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Empowering Citizens' Cognition and Decision Making in Smart Sustainable Cities

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***Abstract*—Advances in Internet technologies have made possible to gather, store, and process large quantities of data, often in real time. When considering smart and sustainable cities, this big data generates useful information and insights to citizens, service providers, and policy makers. Transforming this data into knowledge allows for empowering citizens' cognition as well as supporting decision-making routines. However, several operational and computing issues need to be taken into account: *(i)* efficient data description and visualization; *(ii)* forecasting citizens behavior; and *(iii)* supporting decision making with intelligent algorithms. This paper identifies several challenges associated with the use of data analytics in smart sustainable cities, and proposes the use of hybrid simulation-optimization and machine learning algorithms as an effective approach to empower citizens' cognition and decision making in such ecosystems.**

I. Analytics for Citizens' Cognitive Support

The 'smart city' concept involves the use of Internet technologies (ITs) in urban and metropolitan areas with the main goal of enhancing citizens' cognition, decision making, and lifestyle [1]. Since they involve social, technological, environmental, civil engineering, and transportation aspects, smart cities constitute an interdisciplinary research field. Continuous advances in the aforementioned fields allow for new opportunities in terms of improved information and communication systems, more intelligent transportation systems, energy-enhanced building design, etc. Due to a generalized growth in population, modern cities also suffer from pollution and traffic-congestion problems, among others, that need to be efficiently addressed.

ITs make it possible to gather and transmit large quantities of data about the daily needs of urban citizens [2]: from road traffic to underground schedules, from mobile devices to car sharing options, and from daily activities to participation in social, municipal, and political life. This 'big data' is typically stored and processed in order to provide real-time useful information to the city inhabitants, managers, and policy makers. The transformation of this information into knowledge allows these agents to increase their cognition and empowers them to make more informed decisions. When properly used, ITs can not only increase citizens' cognition but also their sensitivity towards environmental sustainability and public service efficiency. This way, citizens can assume a central role in decision making by means of collective intelligence and continuous improvement in their daily habits. Some authors use the term 'smart sustainable city' or even 'wise city' [3], and point out the need for introducing environmental, social, and economic indicators that measure the impact of technology deployment (Fig. 1).

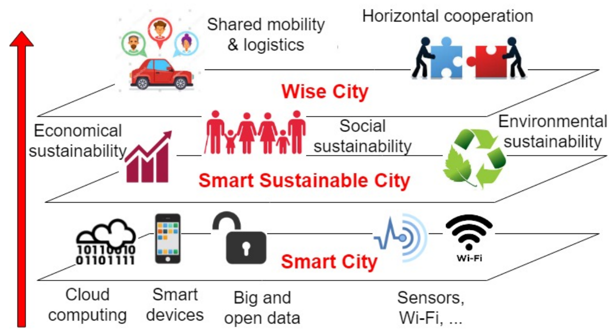

Fig. 1. Evolution from a 'smart city' to a 'wise city'.

Data analytics can be employed to add human cognition and intelligence to citizens' decision-making processes by: *(i)* describing the key performance indicators of the system *(descriptive an-*

alytics); *(ii)* forecasting future trends in these indicators *(predictive analytics)*; and *(iii)* offering support when choosing the 'optimal' option among many different alternatives or comparing different scenario settings via simulation *(prescriptive analytics)*. With the use of a publicly accessible online platform, the three aforementioned views of analytics can be integrated in a smart city: traffic, weather, mobility, service prices, occupancy levels, and other data obtained from different sources allow to increase citizens' cognition about the current status of the city, get insights on how this status will evolve during the next hours or days, and finally support citizens' to make informed decisions.

