Proceedings of the 2015 Winter Simulation Conference
L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, eds.

A META-MODEL FOR INCLUDING SOCIAL BEHAVIOR AND DATA INTO SMART CITY MANAGEMENT SIMULATIONS

Lara-Britt Zomer
Elhabib Moustaid
Sebastiaan Meijer

KTH Royal Institute of Technology
Alfred Nobels Alle 10
Stockholm, 141 52, SWEDEN

ABSTRACT

Smart city management can be regarded to bridge different realms of thinking about cities, i.e. 1) the city as complex-adaptive system, 2) socio-technical operational control center and 3) multi-actor policy-making. Underpinned by different world views and theoretical bodies, integration of the three realms puts forward new demands on simulation approaches and challenges current knowledge and available technology regarding integration of sub-models across different systems. In order to support urban transportation management, a holistic approach is needed that semantically connects the three realms by incorporation of human behavior and knowledge. Combining research on knowledge management and computer science, this paper presents a novel meta-framework as socio-technical hybrid simulation language to generalize integration of simulations, gaming and data for modeling urban transportation.

1 INTRODUCTION

Smart city management aims to minimize problems related to urbanization – i.e. congestion, accessibility and air quality – using integrated platforms to adapt citizens' demands to the city's supply of services and vice versa. The urban transportation system (UTS) is a complex socio-technical system, where we distinguish three realms, a complex-adaptive city, a socio-technical operational control center and a social network for the policy cycle. The European PETRA project provides a technological foundation for developing a service platform to connect city users, transport controllers and planners in Rome and Venice. Both cities, amongst others, can be characterized by both large and heterogeneous numbers of transport users. PETRA aims to improve information flows, to advance sustainable urban transportation development and to increase knowledge on mobility trends.

Service platforms require tools to evaluate the consequences of decisions and actions prior to implementation. To this end, simulation and decision-support models enable stakeholders to analyze and evaluate strategies for effective management of complex systems (Zulkepli et al. 2012). Although simulations and operations research have proved very useful to identify bottlenecks, evaluate alternatives, prioritize decision making and compare performance in closed-loop technical systems, such mathematical models tend to not represent the complete range of human behavior due to simplifications and assumptions (Giannoccaro 2013). In case of socio-technical systems incorporation of ill-predictable and complex human behavior and decisions into simulations, increasingly gains importance when subsystems do not necessarily integrate into one world view of smart city management. Specifically, because of the need to use scarce resources effectively and decrease environmental impacts. Therefore, and in line with

Chahal and Eldabi (2010), we aim to incorporate to a certain extent human behavior into simulation models, that we regard as a form of hybrid simulation. The purpose is to better understand the consequences of alternative decision scenarios in smart city management and to integrate the models of subsystems within the three realms. Further, we propose a meta-model for including human behavior and data into simulations, as improving smart city management demands a holistic approach. Using case studies on Rome and Venice, this article aims to provide some insights into how such hybrid approaches are shaped and what lessons can be learned.

The remainder of this paper consists of five parts. Based on the PETRA project, the next section introduces the case studies on the cities of Rome and Venice, offering a background to the methodology and hybrid simulation approaches. The methodology section elaborates on a holistic approach to innovation for UTS and discusses the three proposed realms. The fourth section presents the proposed building blocks of potential hybrid simulation strategies. Regarding smart city management, this section elaborates on two hybrid approaches using Rome and Venice as case studies. Based on this section, next, findings on the research as well as the contribution to the body of knowledge on hybrid simulation approaches will be discussed. The paper concludes by offering reflections, both for research and for practical applications in using hybrid simulation approaches.

2 BACKGROUND, A TALE OF TWO CITIES

In order to successfully implement smart city management in UTS, Rome and Venice have been selected as two case studies for integrated platforms, aiming to first, improve strategic and operational decision-making to reduce the impacts on the build environment; second, to enhance understanding on the evolving of UTSs over time and, third, to get a grip on how to influence UTSs. The remaining part of this section describes each city, paying attention to its primary goals and available data sources to feed into an integrated platform as a tool for improving smart city management.

2.1 Rome

The municipality of Rome is one of Europe's largest municipal areas, covering an area of 1.285 km² and a registered residents population of 2.7 million. However, the estimated number of city users amounts to 4 million a day. As a result from large numbers of commuters participating in traffic, the city of Rome holds one of the highest motorization levels in Europe (85 vehicles/100 citizens). Along with over 23 million tourists per year, visiting the historic and cultural heritage, the limited capacity of narrow streets is severely challenged and special measures are required to enhance traffic safety by separating motorized traffic from pedestrian and bicycle flows.

The mobility Center may be seen as the city’s core center of mobility governance in terms of control, monitoring and info-mobility. In this center the ITS (information technology services) PETRA platform is integrated using public access. The integrated platform (dashboard) can be used to check the status of private and public transport systems, for example, the real time positioning of buses across the city’s transport network. Based on KPIs (key performance indicators), network managers and controllers can receive indications on systems states to be used to (re)define traffic rules and -restrictions within the build environment and urban infrastructure. The main goals of the integrated platform for smart city management in Rome are to: (1) Detect the type of information needed by the user, (2) present a traffic prediction model (simulation) suiting the needs of the problem at hand and (3) provide both real-time and historical reports on KPIs to policy makers and network managers.

