Mobility as a Service in the Context of Smart City Operations

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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 fundamental challenges that cities face when trying to become smarter, focusing on the particular area of mobility and presenting some sets of mobility-as-a-service ideas, as well as 3 indicative case studies that showcase the effectiveness of the quest for sustainable mobility in smart cities.**

***Keywords*—smart cities, smart city operations, mobility, car pooling, parking management, emergency management**

I. 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 non renewable 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 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 [2][3].

Considering that transportation inside large cities is rapidly increasing, alongside with the addition of new transport media (car pooling, 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 [1].

The contribution of this paper is manifold:

a) It gathers and summarizes all fundamental challenges that arise towards the implementation of Smart City Operations (SCOs);

b) It provides an insight specifically for SCOs focusing on mobility-as-a-service;

c) It defines three representative use cases in order to demonstrate the importance of sustainable mobility services in smart cities and

d) It creates the basis for the design and implementation of such services.

The rest of this paper is organized as follows. Section II provides some fundamental definitions in the smart cities domain, namely Smart City Operations (SCOs), as well as an overview on the relevant research challenges that arise. Section III discusses on sustainable (smart) mobility in smart cities, focusing on the main research achievements and challenges. Then, section IV presents some indicate case studies, used for exemplifying the provision of smart mobility services in urban environments. Concluding remarks are drawn in section V, along with an outlook on future research activities.

II. SMART CITIES AND SMART CITY OPERATIONS (SCOs)

A. *Basic definitions*

There is no unique definition of the term “smart city”. Instead, there have been several attempts to provide descriptive definitions of the term. As such, according to [11], smart city is a city well performing in a forward-looking way in economy, people, governance, mobility, environment, and living, built on the smart combination of endowments and activities of self-decisive, independent and aware citizens. Likewise, the authors of [12] define as smart a city connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city.

In this respect, SCOs constitute an important development that is expected to have a profound impact on the socioeconomic future of Europe. ICT is a strong enabler for cities to turn “smarter” and thus offer their citizens the opportunity of a better quality of life. This can be achieved through better decision making about a variety of domains within a city.
Particular areas where SCOs find fertile ground for development include light and traffic optimization, energy consumption, public and private transport, health care, environmental protection and citizen empowerment.
Those indicative areas are outlined in the figure below.

Figure 1: Fundamental SCO [3]

B. *SCOs challenges*

Smart cities worldwide are becoming increasingly smarter, through capitalizing on new technologies and insights to transform their systems and operations delivery to citizen-centered useful 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]. To extract those requirements, a set of smart city operations challenges, as identified in the international literature, are detailed below.

1) Level of intelligence (“smartness”) required

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, so as to be considered “smart”. Moreover, to do so, 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. Last, scalability of the smart operations to be provided, should also be considered. This means achieving a balance not just between the interests of a particular city’s stakeholders, but also taking into account relationships with neighboring cities. The above seems a complex algorithmic process with multiple variables [8][11][12].

2) Technology

Undoubtedly technology constitutes the primary driver towards the transformation of a city from a conventional one to a smart one. A smart city relies, among others, on a collection of smart computing technologies applied to critical infrastructure components and services. Smart computing refers to 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 people make more intelligent decisions about alternatives and actions that will optimize business processes and business balance sheet results [15].
In this respect, numerous challenges can be identified, such as (i) Lack employees with integration skills and culture, (ii) Lack of cross-sectoral cooperation, (iii) Lack of interdepartmental coordination, (iv) Unclear vision of IT management, (v) Politics, as well as (vi) Culture issues.

3) Scalability of smart solutions

Smartness should be scalable enough, in that a city should appropriately design the objectives to be achieved at various scales.
First come the minimum objectives that will attribute “smart” characteristics to the city and will be able to provide its citizens the minimum levels of quality needed to live a civilized life. At this high-level stage, the values of a city and its residents include many qualitative concepts and things of an emotional nature, such as lifestyle values and a sense of attachment to the neighborhood [4].
Second come the fundamental objectives that will enhance the level of smartness of the city towards a desired level, such as e.g. the reduction of carbon emissions. Such objectives could be agreeable at a local / regional / national level.
Last come some longer term objectives that will further advance the smartness level already achieved, which are usually set at a local level, albeit being negotiable also at an international level in the context of organizations and fora.

4) Formulation of city-specific objectives

A city usually sets at a local level some standards to be achieved at various time scales. Then, some Key Performance

Indicators (KPIs) are monitored, so as to evaluate the achievement of those standards. Those KPIs are nothing less than city-selected criteria / benchmarks. Moreover, KPIs should be adaptive enough to respond to new (external) requisitions [6][7][8].