II. Decision Making in Sustainable Cities

Smart and sustainable cities have received increased attention in recent years. Although the initial documents on this topic appeared before, it is only in the last decade when they show a nearly-exponential growth. When combined, smart cities and big data can support improvement of processes in supply chain networks. Several research trends can be identified in the area of city logistics: integrated location-routing problems, inventory-routing problems, multi-echelon routing problems, horizontal collaboration strategies, dynamic and stochastic vehicle routing problems, autonomous and connected vehicles, electric vehicles, multi-modal networks, traffic congestion and availability of parking space, crow-based logistics, etc. Monfaredzadeh and Krueger [4] discuss the social and human dimensions of smart cities, as well as how sustainable cities can improve the quality of live of their citizens. Lee et al. [5] provide a framework that integrates the technological and the institutional dimensions in order to better understand how smart cities emerge. These authors analyze two case studies regarding the use of open data in modern cities. Kummitha and Crutzen [6] review the different literature approaches to the concept of smart cities and propose a taxonomy that clusters them into four schools of thought. Girardi and Temporelli [7] propose a methodology to assess different sustainability dimensions related to a smart city: environmental, economical, energetic, and social. Eremia et al. [8] review the historical evolution of the smart city concept and discuss its relationship with other related concepts, e.g.: sustainable, digital, future, intelligent, or green cities. These authors also propose to collect and redistribute real-time information about the traffic conditions by means of social networks. Chen et al. [9] discuss the connection between intelligent transportation systems and smart cities. They highlight energy savings and reduction of greenhouse gas emissions as two of the main benefits for citizens derived from investment in intelligent transportation systems. Addanki et al. [10] analyze how new smart sustainable cities can be designed and built considering climate change and population growth. Chauhan et al. [11] provide a complete literature review on the challenges associated with the use of big data to enhance citizens' cognition and lifestyle. Often, the aforementioned issues are extremely complex and require from emergent ITs and intelligent algorithms. This paper analyzes some of these challenges and proposes hybrid approaches that can be employed to address them.

III. The Digital Citizen

ITs are radically influencing and redefining citizens' behavior. ITs are changing public relations in several ways: *(i)* among individuals; *(ii)* among individuals and companies; and *(iii)* among organizations. One of the key points of ITs is the combination of interactivity with the new characteristics of mass communication, such as the unlimited range of contents and the global reach of the audience. The democratized utilization of ITs creates a change in the users behavior. This change allows the evolution from the concept of society to the ones of "digital society" and "digital citizen" [12].

These new digital citizens demand more services from cities and, in particular, an enhancement in their lifestyle, both during working and leisure time. These goals can be achieved by efficiently combining ITs with data analytics, thus increasing the cognitive capacity of citizens, generating new services fro them, and also supporting them to make better decisions in such a complex and dynamic environment. Some authors identify this potential of new services as a double opportunity [13]: *(i)* to improve citizens' cognition levels and satisfaction; and *(ii)* to create a new business model for the city, since some of these services could offer enough value for that. The role of the citizens is critical for the design of these services, since they are not only potential clients but are also willing to actively participate in the city government. In a smart sustainable city, the combination of ITs with data analytics plays a ‘problem solver’ role. Many regions across the world are experiencing a population increase in their main cities. This fact represents a huge challenge that forces us to redefine the role of citizens, organizations, and politicians, as well as to focus the efforts of researchers, managers, and policy makers in the design of technology enhanced, socially aware, and more sustainable urban areas. Therefore, the digital transformation of cities has a double objective: *(i)* to take advantage of new opportunities derived from the change of citizens behavior; and *(ii)* to solve new problems and challenges arising in new cities concepts.

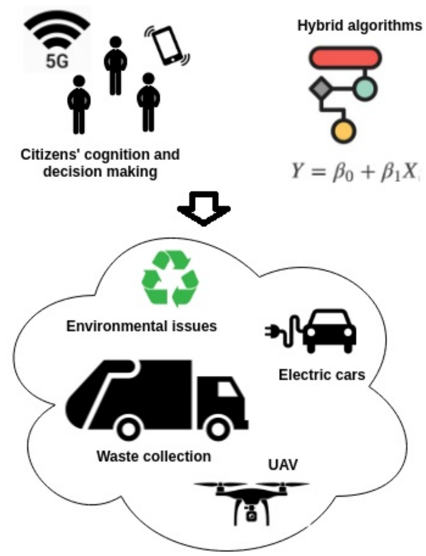

Fig. 2. Improving citizens’ cognition and quality of life in smart sustainable cities.

IV. Improving Life in Sustainable Cities

Different challenges that need to be properly addressed to improve both digital citizens’ cognition as well as their quality of life are reviewed in this section. These challenges include, among others, smart waste collection management, an increase in the utilization of electric and unmanned vehicles, and the optimal location of urban distribution centers (Fig 2).