The city of Rome offers various types and sources of data that are available at different city levels. Within the PETRA project, public transportation data, such as, GTFS (Grand Transportation Feed Specification) files and data on real-time positioning of vehicles are available, as well as information on the parking capacity within several private and public parking lots. The UTS includes electrical cars and bike sharing stations combined with data on occupancy and availability rates. Rome’s cultural heritage is spread across the city, and the positions and locations are available as RSS feed as well as event calendar.

Additionally, the PETRA App intends to collect user centric data using passive and active feedback. Overall, the city of Rome can dispose of extended data sets, consisting of diverse granularity and different frequencies over time. However, it remains important to couple data to predictive simulation models and, in cooperation with decision-makers, to develop and present these in the formats most suitable-for-use.

2.2 Venice

The Venice Region, amongst others, comprises the historical city, that on account of its cultural heritage, annually, attracts about 5 million tourists. Peak day arrivals, particularly in conjunction with special events, may exceed the number of residents in the historical center. One bridge connects the old city to the mainland at the Northwest side, and is accessible to cars, buses and trains. The other transport option is delivered by public and private shipping companies, operating as Venice's waterbus system. Next to a vast number of tourists, the historical city houses 60.000 inhabitants, daily commuting, either to Mestre – the economic center of the region – or to one of the surrounding areas.

The municipality of Venice has estimated mobility demands to increase by 150% in 2027. Hence, ACTV, the public transport company of Venice, feels urged to find innovative ways to manage this increased demand as well as to reduce the possible impact on the environment. ACTV envisage to use an integrated platform (dashboard) to detect present urban transportation scenarios and to observe variations during the course of the day. The platform eases the tasks of network managers and controllers by suggesting possible info-mobility measures and by observing changes in the traffic scenarios after implementation of any management or control action. The main goals for smart city management in Venice are to: (1) detect the transport state, specifically focusing on the historic city, (2) predict the possible trends on the short term and (3) mitigate the traffic situation by an intelligent use of transportation information, i.e. to redirect some of the traffic flows towards a more balanced and sustainable mobility.

The municipality of Venice can dispose of different alternatives and data sources. In the past, the historical city of Venice has been subjected to various studies regarding the pedestrian movements (flow) across the city's pedestrian network, such as, arrivals of people from bus terminals, train stations and airports (Mamoli et al. 2008). Within the PETRA project, public transportation data is available in GTFS format, based on daily ticket validation counts on the water buses. In future, it will be possible to measure pedestrian flows on critical points in the city using camera feeds. Unfortunately, within the historical city center, no user centric data is available, however, the PETRA app may provide some passive and active feedback from users. Summarized, there exists a limited amount of options, especially regarding real-time and user centric data. Hence, it is important to use available data and knowledge, combined with other methods to enable improved decision-making and control, for instance, during events that take place in the historical city center of Venice.

3 METHODOLOGY

In this section we aim to elaborate on a holistic approach to UTS innovation and to discuss the three proposed realms, underpinned by different worldviews and theoretical bodies, as put forward in our introduction to this paper. In order to discuss potential hybrid strategies, we first need to clarify the context. 'Worldview' refers to the view one holds on the whole system of interest, which may encompass several interconnected 'realms'. Using a similar approach as Koppenjan and Groenewegen (2005), to design complex technological systems, we can distillate the three interconnected subsystems, as shown in Figure 1. At the highest level of aggregation, smart cities would make up for the 'whole system of interest', whereas the city as, 1) complex-adaptive city, 2) socio-technical operational control center and 3) social network for multi-actor policy-making (3) can be considered three interconnected realms. Within the realms various closed and open loop 'subsystems' can be distinguished, that serve as the 'building blocks of the realm'. We suggest the main benefit of hybrid models is to combine two (or more) types of subsystems, in such a way the ensuing complementary insights within or between realms can be used to improve the understanding of the system as a whole.

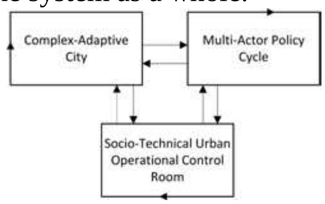

Figure 1: Conceptual framework for integrated smart city management.

To improve the management of smart cities, we propose a pluralistic approach, in which strategic planning meets operational decision-making towards more citizen-centric, demand-adaptive and sustainable urban transportation systems. This approach is necessary to enhance more robust and resilient decision-making at all levels in order to balance demand and supply, by taking into account various constraints in meeting both current and future requirements of controllers and society. The authors of this article view UTSs to be ever changing systems, consisting of (partially) connected subsystems within the three realms, in which dynamic networks of interactions and the emergent behavior of the whole may differ from individual static entities. Both individual and collective behavior can adapt over time as a result of (a combination of) changes at micro-level (Mitleton-Kelly 2003). The remaining part of this section will address each of these realms individually and their relation to the other two realms.

