Smart Cities, Big Data and Smart Decision-making

Understanding "Big Data" in Smart City Applications

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***Abstract*—Smart decision making is based on data combined with analytics to improve decision-making. This paper examines several application areas of smart cities, and related data sources used for decision-making. In many cases, systems may make decisions on their own. Such systems may play an important role in the development of smart cities. In other cases, the data can be combined with historical data or other open data sources to play a role as the foundation for decision-making. Our findings are presented as an analytical framework, which will be used for further empirical studies into this domain.**

Keywords-smart decision-making; smart cities; big data; sensors; analytics.

I. INTRODUCTION

This paper presents an analytical framework for smart or (intelligent) decision making in the context of smart cities. The framework is based on a review of literature, white papers and news sources covering the topic, as well as empirical data from a study on air quality monitoring. The analytical framework shows areas in need of further study and forms the basis for future research projects.

Smart decision-making uses a systematic approach to data collection and applies logical decision-making techniques instead of using intuition, generalizing from experience, or trial and error.

"Smart cities" is a multifaceted concept and has been defined in many different ways; more than 100 definitions of smart cities have been analyzed by the International Telecommunication Union (ITU)'s focus group on smart sustainable cities [1][2]. The mandatory requirement for smart cities is to improve quality of life and achieve sustainable development (economic, social, and environmental) through the use of Information and Communications Technology (ICT) and intelligence [3]. Definitions emphasized the technological aspect of a smart city as being "a technologically interconnected city" or Internet of Things (IoT) using big data is promoted to achieve the efficiency and intelligence in managing cities' resources [4][5].

A smart city is a city that is characterized as an "instrumented, interconnected, and intelligent" [6]-[8]. This can be conceptualized as three layers, as shown in Figure 1.

These characteristics are enabled by use of ICT, which constitute the heart of a smart city [9]. The "instrumentation" layer does data acquisition through sensor-based systems that provide real-time data through sensors, meters and cameras, but also from social media and open data sources. The instrumentation layer enables capturing and filtering data from various sources for timely response. The inputs from the instrumentation layer are integrated and transformed into event-related information at the "interconnection" layer to provide rich insights for decision-making. The interconnection layer provides all forms of collaboration among people, processes, and systems to enable a holistic view supporting decision-making. At the "intelligence" layer, business intelligence and analytics are applied to the information provided by the interconnection layer and other city-relevant data and, then, the analyzed information is visualized to understand the city requirements and city policies, hence, make informed decisions and take actions. The intelligence layer is focused on deep discovery, analyses, and forecasting. These three layers that build up the smartness in a smart city are constructed by smart technology solutions and ICT infrastructure, such as IoT, big data, and Internet.

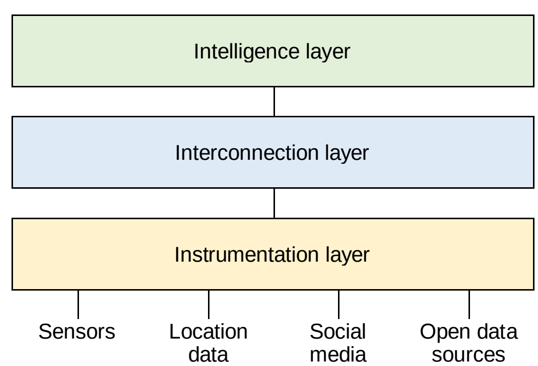

Figure 1. Three-layer model.

Regarding the intelligence layer that is concerned with decision-making, a review of studies on smart city and decision-making resulted in nine articles. This indicates that smart city and decision-making is an area that deserves further investigation on how to make a big impact from big data [10].

In this paper, we elaborate on smart or intelligent decision-making in the context of smart cities. Smart decision-making relies on data and analytics to make better decisions. By using autonomous systems, the decisions can be implemented in real time. Human intervention can be reduced to oversee the decisions and take over if the system is malfunctioning.