A. Electric Vehicles

Operation activities in the area of logistics and transportation (L&T) have not only a business impact but also a social and environmental one. The industry is continuously growing and has a significant impact on the regional gross domestic product worldwide. The inter-connectivity between countries and international trade require especially fast and innovative L&T solutions for road transportation to effectively respond to the extensive usage of motorized vehicles. Engineers and scientists have been focusing on this field, aiming at providing real-life applicable solutions. Among all, the re-occurrence of modeling and optimization of tour assignments stands out, known as the vehicle routing problem (VRP), which is addressed in numerous variants. In Europe and the USA, road transportation accounts for a large percentage of oil consumption, CO_2 emissions, and total greenhouse gas. The high variability in price of oil-based products and the dependency on oil-based energy sources is considered as a long-term risk that requires mitigation, i.e., both business and environmental goals have to be considered when developing distribution models in the ‘on demand economy’, so that low-emission logistics operations are achieved. Besides going easy on resources and optimizing the total usage of traditional vehicles, adequate routing models have to include vehicles empowered by alternative sources of energy, such as electric vehicles (EVs) or even human-powered small vehicles for urban centers [14]. Due to their advantageous use of energy, EVs can effectively reduce primary energy consumption and are highly recommendable from an environmental and energy point of view. Yet, there are still concerns in terms of: *(i)* the limited duration of their batteries; *(ii)* the long recharging times these batteries require; and *(iii)* the insufficient number of battery charging points. In earlier years, the competitive deployment of EVs has not been as successful as some experts predicted due to the high prices of EVs as well as to their driving-range limitations. This is likely to change in the next few years as the market price of EVs is continuously diminishing, their driving-range capabilities increasing, and several governments are promoting regulations that constrain the utilization of traditional vehicles in urban centers and will increase the number of charging points across many cities. More than ever, it becomes a necessity to use low-carbon energy sources in urban freight logistics and citizens' transportation that promote sustainability in modern urban, metropolitan, and peri-urban areas. A positive trend of greater involvement of EVs in road distribution activities is particularly promising in urban areas, where its full potential is yet to be explored. Concerns about additional complications, in terms of planning and handling a higher number of EVs, have to be taken into consideration too. Several strategic, tactical, and operational issues need to be considered, including: *(i)* the design and building of charging stations for EVs; *(ii)* the optimal composition of heterogeneous fleets combining EVs and other type of vehicles; *(iii)* the optimization of routes using vehicles with different driving-range capabilities; *(iv)* the time-related and synchronization factors associated with these driving-range constraints; *(v)* the monetary cost of using EVs and human-powered vehicles instead of traditional trucks; and *(vi)* the use of data collected from drivers to empower other drivers as well as to improve the self-driving capability of cars.

B. *Waste Collection Management*

The increasing number of citizens living in cities is requesting public services to provide a profitable, sustainable, and metropolitan-friendly solution for its waste collection. Currently, operating waste collection is not only cost intensive, but it also comes along with a variety of side effects –such as traffic congestion, noise and air pollution. These side effects put waste collection in the limelight of public services. The waste collection and disposal optimization process is especially interesting due to the interlaced optimization problems, such as the facility location problem, service territories grouping, and the VRP. Numerous constraints make it difficult to use exact methods for optimization. Instead, metaheuristic algorithms are typically employed to generate near-optimal solutions in reasonable computing times even for large-scale WCP configurations. Among other research challenges in this area, one can consider: *(i)* the application of sensors and on-line monitoring of garbage bins to shift from a schedule-based collection plan to a demand-based one; *(ii)* the incorporation of a lean-based approach –so that collection actions are performed just when needed; and *(iii)* the optimization of the routing plans considering different types of waste, uncertainty, as well as horizontal cooperation strategies among different districts or cities.

C. *Unmanned Aerial Vehicles*

Unmanned aerial vehicles (UAVs), also known as drones, offer new services to citizens, firm managers, and policy makers due to their mobility characteristics. UAVs can be used in surveillance and monitoring services, including data gathering, visual recognition of areas, or even transportation of small products. Teams of drones can be coordinated to provide useful services in smart cities, such as monitoring traffic conditions after an accident, recognizing an area affected by a natural disaster or a terrorist attack, surveillance of crowded events, providing a mobile telecommunication infrastructure, or even supporting intelligent transportation systems (ITS). Thus, coordination algorithms will be needed to support the optimal grouping of UAVs and therewith overcome their limitations in distance coverage. Designing these algorithms, however, is restricted by security and privacy rights and challenges associated with UAV-enabled ITS infrastructures in smart cities. Aerial support for citizens is provided via mobile apps or real-time video streaming, where the latter is available for users sharing the same cloud platform and is operated remotely. The introduction of UVAs in smart cities brings new opportunities, but also the necessity to critically scrutinize legal frameworks regarding data collection and processing. Despite these concerns, UAVs remain the most promising answer to the smart city concept due to a lack of comparable competitive alternatives. Both UAVs as well as other types of unmanned vehicles (e.g., self-driving cars) will be increasingly popular during the next years and will require from ultra-fast and ultra-reliable communication systems as well as from advanced coordination and route-optimization algorithms.