3.1 City as a Complex Adaptive System

Complexity science provides new theory-driven methods for studying complex, connected and constantly changing systems surrounding us. In particular, this field of research provides a new paradigm to understand complex-adaptive systems (CAS). Typically, CAS are represented by large numbers of interconnected objects following non-linear dynamics, and possess the ability to learn from past interactions. Cities are CAS, in which people are considered the main drivers reacting to evolving infrastructure, changing rules and external factors whilst, also, interacting with other people. Thus, the city is seen not as a cause-effect system but as a complex dynamic system. The ill-predictability of the human behavior of city-users is considered a side effect of CAS, which should be incorporated in the decision-making processes by policy makers and operational control managers.

Therefore, in this article, we will propose a combination of visualizations, simulations, and human-in-the-loop to serve as complementary modules to the already known closed-loop models, to overcome the deficiencies the models may hold separately. In Figure 2 the realm of the complex-adaptive city is represented as a UTS, characterized by dynamic relations between four subsystems: population, transport services, transport vehicles and constrained by the build environment and infrastructure. The components of these subsystems may be tightly and non-linearly connected. However, the city is subject to external measures, such as the control center, using information services to influence the temporal behavior of the city-users.

3.2 Urban Operational Control Center as Socio-Technical System

Urban transportation control centers (UTCC) consist of social systems (network managers) and technical systems (Supervisory and Data Acquisition (SCADA) and decision-support systems), that are mutually engaging and interacting to achieve goal-directed behavior. Originally, resulting from the disappointing increase in productivity by means of mechanization during the 1950s (Jacques 1951), socio-technical concepts have been developed and grounded in open system theory, coupling technical and social systems and postulating the relations between these as a new field of inquiry. It turned out, productivity did not improve by neither technology nor by taking a social approach, but, instead, appeared to flourish in organizations that were designed and structured as relatively autonomous groups. In such organizational structures, group cohesion increased and self-regulation by means of cooperation resulted in increased productivity (Trist 1981). We propose, today's UTCC, as a result of smart city management and advances in data collection and technology may be compared to the design and structure of autonomous groups. In contrast to regulatory systems, such as the policy making cycle, socio-technical systems are considered to be operative. These systems directly depend on material means and resources needed to deliver the expected outputs, whilst core interfaces are manifest in the relations between nonhuman and human systems (Trist 1981). Hence, effective decision-making in UTCCs will depend on both physical attributes and equipment as well as on communication, roles of technical artifacts and teamwork.

Today, examples for coordinating strategic planning and operational decision-making in transportation management remain limited. It appears that either the focus is on decision-support systems for operational traffic management, or, else, a top-down approach is used (Rijkswaterstaat 2003; Adler et al. 2005; Barthelemy et al. 2013; Xin et al. 2013). It seems, we tend to forget operations also largely determine the effectiveness of the strategic planning. To improve both aspects as well as the field of urban transportation, we suggest to analyze and optimize operations and strategic planning as a whole, instead of separately. Figure 3 is based on examples of intelligent transport systems architectures and human factors in UTCC operations. By means of DSS and SCADA the technical subsystems and the controllers' social systems are being combined through human decision-making by the controllers (Stanton et al. 2010; Engineering Policy Guide 2013). The UTCC as realm is characterized by five technical subsystems: state estimation, infrastructure management, event management, emergency management and information management. These technical subsystems may be tightly connected with the technical subsystem of DDS and SCADA. However, the UTCC is also subject to external measures, such as the weather, changing the urban state, authorities deciding which data collection equipments are available.

3.3 Policy Making Cycle as a Social Network System

Although policy making does not equal a standardized industrial process, in itself, conceptually, the process of developing policies can be viewed to be systematic. Often, policy making cycles appear to be characterized as social network-based systems. Key players in this realm are considered influential actors, either endowed with a formal status, such as politicians or appointed authorities, or else of a more informal nature, such as news agencies or advocacy groups. Analyzing an environmental debate on the ways in which various policy networks have influenced overall policy making on nitrate, both in Denmark and Sweden (Daugbjerg 1998), the dynamics of forming actual policies can be explained from the perspective of network theory (Van Bueren et al. 2003). Other empirical studies show social networks to span the policy domain, and, as compared to actual rational, technical approaches, interactions within these networks, to a far larger extent, determine the outcomes in policy making (Everett 2003). According to institutional framework theories, policy processes can be perceived as four-layered top-down model to involve strategic, long-term thinking (Williamson 1998). More recently, however, management theory acknowledges the need to come up with new concepts grounded in complexity theory. For, operations do become more strategic and strategy will increasingly be expressed in operational ways. One may argue, in a world that is considered a complex system, the top-down approach is no longer valid as operational expert knowledge is required to formulate management policies (Stacey 2007).

