunes 2010; Plata-Rocha et al.

2011; Tang 2011; Thapa and Murayama 2011; van Vliet et al. 2012; White et al. 2012; Liu 2012).

This dominance of aggregate models is understandable considering the constant flirting of geography and regional science with aggregate models, originally developed in physics in combination with the geography background of early developers, and technical considerations such as the fact that the spatial representation of the data in geographic information systems is congruent with the principles underlying these aggregate models. The dominant inclusion of aggregate models in geographical information systems is not only understandable from the evolution of the key underlying disciplines, it is also understandable from a computer science perspective in that limited memory and computing power necessitated constraints on data and model complexity in the early years. Conveniently, the latter was amplified by the methodological principle of parsimony as the hallmark of scientific research and model development (e.g. Klosterman 2012).

The functionality of geographic information systems and associated models served the primary needs of urban planning (e.g. Vonk et al. 2007a, b). In many countries, the process of urban planning is orchestrated by public planning authorities, which on the one hand stimulate particular developments and on the other hand constrain others by formulating norms and guidelines. In addition, detailed land use planning shapes and signals legal authority for citizens and firms. In particular at higher levels of planning hierarchies, an academic approach to plan development and assessment has implied a relatively structured planning process involving the formulation of plan scenarios, the prediction of their likely effects in terms of a set of performance indicators (what-if questions) and an evaluation of plan scenarios and alternatives (e.g. Ligmann-Zielinska and Jankowski 2010; cf. Grêt-Regamey and Crespo 2011). Exogenous trends and scenarios are typically described for official statistical areas (neighborhoods, municipalities, provinces), explaining the use of the areal classification for data representation and model operation. This focus has been further legitimized by the fact that several specific planning domains have been strongly influenced by fundamentally spatial concepts. An example is the functional hierarchy of shopping centers which stimulates a neighborhood-based provision of stores serving local communities for their daily shopping needs, complemented by larger regional shopping centers and the city center itself serving a larger sphere of influence. Another example is the neighborhood concept, which assumes social coherence, and a sense of place, branded in local plans.

Spatial decision support systems provide the functionalities for evidence-based planning and design, with space typically represented at some level of aggregation (grid-polygon). The system produces the values of alternative plans on a set of performance indicators deemed relevant to judge the quality of the plans in meeting a set of corresponding plan objectives. The effects of plan interventions in many cases depend on how individuals and households are reacting to such interventions and adapt their current behavior. For example, the feasibility of new shopping malls and their external effects on the turnover of existing shopping centers depends on how households reorganize their shopping habits and substitute currently used centers for the new malls. Similarly, the success of the concept of high density, mixed land use neighborhoods in curbing mobility rates, depends on how much people's activity-travel decisions are influenced by such spatial characteristics.

2 From Aggregate to Microscopic Models

The question then becomes whether dominant spatial decision support systems, fundamentally based on aggregate spatial interaction, cellular automata and similar models, are suitable for adequately predicting consumer response. We content that in light of the increasing complexity of the decision making process and increasing personalization of decisions and lifestyles, these systems and their underlying models have increasingly become inadequate and obsolete. As argued by Chapin (1968) already decades ago, most land uses and transportation systems do no exist for their own sake, but because they are means for conducting mandatory and discretionary activities. People have certain needs and desires and in order to achieve these, they need to become involved in a set of activities. Because the facilities (or land use) enabling them to become involved in these activities are spatially distributed as a result of a (planned) sorting process, people need to travel. Activities constitute the link between the city and the people, while travel is the mechanism that makes the city working as an integral system. Chapin thus argued that the study of activity patterns, recurring in space and time, might ultimately yield better theoretical explanations and improved predictive models for urban planners and designers. Modelling consumer reactions to changing exogenous circumstances and plan interventions in terms of changes in their daily activity travel patterns thus seems paramount to fulfil the articulated need of policy assessment in some policy domains. Such microscopic models should logically outperform conventional aggregate models in that they capture particular behavioural mechanisms, behavioural heterogeneity and complexity that the spatial interaction models fundamentally ignore. The extent to which the microscopic models outperform aggregate models depends on the relative prevalence of such systematic errors and the extent to which these errors are counterbalanced elsewhere in the modelling process.

