Enabling Smart Objects in Cities Towards Urban Sustainable Mobility-as-a-Service: A Capability – Driven Modeling Approach

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Abstract. Economic growth in Europe has been, strongly associated with urbanization, overwhelming cities with vehicles. This renders mobility inside cities problematic, since it is often associated with large waste of time in traffic congestions, environmental pollution and accidents. Cities struggle to invent and deploy "smart" solutions in the domain of urban mobility, so as to offer innovative services to citizens and visitors and improve the overall quality of life. In this context, the paper discusses on the basic challenges that cities face when trying to enable smart objects, focusing on the particular area of mobility and presenting a capability – driven enterprise modeling approach towards enabling Smart Objects for Smart City Operations (SCO). Moreover, a process towards linking capability models to simulation ones is presented, trying to set the basis for effective SCO based on Smart Objects deployment.

Keywords: Smart cities · Smart City Operations · Mobility · Enterprise modeling

1 Introduction

It is widely accepted that citizens inside large cities at a worldwide level are "bombed" by large amounts of uncorrelated and non-synchronized data, from innumerable sources and through various devices in a complex manner. Citizens are thus not in position to efficiently handle them, this resulting in severe inefficiencies associated with their mobility, such as (i) fragmented travel solutions/lack of door-to-door solutions, especially when dealing with multimodal transportation, as well as (ii) inadequateness in providing real-time, whilst individualized services. Those drawbacks often result in losses of time, decrease in the level of safety in mobility, pollution, degradation of life quality, and huge waste of nonrenewable fossil energy. Moreover, they affect not only citizens, but all relevant stakeholders, such as also public authorities and businesses.

At the same time, cities keep on becoming smarter and smarter, trying to offer traditional services with unconventional methods (e.g. via Information and

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Communication Technologies – ICT), as well as completely novel services, often enabled again by ICT. This trend is reflected on a concept coined by IBM, namely the "smart cities" concept [1, 2].

Considering that transportation inside large cities is rapidly increasing, alongside with the addition of new transport media (carpooling, car sharing, etc.), it is among a city's priorities to improve the quality of living inside them, providing smart services to their citizens and visitors. As such, it would be of great interest to place a special focus on a "smart" city and try to revolutionarize mobility in the aforementioned context. Further, the above necessitate research towards improving novel mobility practices for citizens/policymakers/businesses. This can be done only by engineering innovative strategies for aggregating large amounts of data from versatile sources (conventional and new ones), intelligently processing it and providing accurate directives associated with actual mobility status and potentials, in a multimodal and concurrently individualized fashion [3].

This data aggregation can only be carried out effectively through Smart Objects and IoT (Internet of Things). The application of the IoT paradigm to an urban context is of particular interest, as it responds to the strong push of many national governments to adopt ICT solutions in the management of public affairs, thus realizing the so-called Smart City concept [13]. Although there is not yet a formal and widely accepted definition of "Smart City," the final aim is to make a better use of the public resources, increasing the quality of the services offered to the citizens, while reducing the operational costs of the public administrations. This objective can be pursued by the deployment of an urban IoT, i.e., a communication infrastructure that provides unified, simple, and economical access to a plethora of public services, thus unleashing potential synergies and increasing transparency to the citizens. An urban IoT, indeed, may bring a number of benefits in the management and optimization of traditional public services, such as transport and parking, lighting, surveillance and maintenance of public areas, preservation of cultural heritage, garbage collection, salubrity of hospitals, and school. Furthermore, the availability of different types of data, collected by a pervasive urban IoT, may also be exploited to increase the transparency and promote the actions of the local government toward the citizens, enhance the awareness of people about the status of their city, stimulate the active participation of the citizens in the management of public administration, and also stimulate the creation of new services upon those provided by the IoT [14]. Therefore, the application of IoT technologies and Smart Objects to a Smart City is particularly attractive to local and regional administrations that may become the early adopters of such technologies, thus acting as catalyzers for the adoption of the IoT paradigm on a wider scale.

Based on all the above, the contribution of this paper is manifold, as it (a) gathers and summarizes all fundamental challenges that arise towards enabling Smart Objects for the implementation of Smart City Operations (SCOs); (b) describes a capability – driven enterprise modeling approach to deal with the aforementioned challenges and (c) creates the basis for the simulation, design and implementation of such models.