Hence, we argue, in UTS, the social network system that consists of policy making processes will interact with the social-technical system, and both will form interfaces with the city's complex adaptive system, as shown in Figure 4. From the case studies on Rome and Venice, it appears the list of stakeholders influencing the policy process is manifold and includes both formal and informal actors and artefacts, such as, municipality, mobility agency, transport department, public transportation providers, private transportation providers, parking services, municipal policy makers, data, marketing companies (tourists attractions), inhabitants, tourists, environmental institutions, cultural heritage institutions, water management, cultural heritage, soccer arenas, event organizers and local economic actors.

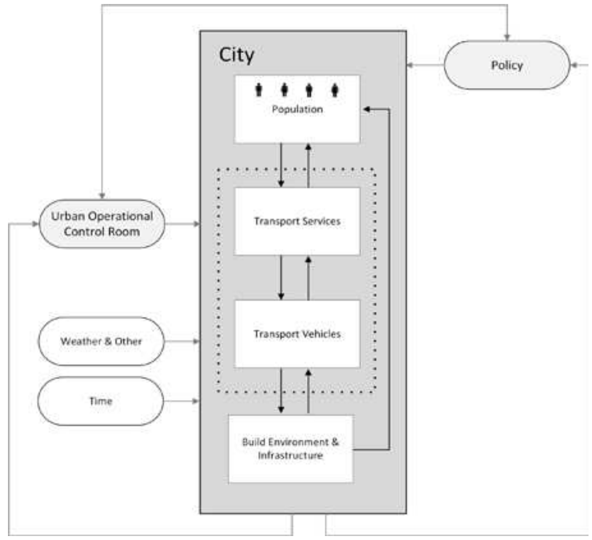

Figure 2: Conceptual framework for complex adaptive city realms.

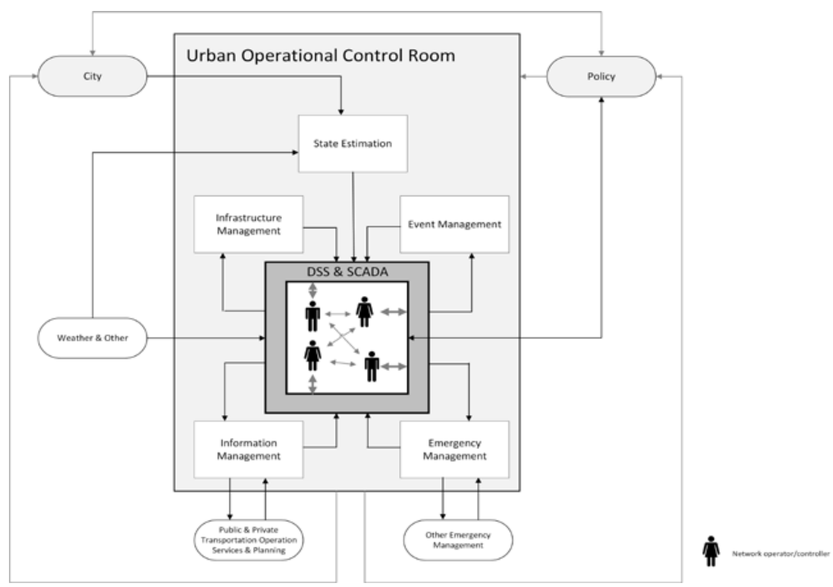

Figure 3: Conceptual framework for socio-technical operational control center realms.

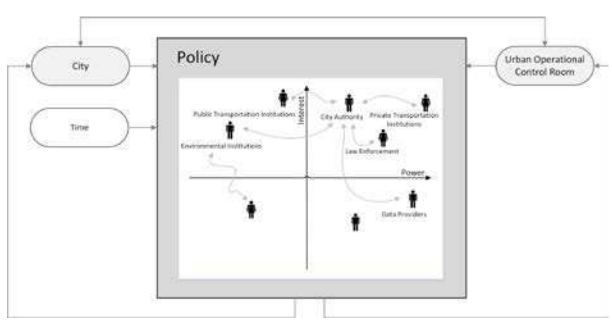

Figure 4: Conceptual framework for social network policy realms.

4 METHODOLOGY

Combining research on knowledge management and computer science, this paper aims to present a meta-framework to use a generic (social) hybrid simulation language for generalizing the integration of simulations, gaming and data. In section 4, we will discuss the conceptual building blocks of hybrid approaches to solve large-scale, multilevel problems between and within the three interconnected realms (complex-adaptive city, urban operational control center and policy).