For a long time, such microscopic models were deemed impossible. However, increasing computing power, and developments in data fusion and modelling frameworks have allowed the first large-scale microscopic activity-based models of travel demand (e.g. Arentze and Timmermans 2000; Bhat and Singh 2000; Bowman and Ben-Akiva 2001; Miller and Roorda 2003; Raney et al. 2003), which simulate at high spatial and temporal resolutions which activities are conducted, where, when and for how long, with whom, and the transport mode involved.

3 The Shift to Integral Performance Assessments

The leading theme of this conference is sustainability. Our contention is that a shift from aggregate spatial interaction models to microscopic spatial choice and decision-making models would enhance our ability to better support urban decision making processes. Energy efficiency, social cohesion, cultural and economic prosperity, health and safe built environments characterize sustainable urban development. All these topics are strongly intertwined with how individuals and households organize their daily lives, reflected in their activity-travel patterns in different urban settings. Assuming that the achievement of these goals depends, at least partially, on a good understanding of urban activity-travel patterns, the development of valid and reliable activity-based models seems paramount to better support urban planning processes. It does not only have the advantage that actual decision makers as opposed to spatial units, which do not make any decisions, are modelled, the attention to space–time behaviour at a high level of spatial and temporal resolution also implies that in addition to the usual economic and social performance indicators, environmental impacts can be simulated.

Traffic contributes significantly to urban emissions and thus the impact of daily travel on emissions can be predicted. In this context, it should also be emphasized that current legislation articulates the importance of high spatial resolution at the level of a building plan. This level of resolution is also required if we move from emissions to air quality and exposure. The current models express exposure based on zonal population statistics. However, as a direct result of their daily activity-travel behaviour, the population moves across the city during the day. Therefore, exposure assessments, based on zonal population statistics are fundamentally flawed. Other examples of improved sensitivity of microscopic models to policy indicators where aggregate models fail include the amount of social exclusion, quality of life, and time pressure.

4 Ubiquitous Pervasive Information

The relationship between the urban systems and activity-travel patterns is of central importance in this context. As argued, several urban planning and design concepts saluted to this intricate connection. A better understanding of activity-travel patterns should ultimately lead to improved evidence-based planning, but due to dynamics in both the urban system and people's preferences, and the omnipresence of imperfect information, by definition urban systems will always be out of equilibrium. Wardop's user equilibrium assumes that network equilibrium occurs when no traveller can unilaterally change his route choice to reduce travel times. It may be a theoretically appealing concept, but has no behavioural foundation in the sense that the implicit notion of complete and full information does not have any credibility.

Information and communication technology can play a critical role in reducing user disutility of out-of-equilibrium artificial urban systems. First, by providing the right information at the right time, the uncertainty and possibly ineffective behavioural response and decisions that stem from incomplete and imperfect information may be reduced. In some cases, for example whether there is a direct bus connection between A and B, static information may suffice. In other cases, whether it is better right now to choose the car or the bus between A and B, real time traffic information will be more effective. Second, in addition to user benefits, public and private firms and organisations may also profit. For example, park guidance systems will allow park managers to maximize the use of their parking facilities. Users also benefit in this case assuming that indeed they prefer to find a vacant parking place as quickly as possible. Hence, the inherent disequilibrium may at least partially be addressed by providing the right information to the right people such as to optimize system level performance. Thirdly, whereas these examples involve neutral information about the (time-varying) state of the urban system, information and communication technology may also be used to try and persuade people to behaviour in a certain way. The underlying objective may be to improve personal service, but also to optimize service-level performance or some combination of these. Examples such as minimizing system-wide congestion, discouraging trucks traveling through environments with many children, and reducing emissions quickly come to mind.