The rest of this paper is organized as follows. Section 2 provides an overview on the relevant research challenges that arise in SCOs. Section 3 briefly discusses the role of Smart Objects for the implementation of such operations, and Sect. 4 presents a detailed analysis of the capability – driven enterprise modeling approach, followed by a method to link capability models to simulation models in Sect. 5. Concluding remarks are drawn in Sect. 6, along with an outlook on future research activities.

2 Smart Cities and Smart City Operations Challenges

Cities tend to become increasingly smarter through leveraging on (often ICT-enabled) insights to transform their systems and operations delivery to citizen-centered service delivery [1]. To be able to continue advancing in this area and consolidate a solid "smart" background", several fundamental requirements need to be addressed from an operational point of view [4]. A set of requirements/challenges that affect the design of Smart City Operations, is described below.

(1) Social Considerations

Intelligence ("smartness") might be a difficult concept to sketch from various viewpoints. As such, a city should appropriately consider a priori the desired levels of smartness to be achieved at short, medium and long time scale. This depends of course to a number of services that a city wants to provide to its citizens and visitors, especially during large scale events. In such cases, a city should consider the needs, plans and opinions of all stakeholders involved in its operations, such as (i) citizens, (ii) service providers, (iii) businesses, (iv) municipal authorities and (v) national standards. At the same time, all economic, environmental and people oriented viewpoints should be considered. This means achieving a balance not just between the interests of the particular city's stakeholders, but also taking into account relationships with neighboring cities affected by the events. The above seem as a complex algorithmic process with multiple variables ([7]).

(2) Technological Considerations

As technology constitutes the primary driver towards the provision of Smart City Operations during large scale events, technological requirements should be treated as having high significance. This implies the deployment of solutions of a new generation of integrated hardware, software, and network technologies that provide IT systems with real-time awareness of the real world and advanced analytics to help visitors and citizens (during the events) make more intelligent decisions about alternatives and actions that will optimize business processes and business balance sheet results [8].

In more detail, certain factors when implementing ICT with regard to resource availability, capacity, and institutional willingness should be considered [9]. Ebrahim and Irani [10] have outlined some of the challenges of using technologies in smart cities, including lack of employees with integration skills and culture, lack of cross-sectoral cooperation and inter-departmental coordination, politics and others.

More detailed technical challenges are related to specific technologies required for smart city operations. For instance, UAVs are key technology aspects for smart transportation systems. Technical considerations in that field include (i) adaptable middleware to ensure smooth operation, (ii) development of fail-safe systems, to guarantee high safety confidence levels in the event of aircraft failure, (iii) development of very efficient, low vibration, engines and a gyro-stabilized platform technology, for high resolution imaging and accurate measurements of gravitational field strength, (iv) development of automated image data compression algorithms, stitching of aerial imagery and others [11]. Similarly, a number of technology considerations is related with privacy and data protections issues. Data collection, information sharing, security risk management, malicious attacks and human errors are only some of the security aspects to be considered within the framework of a Smart City [12].

(3) Economic Considerations

The contribution of large scale events to the economic growth of a city seem as a fundamental prerequisite for any kind of smart city operation to be provided. From a high level, economics viewpoint, a city can be thought of as an entity that enables internally operating business groups to obtain income from outside its geographical region, and then enables the obtained revenues to circulate within its region. This of course can function the other way round (extroversion).

Accordingly, the economic performance of a city during and after the events can be viewed from two viewpoints: its industrial competitiveness relative to other regions, and the soundness of the finances within its region.

In this respect, it is essential that when planning and designing the provision of smart city operations, one must take a holistic, long term approach (i.e. way after the events). In particular, the assessment of strengths, weaknesses, opportunities and threats needs to look 10 or even 20 years ahead. Such a process will allow a city to continue attracting immense attention for businesses, whilst being comfortable and secure for its citizens [7].

3 Smart Objects in Smart City Operations

A key role in IoT, as well as in smart city scenarios and services, is played by the concept of smart object, first introduced in [15], which is a physical/digital object having a unique identifier that is used to digitally manage physical things (e.g., sensors), to track them throughout their lifespan and to annotate them (e.g., with descriptions, opinions, instructions, warranties, tutorials, photographs, connections to other objects, and any other kind of contextual information imaginable), and to consciously handle its relationships with other smart objects and with remote systems. In sum, a smart object is a physical/digital object augmented with sensing/actuating, processing, and networking capabilities that may embed human behavioral logic [16].