In order to formulate city specific objectives, factors that need to be taken into account are (i) the people and cultural diversity, as well as (ii) the environment [9][10].

5) Economic growth

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 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. 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 [6][7].

6) Management and organization

There are only a few studies in the academic literature on smart city initiatives that adhere to address issues related to managerial and organizational factors of a city. In contrast, a wide array of previous research on IT initiatives and projects has highlighted these issues as important success factors or major challenges [13][14]. Thus managerial and organizational concerns in smart city initiatives need to be discussed in the context of the extensive literature on e-government and IT projects success.

In this respect, the authors of [13] suggested several challenges, namely (i), Project size, (ii) Manager's attitudes and Behavior, (iii) Users or organizational diversity, (iv) Lack of alignment of organizational goals and project, (v) Multiple or conflicting goals, (vi) resistance to change, as well as (vii) Turf and conflicts.

III. Smart Mobility in Smart Cities

The latest mass transit and e-mobility technologies match with city infrastructures from monorail and metro systems running through buildings at-grade, elevated or underground, to new solutions for electric vehicles. These solutions support a better way, which helps us thinking from traditional transport modes to electric public transport.

Smart mobility is a key challenge in the world. The huge increase in urban population and the growing environmental topic find prosper ground to the concept of smart mobility, which proposes solutions for greener, safer and more efficient transfer of humans and freight.

Historically, mobility has been seen as a product. That includes the vehicles, physical infrastructure and fuels which used people to mobilize. But, mobility is approached as a service also. This means that mobility is a method by which we provide food, engage in economic activity, access entertainment or meet with friends and family, all through ideal movements from place to place. When we use mobile phones, web and video to manage our lives on the go, the ways in which we discharge these tasks are changing. These new capabilities rely on physical and digital infrastructure whose potential is only beginning to be carried out. By supplementing urban planning and management practices with digital technologies, there is an opportunity to improve mobility services for citizens, while managing demand on physical transport networks and generating wider economic and environmental value [17].

In this way, the challenges in smart mobility are [18]:

i) To develop a system that can communicate with the vehicle and so the user is able to receive information from the surrounding environment, which can have influence in the vehicle performance (traffic information, internet-connected vehicles, parking management, car pooling, etc);

ii) To make the best effective use of the trip planning and routing of fully electric vehicles, using information from these sources including alternatives from other transport modes adapted to user's needs;

iii) To set efficient and optimum charging strategies which match to user and fully electric vehicles needs and grid conditions, as well as

iv) Using energy saving methods (as driving modes and In-Car Energy Management Services) within the fully electric vehicles interaction with the driver.

An example is a new mobility model, the Mobility-as-a-Service (MaaS). MaaS bridges the gap between public and private transport operators, envisaging the integration of all the fragmented tools (planning, booking, real time information, payment and ticketing) a traveler needs to conduct a trip. This model reduces the dependence on private vehicles and allows modern travelers in urban areas to plan and manage their transit quickly and safely using their smart phones. The key to successful uptake of such services is the effective integration among different technologies and tools.

Several EU funded initiatives are relevant to the smart mobility in smart cities in general, as well as MaaS in particular. The InSMART [20] concept brings together cities, scientific and industrial organizations in order to establish and implement a comprehensive methodology for enhancing sustainable planning addressing the current and future city energy needs through an integrative and multidisciplinary planning approach. READY4SmartCities [21] operates in a European context where other initiatives are currently running in order to create a common approach on Smart Cities. STEP-UP - Strategies Towards Energy Performance and Urban Planning [22] takes an integrated approach to energy planning, integrated project design, and implementation by addressing 3 vital themes together: energy and technology; economics; organisation and stakeholders.

TRANSFORMation Agenda for Low Carbon Cities [23] supports cities to meet the 20-20-20 targets by the integration of energy in urban management. PLEEC Planning for energy efficient cities [24] gathers cities with innovative planning and ambitious energy saving goals. SMART-ACTION [25] supports the development of strategic research agendas and serves as an enabler for the dissemination and further integration of results into future research and industrial developments, while coordinating international efforts.

Also, smart mobility can improve the economic gains. One way is to improve intermodal transport for better efficiencies and economic activity, for example, in Osaka, Japan, high-speed rail is blended with connections to local public transport networks to encourage public transport use and drive down the demand for roads. This reduces congestion, travel times and supports greater productivity. In another case, the efficient, integrated intelligent transport system in Medellin, Colombia, is cutting travel time into the city from many hours to 30 minutes, linking residents to jobs and education and driving economic gains.

In accordance with the above, the next section presents 2 indicative case studies that fall in the realm of smart mobility services offered to the citizens and visitors of smart cities.