This argument acknowledges the shift in policy from urban development to urban management and control. Such management and control stems from the notion that urban systems almost by definition are in a constant state of disequilibrium. Development strategies are ineffective in reducing the short-term negative effects of disequilibrium. The use of information and communication technology has become increasingly more prevalent in this context. Our contention is that ICT will be the new layer for the "smart" city of the future. Mobile technology, combined with intelligent systems, will create ubiquitous environments and make information omnipresent. Intelligence, accuracy, personalization, persuasion, real time are some of the buzzwords in this development (e.g. Lu and Liu 2012).

Mobile tools and mobile e-services will mark the next major developments in spatial decision support systems. The emergence of grid computing and service-oriented architectures, computing is becoming increasingly less confined to traditional computing platforms. Grid computing promises the accessibility of vast computing and data resources across geographically dispersed areas. Mobile wireless devices significantly enhanced this capability to deliver access to high-performance computing under demanding circumstances. Cloud computing makes storage of large amounts of data a lesser problem. E-services guarantee access to software. New dedicated languages and platforms will allow users to easily perform a set of related analyses, with dedicated support of how to conduct such analyses.

This shift to mobile platforms should not necessarily imply different content as evidenced by services and apps supplied by particular municipalities which have continued to provide access to city statistics, maps and current plans: the communication tool differs—the contents does not. However, Web2.0 technology does offer new opportunities. In particular, social media provide interesting new opportunities. Members of a community can exchange information, trace particular others, identify the most current location of particular friends, etc. These functionalities offer the co-production of maps, databases, exchange of real time information, a platform for organizing meetings and location-based services, etc. Applications rapidly emerge: updates of databases, underlying navigation systems, group-tracing systems, updates and experiences of actual, real time transport systems, community-based portals in the context of plan development, and many similar examples could be mentioned.

5 Implications for Research Agenda

To this point, we have contemplated that effective decision and planning support systems for sustainable urban development should address space–time behavior of its citizens as this constitutes the logical basis for developing an integrated model system that derives emission, exposure, noise, social exclusion and other performance indicators from the way people organize their daily lives in a particular urban setting as reflected in their daily activity-travel patterns. The main consequence for the development of geographic information systems is that areal units no longer make up the core of the system because individuals, households and activity locations should be represented at higher levels of spatial resolution. This need for higher resolution is reinforced by the requirements of especially environmental policies. In addition, with time as the linking pin, the need for a temporal organization of data emerges, creates a new challenge as most mainstream geographical information systems are not organized around temporal data.

Models themselves need major elaboration and new model types need to be developed. Whereas operational activity-based models of travel demand are not widely available, considerable progress is still required in short-term traffic forecasting, individual use of travel information, and particularly in modeling traveller response to persuasive information as a function of different underlying goals (personal preferences, system performance or some combination). Travellers will be aware of the fact that other travellers may also receive recommendations and hence have to make decisions, considering their beliefs of how other travellers will react. Such models of strategic decisions under conditions of uncertainty are still at the very early stages of development (Han and Timmermans 2006a, b). Assuming that such models will be developed with a sufficient degree of accuracy, then distributed recommendations have to be provided in case of a single control agent. What-if questions will be complemented by if-what questions! Such information provision systems are currently not available either, at least not any systems that go beyond simple practical solutions.