Smart objects are typically part of a Smart Environment, which is “a physical world that is richly and invisibly interwoven with sensors, actuators, displays, and computational elements, embedded seamlessly in the everyday objects of our lives, and connected through a continuous network” [18]. Smart Environments are often based on a suitable middleware that enables communication and management of smart objects in distributed applications ([17, 19, 20]). Enabling Smart Objects and realizing Smart Environments is critical in order to provide efficient SCO. It is important to define accurate and effective modeling approaches towards enabling Smart Objects – in the following section, we describe in detail such a capability – driven approach.

4 A Capability Driven Approach

The notion of ‘capability’ can be found in *strategic management* where one can distinguish between two prevailing views namely those of the Resource Based View (RBV) [21, 22] and the Dynamic Capability View (DCV) [21]. In the field of *Information Systems* modeling enterprise capabilities has been proposed by both academia [23, 24] and practice [25] as the lynchpin to connecting strategic objectives and high level organizational requirements to technological artifacts. From a service orientation perspective a business capability is defined in [26] as: “A particular ability or capacity that a business may possess or exchange to achieve a specific purpose or outcome. A capability describes what the business does (outcomes and service levels) that creates value for customers; for example, pay employee or ship product. A business capability abstracts and encapsulates the people, process/procedures, technology, and information into the essential building blocks needed to facilitate performance improvement and redesign analysis”.

The Framework

We propose the adoption of an Enterprise Modeling approach in order to enable smart objects in SCO, based on the notion of ‘capability’ within a framework that considers 5 interrelated viewpoints as shown in Fig. 1. This is based on a paradigm [27], which is partly influenced by previously developed schemes in Enterprise Modeling e.g. [28], and extended with new features that offers opportunities for a greater level of analysis [27]. Within this modeling framework, developers can follow a process that is depicted graphically in Fig. 2.

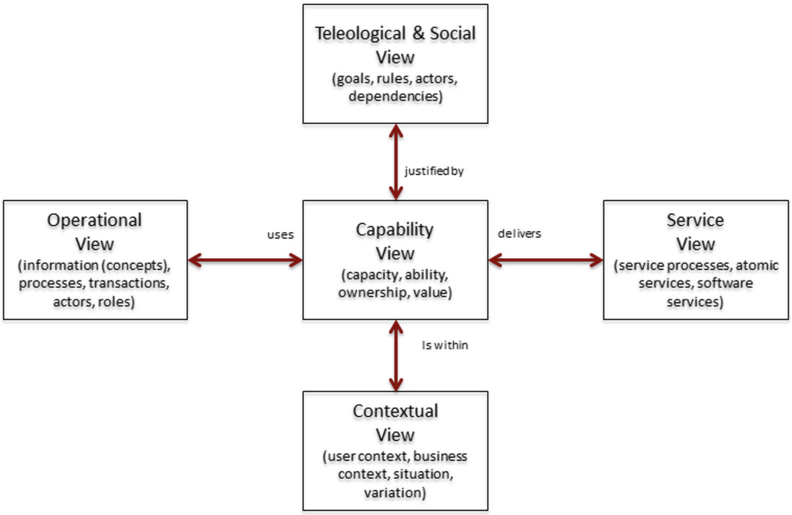

Fig. 1. The capability-driven framework

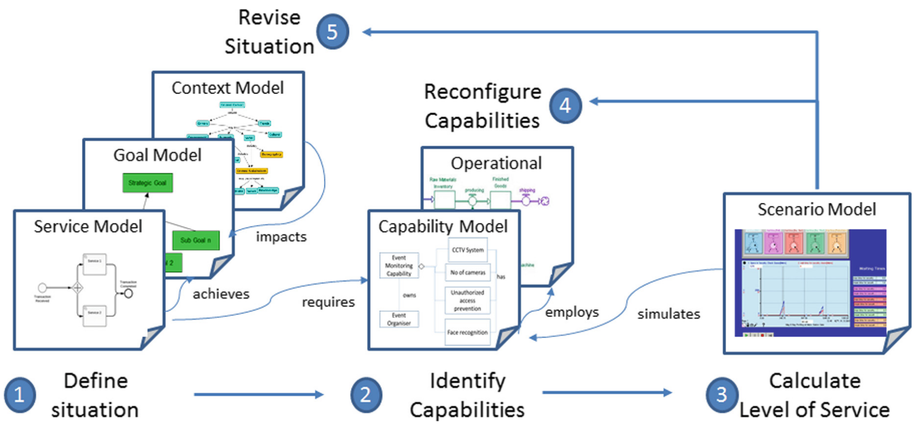

Fig. 2. The process of enterprise modeling

(Step 1) define the enterprise situation in terms of the enterprise goals and the services that achieve these goals in a specific context; (step 2) identify required capabilities as a configuration of resources; (step 3) calculate the level of service based on capabilities; (step 4) reconfigure capabilities and (step 5) revise situation, if necessary.