IV. Indicative Case Studies

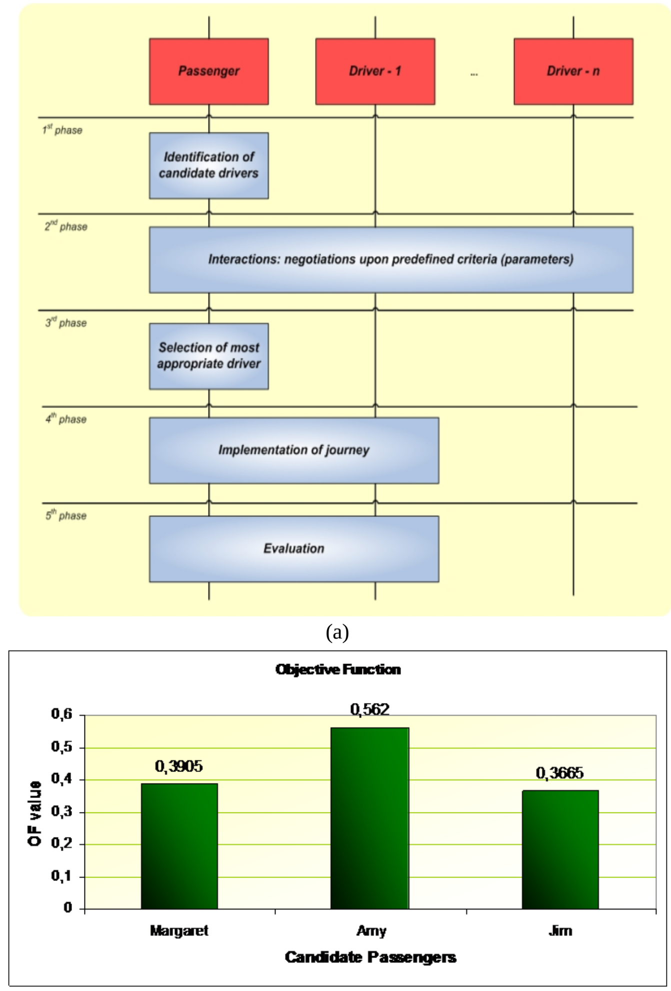
A. Car pooling

Car pooling is an idea that has been proposed by several researchers since many years, mainly for reducing traffic [26][27]. However, with the advent of ICT, this idea has turned into a smart mobility service offered by some cities/regions, to their citizens and visitors [28].

The service assumes a set of candidate drivers, namely the drivers' pool, as well as a set of prospective passengers, namely the passengers' pool. Drivers and passengers are associated with context information parameters, i.e. data on their current positions and itineraries. Furthermore, they are associated with personal profile parameters, as well as with service related parameters. Last, a set of overarching policies reflects driver/passenger preferences, in the form of weights (importance) attributed to the aforementioned parameters. The above are depicted on

In general, personal profile and service parameter values can change from time to time. The authors of [29] propose a functionality that can interact, on behalf of the prospective passenger, with all candidate drivers and find and propose an optimum match, taking into account the request, the available context, personal and service profile information, the policies, as well as previous knowledge turned into experience, which increase the degree of reliability of the decisions reached.

The SCO functionality presented in [29] uses previous knowledge in proposing valid car pooling matches. Knowledge is obtained through the exploitation of Bayesian networking concepts and specifically the Naive-based model. Results showcase its effectiveness, the advantage of which lies in that the reliability of the knowledge-based selection decisions is higher. This means that there is higher probability of satisfying the drivers' and passengers' preferences through the selected matches. Overall, car pooling is a representative case of an SCO that more and more cities tend to offer, often combined with most modern ideas/services, such as car sharing.



(b)

Figure 2: Car pooling, (a) indicative business case, (b) selection of the most appropriate passenger

B. Intelligent parking management

A major contribution toward the improvement of the quality of transportation in large cities would be the introduction of a system that would reside inside vehicles or even consist in a smart phone application, communicate with the transportation infrastructure using IP, obtain information on "white parking spaces", and then issue the appropriate directives to the driver so as to drive the vehicle to the desired parking space.

The information acquisition is based on a parking management system on the infrastructure side, which disposes a database of white parking spaces through information received from sensors (cameras) that constantly updates the database on the location and size of white parking spaces.