4.1 Need for a new Meta-Model

At the moment one of the best known meta-model approaches is UML, a simple principle to describe elements, constraints and relationships of OMGs (Object Management Group). The clear methodology for software development provides a generic method, applicable to every OMG oriented approach (Greenfield 2003). In transportation science we find examples of agent-oriented meta-models, i.e. the Extended Gaia model. The Platooning Meta-Model is an extension of this approach, allowing specification and modeling of a transportation system capturing the knowledge of an organization (Garoui et al. 2014). Generally, these approaches are not designed for open systems or the inclusion of 'human sense-making', which we consider necessary in order to understand complex socio-technical systems. The complex systems of smart city management requires better synchronized and robust strategies than developing (individual) solutions purely aiming to reduce negative impacts on the build environment, whilst reducing cost and time of all city users. A holistic meta-model provides a well-defined exchange of data, simulation and social subsystems to increase the understanding of the UTS as a whole. As a result, the wisdom one holds on the system improves whenever more accurate or reliable data, simulation or social models become available. Hence, the benefit is an interoperable and robust approach that includes human interaction as non-synthetically hard coupling of elements.

4.2 Building Blocks and Connections

We regard the subsystems within the three interconnected realms to make up the “building blocks”. Building blocks can be represented in three different ways: *Data* as building block are perceived as a component for publishing, maintaining and integrating data sources, files and reports. Depending on the type of data, the interface enables different management tasks, such as publishing, indexing or storage. Examples may be an API or excel sheet as an input source for simulation models or, else, a policy report as input for social models. *Simulation models* as building block are considered the applications of scientific theory to closed loop subsystems within the theoretical realms (Winsberg 2003). Based on one’s understanding of closed loop systems, simulation models can be used for mimicking a subsystem’s behavior within a certain realm. In contrast to Winsberg, we consider simulation models to be autonomous systems with a limited degree of freedom, using the control over boundary conditions, instead of model mechanisms underlying the simulation. Hence, only by connecting simulation models to social models (i.e. social hybrid simulation model) the ensuing model would become semi-autonomous, exposing new heuristics to the simulation model. *Social models* as building block can be conceived of as human participants playing a role in an artificial setting that mimics an aspect of reality. Examples are gaming simulations, participatory simulations or experiments used as operating models of a real-life systems in which actors recreate the behavior of the system (Duke and Geurts 2004; Meijer et al 2012).

As building blocks are placed within a realm, the coupling of building blocks may connect two or more realms. Based on theory on knowledge management, communication flows between subsystems can manifest themselves as data, information and/or knowledge, ultimately striving to create wisdom about (a part of) the system to increase its effectiveness (Ackhoff 1989; Bellinger et al. 2006; Rowley 2007).

- *Data flow* can be a spreadsheet, representing properties of objects, events and their environment. It can be the product of observation, but without any relational connection it has no significance.

- *Information flow* can be a relational database. It involves understanding the relation within the generated, stored, retrieved or processed data.
- *Knowledge flow* can be seen as collection of information with a useful intent. Within simulations stored knowledge is not uncommon, for example decision-support systems which translate processed data into instructions or pattern recognition and more recently it is possible for artificial intelligence (AI) and machine-learning to synthesize new knowledge, but today only people can take useful actions based on this synthesized knowledge.
- *Wisdom* can be looked upon as the process of (human) judgment between right and wrong, good and bad. Wisdom tries to add value or, within the scope of this article, aims to increase effectiveness in improving smart city management of UTS.

In order to shape a potential hybrid simulation strategy to study large-scale, multilevel problems, one should find a well-suited combination of available building blocks and feasible connections. When two or multiple building blocks share the same worldview, they may be technically connected. This has been attempted by Viana et al., when combining a discrete-event simulation amongst outpatient clinics with an agent-based simulation representing individuals with a disease (Viana et al. 2012). However, when trying to connect different worldviews, such technical connections may not be feasible. In those situations, solutions may be found in so called 'humanaware' (Belete et al. 2014), i.e. the use of human sense-making to provide knowledge when interpreting highly partial models and simulation outcomes.

4.3 Meta-framework of model interactions

To shape and structure hybrid simulation strategies we will use a systematic approach, similar to the periodic table of elements, in which a variety of molecule structures may emerge when connecting atoms by means of covalent bonds (re. the building blocks and communication flows described in the previous section). The number of combinations is limited based on four characteristics of different combinations that are possible (see Figure 5). Output consists of data, simulation or human interference (resp. row classes yellow, purple and pink). Input relates to data, simulation and human interference (resp. row subclasses within a color 1, 2, 3). Type of combination are stand-alone, unidirectional, bidirectional, human interference, participatory experiments or simulations (resp. column classes 1, 2, 3, 4 and 5). And last, with type of communication we consider data, information and knowledge (resp. column subclasses A/dashed line, B/solid line and C/striped-dotted line).

In Figure 5 the first group consists of stand-alone approaches, as data-mining and discrete choice models on route choice behavior or processes of creation of information and knowledge by humans (columns 1A to 1C). Hybrid approaches may be derived when connecting two (or more) building blocks of the first group with each other. The traditional concept of a hybrid simulation model is the coupling of simulation model to simulation model, using a data or information flow (2Sim-1/2). A knowledge flow between two simulation models is, at the moment, not feasible, as the creation of knowledge defined in this article requires human interference. Human sense-making, as a form of non-synthetically hard coupling, can be used to bridge multiple realms, represented by class 4 and 5, using for example participatory experiments.