For example, a strategic goal is to ‘Smooth traffic in rush hours’, which is achieved by the ‘Traffic control service’ provided by the ‘Traffic control Smart objects Division’. The contextual parameters affecting the delivery of this service include the particular traffic/geographical characteristics, the type and number of expected cars in specific locations and the expected routes, etc. (Step 1). Provision of the ‘Traffic control service’ requires ‘Route screening capability’ which is based in smart objects around the city and in turn employs a number of screening stations, having certain throughput, i.e., number of cars crossing a specific point per time unit (Step 2). Analyzing the ‘Route screening capability’ in the current context (referred to as scenario modeling) signifies the level of service that is achieved in terms of delay time per car (Step 3). Depending on the estimated level of service it might become necessary to reconfigure the ‘Route screening capability’ (e.g., increase number of screening stations and/or add ‘route management capability’) (Step 4) or even revise the situation (e.g., allocate/propose additional routes) (Step 5).

The Ontology

The key concepts that need to be considered in a capability-oriented approach have been defined in [29] and are summarized in the meta-model of Fig. 3.

A capability enables an enterprise to provide a *service* in order to achieve a *goal* in a specific *context*. We refer to this triplet (goal, context, service) as *situation*. In the traffic management example mentioned above, the ‘Route screening capability’ enables the provision of the ‘Traffic control service’ in order achieve the goal ‘Smooth traffic in rush hours in the context of specific traffic/geographical characteristics with 5 screening points per Km, with specific expected car entrance rate in the monitored area.

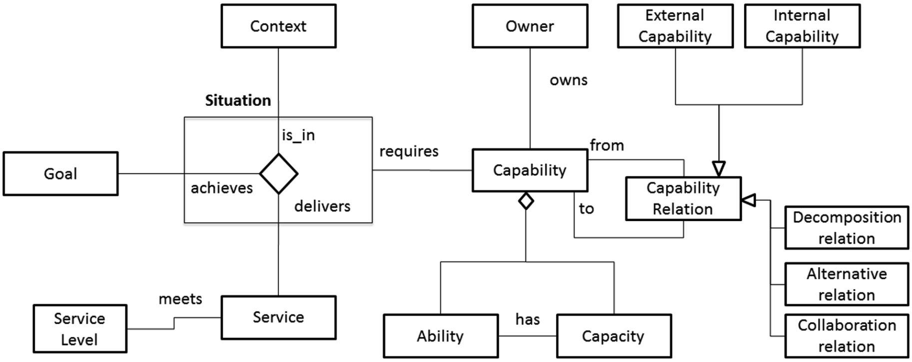

Fig. 3. A meta-model focusing on capability

A capability is associated to a certain *owner* (an entity such as a department, an organisation division, a person, a system). In the traffic control example, the 'Traffic control Smart objects Division' owns the 'Route screening' capability.

A capability denotes the *capacity* and *ability* of its owner for realising certain *level of service* targeted in a given situation. The level of service targeted in our example might refer to the average delay time per car with respect to no-traffic route time.

Capacity encapsulates the resources (processes, people, technology, information) employed by the capability owner for the purpose of possessing this capability, while ability is a measure of this capacity in terms of quantity or level of quality. For example, the 'Route screening capability' encapsulates the capacity of a number of screening stations, whose ability can be measured in terms of the number of cars screened per unit of time (throughput).

Capabilities may be *owned* by different actors (e.g. the Traffic control Smart objects Division and the Route Management Division, respectively). A capability owner may be external to the enterprise (e.g., the Traffic control authority might decide to use the Route Management Capability of an external company). Thus, there is a need to distinguish between capabilities owned by the enterprise (*internal capability*) and capabilities where the owner is external to the enterprise (*external capability*).

Capabilities may be related, making a distinction between *collaboration*, *decomposition* and *alternative* capability relations. The collaboration relation denotes inter or intra organization integration of capabilities towards the realization of a common end result. Decomposition expresses the fact that in order to own a composite capability one needs to acquire all its component capabilities. Finally, the alternative relation is used to represent the diverse capabilities that can be used to bring about the same end result.