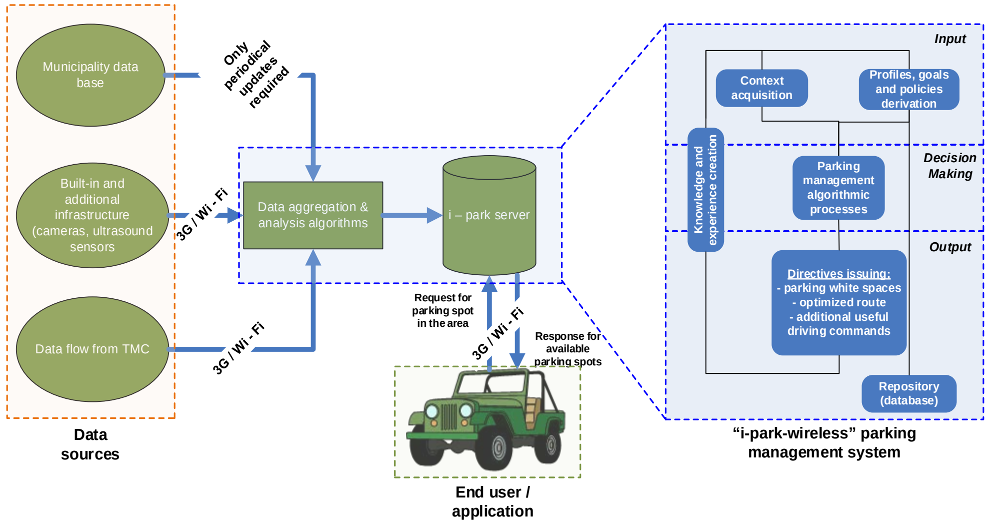


Figure 3: Intelligent parking management

Cities tend to study more and more systems like the one shown in Figure 3, since, in doing so, several impressive achievements could arise, namely:

- minimization of the time consumed in searching for a white parking space,
- improvement of the quality of the driver's life through a most productive utilization of time,
- increase in the mobility efficiency through the identification of the most appropriate route towards the white parking space,
- adoption of "green transportation" techniques through the real time adaptation to changes (e.g. sudden occupation of a parking space) and minimization of the GHG (Greenhouse Gas) levels in terms of the energy required / consumed from the moving vehicles.

C. Emergency management: early warning system for vehicles

As mentioned also above, by enabling vehicles to communicate with each other, as well as with roadside base stations via Vehicle-to-Infrastructure (V2I) communication, ITS can contribute to safer and more efficient roads and cities can offer smarter and smarter mobility services to their citizens and visitors.

In the light of the above, [30] proposes a mobility SCO, targeted at proactively managing vehicles and the surrounding transportation infrastructure quickly and efficiently, in a way that guarantees significant improvements in traffic / safety / emergency management.

The proposed approach is a smart city operation indeed, as it combines (i) wireless sensors placed on the vehicles and on specific parts of the transportation infrastructure (traffic lights, road signs), (ii) Wireless Sensor Networks (WSNs) formed by neighboring vehicles and parts of the infrastructure, thus referred to as "vehicular sensor networks" (VSNs) and (iii) a computationally efficient heuristic for evaluating the available information and proactively issuing directives to the drivers and the overall transportation infrastructure, which may be valuable in context handling.

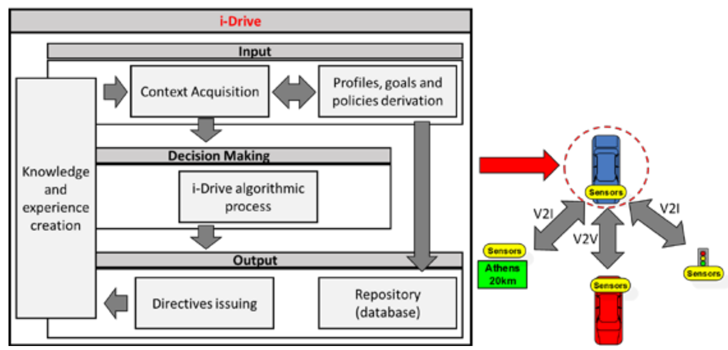


Figure 4: Warning system for vehicles as an SCO

The particular contribution of this SCO mainly lies in the utilization of a knowledge-based decision making algorithm, which can increase the overall levels of safety through recognizing potential emergencies a priori, improving thus the total transportation quality. Moreover, it laterally also addresses the integration of the advantages of vehicular sensor networks in ITS through the description of a whole framework that can incorporate various services/applications that can improve the quality of transportation.

V. Conclusions and Future Directions

This paper discussed on smart mobility services offered in the context of SCOs. As such, it first provided some fundamental definitions in the smart cities domain, as well as some basic challenges that cities face when designing SCOs. Then it focused on smart mobility that falls in the realm of SCOs, presenting its main research achievements and challenges. Then it went through some indicative case studies for exemplifying the provision of smart mobility services as SCOs.

Overall, smart cities are continuously getting smarter. This naturally requires capital expenditure and calls for novel solutions in various areas. 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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