While the focus of this article is on the incorporation of human behavior into smart city management, some examples are given on combinations with social models and their place in the meta-framework. A potential example of a unidirectional combination of a social and simulation model could be a land-use model based on data of decisions made during the Portuguese game (3Sim-2A). Bidirectional combinations could be game simulation models used as training (3Sim-3A), both the simulation and social model process in the incoming data into useful information. Within the domain of gaming simulation it is important to distinguish games using results from a previous game round as initial condition (Soc-2), from social model using results from another social model (3Soc-2 or 3Soc-4, in case the connection is not synthetically hard).

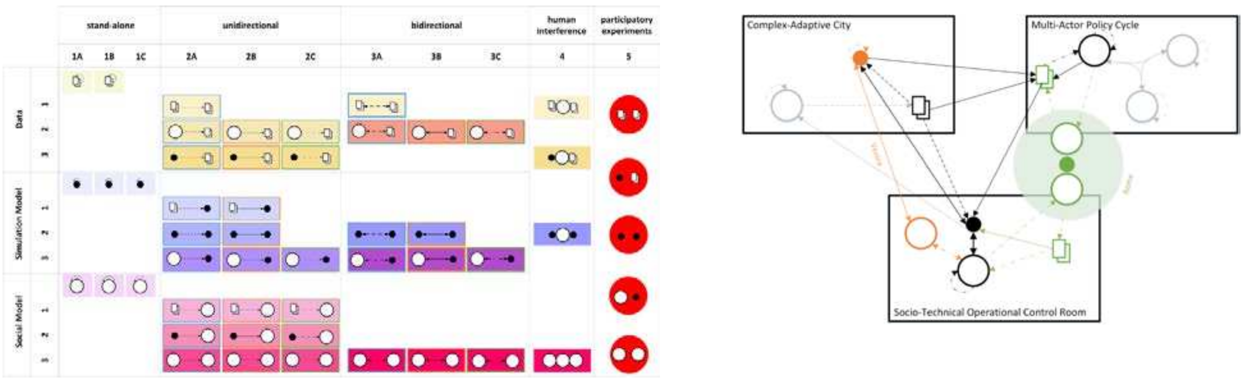

Figure 5: Proposed meta-framework of model interactions and social hybrid participatory simulation approach for smart city management.

4.4 Hybrid Simulations Approach for Smart City Management

To clarify our holistic approach on social hybrid models and the three realms of smart city management, we will apply the meta-framework to the case studies of Rome and Venice. In order to align strategic policies and operational decision-making in control centers, Rome uses a participatory experiment to derive more resilient and robust management plans. The goal is to construct an objective function that reduces the impacts of urban mass events on the build environment against an uncertain future. Venice focuses more on the understanding on how UTSs evolve over time and how they are influenced by network managers. The strategy is to improve existing models by connecting simulation models of the complex-adaptive city with human behavior in the operational control center.

4.4.1 Social Hybrid Simulation Approach for Rome

Important to smart city management in the field of urban transportation are the decisions affecting possibilities to measure (observe) and influence (control) movements of people and vehicles. Implementation of new information technology services (ITS) support tools, as integrated platforms, usually takes time before they become fully operational. Since UTSs are complex-adaptive systems, such a platform should be resilient and robust against an uncertain future. Strategic decisions made by formal authorities, such as policy makers, may cause limitations for network managers to correctly asses and react to information shown on DSS and SCADA systems in the UTCC. For example, inadequate(-ly located) measuring instruments may not be suitable for state estimation and an overload of restrictions on management- and control options for influencing movements may lead to an uncontrollable situation. The participatory experiment (represented by the building blocks in the multi-actor policy cycle and socio-technical operational control room in Figure 5b) investigates how the minimum number of management and control systems and their corresponding locations can be determined, while ensuring an observable and controllable urban environment. The experiment requires participation of both network managers and policy makers and authorities, in order to extract valuable knowledge. Based on predefined scenarios regarding the Vatican City, a dynamic allocation simulation can be developed to manage the flows of visitors and commuters to and from the Vatican City. The outcomes of the experiment aim to improve strategic operational management plans and decision-support systems in the operational control center.

4.4.2 Social Hybrid Simulation Approach for Venice

The assumption that people, such as network managers, would never make mistakes appears flawed. Therefore, we need to integrate the controllers' human behavior into mathematical simulations (represented by the colored building blocks in the complex adaptive-city in Figure 5b). Instead of using heuristics only, integration of actual human behavior is expected to improve the simulation's quality and validity. In other words, by using a social hybrid approach, we propose to bridge and connect the realm of the social-technical system in the control center to the realm of the city's complex adaptive system. Moreover, in using this approach, network managers may both increase their knowledge on UTSs as well as improve their coping skills in dealing with stressful situations, as the simulation may also be put to practice as a training tool.