Models need data for estimation and validation. This new generation of models is no exception. In fact, data requirements are formidable, considering the real-time and high spatial and temporal resolution of the envisioned models. Traditionally, the data for activity-travel models stem from one-day travel surveys. It does not need many arguments to reason the pure inadequacy of such data for the next generation of models. We need "technology for technology". Fortunately, several recent technological developments may provide a solution. In recent years, transportation research has witnessed a tremendous growth of interest into the use of modern information and communication technology (ICT) for data collection. Modern mobile technology will become a superior alternative for these traditional surveys in collecting data about individual travel patterns. Mobiles devices range from laptop computers, Personal Digital Assistants (PDAs) and mobile phones to mobile game computers. In the near future, new technologies such as Augmented Reality may become widely available. Also changes in wireless networking will offer new opportunities: cellular telephony is moving from low-bandwidth to higher bandwidth Universal Mobile Telecommunications System (UMTS) to support more advanced services (e.g. graphics). Wireless networks provide a higher bandwidth but are primarily used for laptops and PDA's. Hotspots support access to the Internet. Bluetooth provides a low-bandwidth, short-range protocol for communication between devices (e.g. mobile phone and head set). An upcoming technology is Worldwide Interoperability for Microwave Access (WI-MAX) that provides a long range, fast connection and potentially competes with the UMTS standard. These developments lead to ubiquitous travel environments: information can be shared in a network environment from some geo-sensors providing users with information readily available anywhere, for any person and at any time. This information can be descriptive, but can also relate to recommendations. The same technology however can also be used to track individuals. When used in isolation, tracking technology such as GPS is insufficient as it only provides information about route choice behaviour and the current position of the person tracked. However, in principle such data can be enhanced with other spatial and non-spatial data. Moreover, GPS traces can be interpreted using particular algorithms to derive information about other facets of activity-travel patterns.

It should also be articulated that cars of the future are driving computers. Data on routes, emissions, energy consumptions, driving style, use of travel information and navigation systems, etc. can be directly extracted from the computer. Similarly, smart cards offer huge potential datasets on the use of public transportation systems. Devices recording energy consumption of home appliances should be very useful for modelling energy consumption. Admittedly, the different sources of data relate to different people. However, modern data fusion techniques can be used to create synthetic populations. These will not be perfect, but perfect for the task at hand, certainly offering much richer and larger data sets than the data that we currently are forced to use.

Indeed, these datasets will be huge, so huge and complex that it becomes difficult to process using current database management tools. A GPS device with a 1 s time interval will record 35 million data points over a 100 day time period. The Smart Card data in Seoul generates 10 million observations per day. The so-called "Big data" are difficult to handle with existing geographical information systems and associated relational and object-oriented databases, desktop statistical, estimation and mapping/visualization packages. Planning authorizes are currently exploring the opportunities of parallel and cloud computing using tens, hundreds, or even more servers. They did not touch these increased data set sizes. Hence, there seems a bright future for intelligent supervised machine learning and data mining algorithms.

The combination of these imperfect, imputed data and the anticipated use of microscopic simulation models with their inherent model uncertainty, bring about the need to systematically and more fundamentally address the issue of uncertainty in complex model systems (Rasouli and Timmermans 2012a, b). To differentiate policy impact from model uncertainty, a formal uncertainty analysis is needed. To support individuals in making decisions by suggesting certain actions, it is critical to analyze the impact of data uncertainty on the suggested actions, particularly in the parameter space where one advice shifts to another. Furthermore, the future itself is inherently uncertain. Uncertainty in scenarios should not be met with a fatalistic attitude. Rather, new concepts, tools and approaches should be developed to explicitly deal with the fundamentally probabilistic, conditional forecasts in policy assessments. Approaches should enhance our understanding of critical paths in the dynamics of spatial systems, possible bifurcations points and critical transition states? Rather than producing a single forecast for different scenarios, we should perform sensitivity analyses for critical parameter subspaces, use ensembles of models to derive probabilistic forecasts (e.g. Rasouli and Timmermans 2012c), identify trajectories that imply a resilient system, simulate internal system adjustment to external perturbations, etc. Such endeavours might help in arbitrating intelligently between different plan options.

To end this presentation, in the beginning we have argued for the need of increased disaggregation to make our models more sensitive to behavioural heterogeneity and the required sensitivity to higher spatial and temporal resolution. However, the results of the uncertainty analysis stipulated above with certainty indicate that the degree of model uncertainty in model forecasts and impact assessment will, albeit not linearly, increase with increased spatial and temporal resolution. Moreover, one would also expect input uncertainty to be higher at higher spatial and temporal resolution. In other words, the development of increasingly more disaggregated model of spatial choice behaviour should go hand in hand with a systematic comparison of model performance against simpler, more aggregate models. Keeping in mind limited resources and relevant margins in policy formulation and decisions, some optimum should be expected.

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