The main focus of this paper is on the instrumentation layer, and the data sources used by this layer. The data is refined through the interconnection layer and processed by the intelligence layer to enable decision-making. The three-level model provides a systematic approach to collecting facts and applying logical decision-making techniques, instead of generalizing from experience, intuition (guessing), or trial and error.

The rest of the paper is structured as follows: Section 2 discusses methodology. Section 3 focuses on the instrumentation layer, including identification of common data sources. Section 4 describes some selected smart city application areas. Section 5 presents our analytical framework. Section 6 contains our conclusion, some limitations, and ideas for future work.

II. Methodology

The purpose of this paper is to begin exploring how typical application areas of smart cities use, analyze and visualize data. Data analysis and visualization is essential for decision-making and intelligence in smart cities [6]-[8]. However, our literature review reveals little research in this area.

Figure 2 shows how data is analyzed and visualized. The analytics typically stores data for future use, e.g., for predictions. The visualization is used for human decision-making.

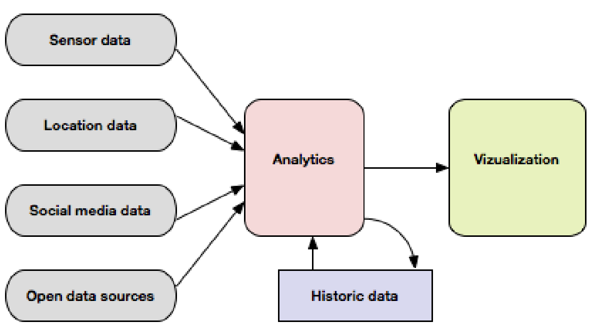

Figure 2. From data to decisions.

Thus, an analytical framework outlining the possible data sources, analytical and visualization techniques could be a valuable contribution to decision-making, as well as for future studies in this domain. Our research question for this study is "*Which data sources are applicable to the different application areas of smart cities*?"

Data collection was done through several iterations. Initially, we planned on conducting this study as a pure literature review. However, there are few studies of this area so far. We were only able to identify nine research papers (referenced in Table 1), using the search phrases "smart city" and "decision-making" in the title. Thus, we had to rely on additional data sources and conduct a document analysis of industry white papers, as well as industry, technology and regular news sources. In addition, we applied existing empirical data from a previous study on air quality monitoring.

This exploratory approach led us to three themes, which we summarize in Section 3, Table 1. Further, the examined news sources and white papers identified eight application areas of data analysis in smart cities; parking, speed monitoring, public transport, traffic, environmental monitoring, energy management, waste handling, and crime prevention. For analysis, we have applied literature, findings from the air quality monitoring study, as well as data from industry to map potential data sources for each of the eight categories. This allowed us to create an initial framework of data sources for the eight identified categories.

III. Data for Decision-making

At the instrumentation layer, data for decision-making may originate from many different sources. Laney [11] defines big data as data having high volume, high velocity and/or high variety. High volume refers to large amounts of data demanding both specialized storage and processing. High velocity refers to streams of real-time data, e.g., from sensor networks or large-scale transaction systems. Finally, high variety is about dealing with data from different sources having different formats.

Big data may originate from sensors. Another important source for big data is the world-wide-web. Web mining can be used to retrieve unstructured data (text) related to everyday events happening in a city. In this context social media, such as Facebook and Twitter can provide information about problems and citizen sentiments. Many government organization and private companies offer open data sets online that can be used for analysis and decision- making.

Marr [12] argues that the real value of big data is not in the large volumes of data itself, but in the ability to analyze vast and complex data sets beyond anything we could ever do before. Due to recent advances in data analysis methods and cloud computing, the threshold for using big data has diminished.

A. Sensors

Sensors and sensor networks are important for smart decision-making. Sensors provide real time information about weather, traffic, air quality, energy consumption, water consumption, and waste. Data from sensor networks are structured and easy to process. According to Cambridge dictionary, the word "sensor" means a device that is used to record that something is present or that there are changes in something. IoT is an infrastructure with interconnected units that may among other things act as sensor platforms. Botterman [13] defines IoT as:

"A global network infrastructure, linking physical and virtual objects, through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and connection capability as the basis for the development of independent federated services and applications. These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability". (p.12).