5 Linking Capability Models to Simulation Models

The simulation results comprise quantitative, time-based and cost-related information about process execution and resource usage, e.g. waiting times, throughput times, resource utilization. In output analysis, it can be interesting to evaluate the data at a certain point in time, e.g. the number of completed process instances at the end of the simulation time, or over time, e.g. the development of waiting times after a peak in demand. The specific type of data to be generated by simulation and how it is analyzed depends on the analysis goal.

In the capability-driven approach, capabilities need to be expressed in terms of output analysis goals. As a capability enables an enterprise to provide a service in order to achieve a goal in a specific context, we need to investigate whether the triplet (goal, context, service) may be fulfilled. This means that all three attributes need to be expressed in simulation terms. To ensure validity, the description of both the level or service and the context needs to be very specific.

For this purpose, the following steps are proposed to ensure mapping of the (goal, context, service) triplet to the simulation environment.

1. Express context in terms of simulation parameters, decisions variables or other model aspects, e.g. in a specific Avenue there are 5 smart objects for car screening, mean car velocity is 15 km/h, distribution is exponential
2. Express level of service requirements in terms of specific simulation output parameters, e.g. level of service is the percentage of cars finding a route faster than the average
3. Express goals in terms of output analysis goals, e.g. percentage of cars finding a route faster than the average = 100%
4. Perform experimentation to determine if output analysis goals may be satisfied at the required level of service

To provide extensive design support through simulation, we also consider employing goal driven simulation. In goal driven simulation (GDS), we may automate many of the output analysis and experimental design tasks of a simulation study. This may include determining parameters to change, suggesting a rate of change, and testing these changes against a pre-established set of goals. To accomplish goal driven simulation, we need to integrate techniques such as object-oriented design, knowledge based systems and neural nets. In this case, there are still several issues to resolve including the type of interaction between these techniques and output analysis.

Goal driven simulation may be employed when goals are not met at the required level of service for a specific context, to indicate alternative contexts where goals may be met. In this case, we may then examine whether this context may be realistic in terms of design, cost etc. constraints.

To provide this capability, we add an extra step:

5. Experiment with different model parameters (decision variables) or the model itself to test various process and environment scenarios, to determine alternative contexts where goals may be met.

Our overall proposed approach for linking capability models with simulation modeling and experimentation is presented in Fig. 4.

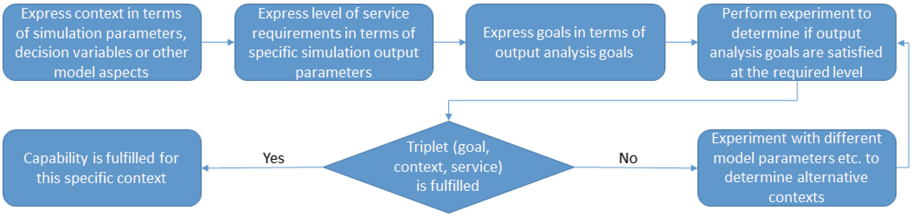

Fig. 4. Steps towards capability fulfillment

6 Conclusions and Future Directions

This paper discussed on a capability – driven modeling approach, towards enabling Smart Objects and providing SCO, focusing on smart mobility services. As such, it first provided some basic challenges that cities face when designing SCOs. Then it focused on the role of Smart Objects for the implementation of such operations, and presented a detailed analysis of the capability – driven enterprise modeling approach, followed by a method to link capability models to simulation models.

Overall, smart cities are continuously getting smarter. This naturally requires capital expenditure and calls for novel solutions in various areas, especially regarding Smart Objects and similar infrastructure. Transportation is an area where SCO find prosperous ground since it can increase the quality of living in large cities.

Several exciting areas are yet to be explored in the area of mobility offered in the context of SCOs. In particular, the further exploitation of intelligent transport systems principles in SCOs can lead to a 100% real-time assessment of traffic congestions, a priori identification of forthcoming dangers, as well as to the provision of open APIs and interfaces for intermodal MaaS inside cities/regions. Moreover, city-wide services can inform drivers on city-specific events (cultural, etc.), as well as on city-specific incidents (e.g. protests, works, etc.) and offer also targeted/focused ads and infotainment. Last, the exploitation of modern mobile communication infrastructures (e.g. 5G D2D) with which cities are more or less equipped, can naturally reduce deployment costs and provide low-latency emergency management services.

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