D. Urban Distribution Centers

Urban consolidation centers help to reduce the number of kilometers traveled by larger and more polluting freight vehicles. This saves fuel and reduces gas emissions, thus making cities cleaner and healthier for citizens. Optimally determining the location, size, and operation of urban consolidation centers might have not only an economic impact, but also an environmental and social one. Accordingly, determining the optimal location of these centers, the allocation of customers to them, and the eventual routing plans, constitutes a considerable research challenge yet to be explored in detail. Additional aspects that should be also investigated are: *(i)* the incorporation of hybrid fleets including both traditional vehicles as well as EVs with limited driving-range capabilities; and *(ii)* the integration of horizontal cooperation strategies, which might contribute to make the distribution more efficient and less pollutant.

E. Other Emerging Challenges

When dealing with smart and sustainable urban centers, other issues need to be also analyzed as well. Among these, the following ones seem quite relevant to us: *(i)* smart water management and smart water systems; *(ii)* public transportation systems; *(iii)* resilient intelligent transportation systems; *(iv)* home health care services; *(v)* car sharing practices; *(vi)* smart energy management and smart energy systems; and *(vii)* smart building design.

V. Intelligent Algorithms for Supporting Citizens' Decision Making Under Uncertainty

Intelligent algorithms –such as those based on forecasting, simulation, machine learning, and optimization– have been frequently used in the design of complex networks and systems operating under realistic conditions. A smart and sustainable urban center is quite a complex and multi-layered network with a high number of variables and components that interact among them. Thus, the effective design and building of a smart city requires the use of advanced –and typically large-scale– analytical and computing models. While these models can represent a vast number of real-life features influencing different components of a smart sustainable city, capturing the citizens' behavior is still a difficult task. Depending on the model, these behaviors might characterize individual citizens as well as social communities. Therefore, various behavioral factors need to be considered. Based on that, many efforts were made to simulate and optimize some social aspects of relations within social networks, and it has been found that agent-based simulation (ABS) is one of the best approaches for modeling dynamism and uncertainty. Uncertainty and dynamism, in terms of time-evolving conditions, are also frequent properties of smart city models. Despite ABS has shown to be able to effectively represent uncertainty with regard to interrelated actions among individuals or groups, it is not an optimization technique. Accordingly, in order to support citizens' decision making under realistic conditions, it becomes necessary to hybridize ABS (and other simulation techniques) with optimization approaches. The proper optimization technique should be chosen according to the size of the problem. Thus, for large-scale instances, such as a smart sustainable city system, metaheuristics are considered as effective optimization tools. This is why today research is looking into best possible ways to integrate simulation techniques and metaheuristic algorithms. This integrated approach is described as simheuristics [15]. Another research area of interest points at the anticipation of human behavioral changes due to varying environmental circumstances during the design of the solving plan or solution. This is achieved by combining metaheuristics with machine learning. Likewise, the use of cloud computing to speed up the process of providing effective support to citizens and other stakeholders in a smart sustainable city is worthy to be further investigated. These techniques contribute not only to achieve the aforementioned 'wise city' concept, but also to accurately model citizens' behavior and to empower their participation as a driving force in modern cities across the world.

VI. Conclusion

From the perspective of human cognition and decision making, this paper has identified some of the main challenges and open research lines related to smart sustainable cities –many others might be recognized, but this paper focuses on those that are mainly associated with the area of data analytics. This paper discusses how smart cities can become also sustainable by taking advantage of both Internet technologies, big data, and advanced analytical methods in sectors such as freight logistics and citizens' transportation. By incorporating electric vehicles, unmanned aerial vehicles, an intelligent management of waste collection, and optimally located urban consolidation centers, smart cities can also become more sustainable. However, all these innovations also require to properly address a series of technological and operational challenges, which need to be effectively solved in order to increase citizens' cognition and decision-making capabilities. Accordingly, advanced algorithms based on the combination of simulation-optimization and machine-learning techniques are needed. These analytical tools are needed in order to support efficient decision making in scenarios under uncertainty which also include dynamic conditions. Only then, the desirable change towards more cognitive, smart, and sustainable cities will be achieved.

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