B. Location data

Location data places an object in a specific position. Location is important both for stationary and mobile objects. For mobile objects, location data comes from the Global Positioning System (GPS) or from triangulation of radio signals, e.g., belonging to a mobile network.

C. Social media

Another possible data source for smart decision-making is social media. Social media has been defined differently among scholars [14]. However, we adopt the definition by Kaplan and Haenlein [15]: "Internet-based applications that build on the ideological and technological foundations of Web 2.0, and that allow the creation and exchange of User Generated Content" (p.62).

Data retrieved from social media will mostly be unstructured (text, images, video), but also structured meta-data providing additional information, e.g., tags containing author, content type, title, date/time and location. Unstructured data from social media may provide insight in the perceptions and sentiments of smart city citizens.

D. Open Data Sources

Open data is data that can be freely used, reused and redistributed by anyone - subject only, at most, to the requirement to attribute and share alike. Open data has the following characteristics [16]:

- Availability and access: The data must be available as a whole and at no more than a reasonable reproduction cost, preferably by downloading from the Internet. The data must also be available in a convenient and modifiable form.
- Reuse and redistribution: The data must be provided under terms that permit re-use and redistribution.
- Universal participation: Everyone must be able to use, re-use and redistribute - there should be no discrimination against fields of endeavor or against persons or groups.
- Interoperability: The ability to interoperate - or intermix - different datasets (i.e., one piece of open material contained therein can be freely intermixed with other open materials).

E. Decision-making in Smart Cities

In the context of smart city, decision-making has been given less attention in the literature; Google Scholar found nine articles discussing decision-making in smart cities (See Table 1). The nine articles investigated various aspects of the three layers described earlier.

Studies related to interconnection layer have highlighted various collaboration aspects that are important for smart cities. Ojasalo and Tähtinen [17] proposed a model of an open innovation platform for public sector decision-making in a city. The authors identified three different kinds of relationships that are present and partly interwoven in open innovation platforms (i.e., governing, sparring, and collaboration). The proposed model helps organizing the three types of relationships of an innovation platform with the city's decision-making and external actors, by combining different decision-making cultures between the public and private sector.

TABLE I. MAPPING LITERATURE TO SMART CITY LAYERS

Ref.	Instrumentation layer	Interconnection layer	Intelligence layer	Others
[17]		X		
[18]			X	
[19]			X	
[20]			X	
[21]	X			
[22]	X			
[23]	X	X	X	
[14]				X
[22]				X

At the intelligence layer, Eräranta and Staffans [18] discussed knowledge creation and situation awareness in collaborative urban planning practice, and how digitalization changes it. The authors argued that smart city planning is not only a data-driven super linear scaling practice, but an integrative and collaborative learning process facilitated by face-to-face interaction, advanced analyses and visualizations of available data, ongoing processes, and local history and stories. The authors brought in collaboration at the intelligence layer.

At the intelligence layer, Passe et al. [19] attempted to understand human behavior and decision-making about the built environment within an expanding range of spatial, political, and cultural contexts. The authors emphasized the importance of participation by a broad range of stakeholders in making decisions for the future of smart cities. The authors argued for the need to consider social dynamics in addition to building-occupant interactions, which requires investigating multiple scales and types of data to create new methodologies for design and decision-making processes. This approach moves data collection, analysis, design, and decision-making away from hierarchical relationships and utilizes the expertise of all stakeholders.

Also at the intelligence layer, Honarvar and Sami [20] talked about the various sensors embedded in different places of smart cities to monitor and collect data about status of cities. Mining such data to extract valuable knowledge creates a challenge because various sources of data in smart cities are big, independent, heterogeneous and no semantic is integrated and annotated to them. The authors proposed an approach to leverage linked open data and semantic web technologies, data mining mechanisms, and big data processing platforms.