4.5 Hybrid Simulation Approach to Smart City Management

Although both cases presented in this paper serve different purposes, we have attempted to clarify how our proposed meta-model framework differs from original, tightly coupled multi-scale approaches. We consider the main contribution of this meta-framework to provide possibilities for structuring and incorporating human behavior into a hybrid simulation approach in order to semantically connect domain specific knowledge and models. This application is most useful when world- and/or realm views do not enable easy technical connections. Secondly, applying the framework to case studies allows a comparison of different research approaches, since it provides a generalized and holistic approach towards the building blocks.

5 CONCLUSIONS AND DISCUSSION

This article proposes a meta-model for including social behavior and data into simulations conducted in the smart city context. Combining insights from different domains, a framework is proposed to help determine appropriate combinations of building blocks and to coherently design integral model approaches. We have put forward the necessity for smart city management regarding today's and future urban transport systems (UTSs) and, in doing so, we have attempted to clarify the need for holistic approaches to overcome integration issues when connecting different realms, relevant to smart city management, namely the city as a complex-adaptive system; the socio-technical operational control center and the multi-actor policy making cycle. As these three identified realms are grounded in differing bodies of knowledge, available models cannot always be integrated into one world- or realm view. Therefore, according to us, a different approach to simulation methods is required. To this effect, we have adopted participatory simulations or experiments as a concrete method for hybridization of simulation models. Also, to connect data, social and simulation models without technically coupling them we have included higher order human knowledge. Hence, we have extended the meta-models of tightly coupled, often technically integrated, hybrid simulation approaches to a more semantic discussion. We expect the proposed approach to evolve in time, when new technologies enable more connections and/or the problems at hand will demand attention to novel building blocks or even realms for beneficial solutions. Elaboration on the case studies in Rome and Venice covered the use of smart city management and integrated platforms to reduce the impact of increased transportation needs on build environments both at the systems- and at the individual travelers level. Although large numbers of data is available, it becomes apparent that the levels of detail turn out insufficient for use in the most precise simulation methods. Additionally, the case studies have made clear that application of the framework is advantageous for comparing studies, considered a prerequisite for validation and closure with empirical data. Future research, for example hypothesis testing on models and using expert knowledge, will include verification and validation of social hybrid approaches, especially when the interfaces are made up of human-ware. Hence, we will aim to allow models to be evaluated for syntactic correctness using automated algorithms that implement the rules and constraints defined by the meta-model (Greenfield 2013).

ACKNOWLEDGMENTS

The authors wish to thank all participants in the PETRA project, funded by the European Commission 7th Framework Program (FP7-SMARTCITIES-2013) under project number 609042 for support to this work.

REFERENCES

Ackoff, R.L. 1989. "From Data to Wisdom." *Journal of Applied Systems Analysis* 16:3-9.

Adler, J. L., G. Satapathy, V. Manikonda, B. Bowles, and V. J. Blue. 2005. "A Multi-Agent Approach to Cooperative Traffic Management and Route Guidance." *Transportation Research Part B* 39(4):297-318.

Barthelemy, M., P. Bordin, H. Berestycki, and M. Gribaudi. 2013. "Self-Organization Versus Top-Down Planning in the Evolution of a City." *Nature Scientific Reports*, 3.

Belete, G. F., A. Voinov, and N. Holst. 2014. "An Architecture for Integration of Multidisciplinary Models." In *7th International Congress on Environmental Modelling and Software*, San Diego, California, USA.

Bellinger, G., D. Castro, and A. Mills. 2004. "Data, Information, Knowledge, and Wisdom." (accessed March 8th, 2015) http://www.systems-thinking.org/dikw/dikw.htm.

Chahal, K., and T. Eldabi. 2008. "Applicability of Hybrid Simulation to Different Modes of Governance in UK Healthcare." In *Proceedings of the 2008 Winter Simulation Conference*, edited by S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, and J. W. Fowler, 1469-1477. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Daugbjerg, C. 1998. "Linking Policy Networks and Environmental Policies: Nitrate Policy Making in Denmark and Sweden 1970-1995." *Public Administration* 76(2).

Duke, R. D., and J. L. A. Geurts. 2004. *Policy Games for Strategic Management*. Dutch University Press, Amsterdam, The Netherlands.

Engineering Policy Guide. 2013. "910.4 ITS Architecture." (accessed March 8th, 2015) http://epg.modot.gov/index.php?title=910.4_ITS_Achitecture.

Everett, E. 2003. "The Policy Cycle: Democratic Process or Rational Paradigm Revisited?" *Australian Journal of Public Administration* 62(2):65-70.

Garoui, M., B. Mazigh, B. El Ayeb, and A. Koukam. 2014. "Agent-Oriented Meta-model for Modeling and Specifying Transportation Systems: Platoon of Vehicles." In *Proceedings of* the *6th Intelligent Information and Database Systems; Advanced Approaches to Intelligent Information and Database Systems Studies*, edited by J. Sobecki, V. Boonjing, and S. Chittayasothorn, 551:305-314. Springer International Publishing.

Giannoccaro, I. 2013. "Complex Systems Methodologies for Behavioural Research in Operations Management: NK Fitness Landscape." *Behavioral Issues in Operations Management*, 23-47.

Greenfield J., and K. Short. 2003. "Software Factories Assembling Applications with Patterns, Models, Frameworks and Tools." In *OOPSLA'03, Anaheim, CA, Companion Volume*, 16–27.

Jaques, E. (Ed.). 2013. "The Changing Culture of a Factory." (Vol. 7). Routledge.

Koppenjan, J., and J. Groenewegen. 2005. "Institutional Design for Complex Technological Systems." *International Journal of Technology, Policy and Management* 5(3):240-257.

Mamoli, M., P. Michieletto, A. Bazzani, and B. Giorgini. 2012. "Venice as Pedestrian City and Tourist Magnet Mass Events and Ordinary Life." (accessed March 8th, 2015) https://upcommons.upc.edu/bitstream/handle/2099/12359/C_91_3.pdf?sequence=1.

Meijer, S. A., I. S. Mayer, J. van Luipen, and N. Weitenberg. 2012 "Gaming Rail Cargo Management Exploring and Validating Alternative Modes of Organization." *Simulation and Gaming* 43(1):85-101.

Mitleton-Kelly, E. 2003. "Ten Principles of Complexity and Enabling Infrastructures." In: E. Mitleton-Kelly (ed.) *Complex Systems and Evolutionary Perspectives on Organisations: the Application of Complexity Theory to Organisations. Advanced Series in Management*, Elsevier Science Ltd, Oxford, UK, 3-20.

Rijkswaterstaat 2003. *Handbook Sustainable Traffic Management*. Rotterdam.

Rowley, J. 2007. "The Wisdom Hierarchy: Representations of the DIKW Hierarchy." *Journal of Information Science* 33(2):163-80.

Stacey, R. D. 2007. *Strategic Management and Organisational Dynamics: the Challenge of Complexity to Ways of Thinking About Organisations*. 6th ed, Harlow, England: Financial Times/Prentice Hall.

Stanton, N., P. Salmon, D. Jenkins, and G. Walker, Eds. 2010. *Human Factors in the Design and Evaluation of Central Control Room Operations*. CRC Press.

Trist, E. 1981. “The Evolution of Socio-Technical Systems.” *Conference on Organizational Design and Performance*.

Van Bueren E., E. Klijn, and J. Koppenjan. 2003. “Dealing with Wicked Problems in Networks: Analyzing as Environmental Debate from a Network Perspective.” *Journal of Public Administration Research and Theory* 13(2):193-212.

Viana, J., S. Rossiter, A. R. Channon, S. C. Brailsford, and A. J. Lotery. 2012. “A Multi-Paradigm, Whole System View of Health and Social Care for Age-Related Macular Degeneration.” In *Proceedings of the 2012 Winter Simulation Conference,* edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose and A.M. Uhrmacher, 1070-1081. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Williamson, O. E. 1998. “Transaction Cost Economics: How it Works; Where it is Headed.” *The Economist* 146(1):23-58.

Winsberg, E. 2003. “Simulated Experiments: Methodology for a Virtual World.” *Philosophy of Science* 70(1):105-125.

Xin, W., J. Chang, S. Muthuswamy, and M. Talas. 2013. "Midtown in Motion: A New Active Traffic Management Methodology and Its Implementation in New York City.” In *Transportation Research Board 92nd Annual Meeting*.

Zulkepli, J., T. Eldabi, and N. Mustafee. "Hybrid Simulation for Modelling Large Systems: an Example of Integrated Care Model." In *Proceedings of the 2012 Winter Simulation Conference,* edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose and A.M. Uhrmacher, 1070-1081. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

AUTHOR BIOGRAPHIES

LARA-BRITT ZOMER is a PhD student in Transport Science at KTH Royal Institute of Technology, Sweden. She holds a B.Sc. in architecture and a M.Sc. in Transportation, Infrastructure and Logistics from Delft University of Technology. Her research interests include data analysis, theory and model development, crowd and transportation management, graph theory, system dynamics and the use participatory experiments as methodology to model human behavior within complex socio-technical systems of cities. Her e-mail address is lara-britt.zomer@sth.kth.se.

ELHABIB MOUSTAID is a PhD student in Transport Science at KTH Royal Institute of Technology. He holds a B.Sc. in Computer Science from Grenoble Institute of Technology and a double M.Sc. in Engineering degree in Applied Mathematics, Computer Science and Communication from KTH and Grenoble Institute of Technology. His research interests are operational research, statistics and the combination of mathematical models and the social models in complex adaptive systems via participatory methods. His e-mail address is elhabib.moustaid@sth.kth.se.

SEBASTIAAN MEIJER is a full professor in Health Care Logistics at KTH Royal Institute of Technology and part-time associated with TU Delft. He leads the gaming and participatory simulation lab (GaPSlabs), focusing on games, simulations and visualizations for design of complex systems in society. Meijer is currently coordinator for several EU projects, chairman of ISAGA, and frequent reviewer for a series of journals and conferences, especially when gaming and simulation methods are involved. His email address is sebastiaan.meijer@sth.kth.se.