At the instrumentation layer, Khan et al. [21] emphasized the role of citizen participation as an important data source for social innovation and co-creating urban regeneration proposals through innovative IT systems. Those IT systems can use open government data, visualize urban proposals in 3D models and provide automated feedback on the feasibility of the proposals. Using those IT systems as a communication platform between citizens and city administrations offers an integrated top-down and bottom-up urban planning and decision-making approach to smart cities. In the same line, Foucault and Moulier-Boutang [22] proposed a governance model called “Smart City – organological”. The model consists of an adaptive device built around a differentiation of smart sensors and tags to improve human decision-making. The device is taking into account both “physical sensors” and “economic and social sensors” to capture the explicit or implicit needs.

At the level of the three layers, Nathali Silva et al. [23] worked on an area of concern regarding the continuous growth of the complex urban networks that is challenged by real-time data processing and intelligent decision-making capabilities. The authors proposed a smart city framework based on big data analytics. The framework operates on three levels: instrumentation layer (data generation and acquisition level), interconnection layer (collecting heterogeneous data related to city operations, data management and processing level), and intelligence layer (filtering, analyzing, and storing data to make decisions and events autonomously, and initiating execution of the events corresponding to the received decisions).

Some other topics were studied in the literature, e.g., Gang and Yang [24] studied design issues to improve the intelligence layer of city emergency management. Kurniawan et al. [25] investigated the development and optimization possibilities of Makassar City smart operation room. The authors used fuzzy multi-criteria decision-making to illustrate the project priority rank and further to determine the alternative optimal option in conducting the project.

IV. Application Areas

In order to understand more about data sources and decision-making techniques, we have examined some common application areas connected to smart cities (See Table 2). The first four areas are connected to transport:

- Smart parking
- Speed monitoring
- Smart public transport
- Smart traffic

The rest of the application areas represent the broadness of the smart city concept:

- Environmental monitoring
- Energy management
- Waste handling
- Crime prevention

A. Smart Parking

Smart parking assists drivers to find a nearby parking spot. The information provided to the driver can have many different forms, from public displays placed next to roads to mobile apps directing the driver to a free parking spot [26][27][28].

Smart parking data is sensor based. Outdoor sensors may be magnetic sensors located in capsules embedded in the ground, detecting the presence of a car, or cameras detecting if a parking spot if free or not. Indoor parking spots may instead have infrared or ultrasound sensors to detect the presence of cars.

Smart parking may also include payment solutions based on mobile phone apps, use of SMS, or dedicated devices like SmartPark™ [29]. The payment solutions may give the user the opportunity to pay for time actually used instead for paying for a fixed time period.

Smart parking sensor data provides information to city planners and car park companies about the occupancy of parking spots over time. The collected information can be used for decision-making regarding the construction of new parking sites, and to decide on pricing.

B. Vehicle Speed Monitoring

Vehicle speed monitoring warn drivers about their driving speed. The idea is to make drivers slow down if they are driving at excess speed. Speed monitoring units may be stand-alone, but state-of-the art units are connected to the Internet and provides real-time information on driving habits [30].

Several technologies have been demonstrated for vehicle speed monitoring including use of cameras, RADAR, LIDAR, and underground sensors [31]. A measurement station is put in a fixed position, and excess speed is shown on a display device.

Another approach is to install mandatory units in all vehicles. The driver can then be alerted of excess speed directly by the unit. Such units can also upload speed data through some kind of network [31].

(Some GPS devices warns the driver about excess speed, but such data are not relevant, since data are not uploaded for use by traffic authorities.)

Vehicle speed monitoring data can be used by traffic authorities and police to decide on traffic control locations. Such data can also be used to implement speed reducing measures, such as speed bumps or traffic lights, and even control such measures in day-to-day operations.

C. Smart Public Transport

One important measure to reduce environmental footprint is to reduce car traffic, in particular the use of private cars. A well-developed public transport infrastructure can be an incentive to reduce traffic load. Car owners may also be discouraged by the toll charges or congestion charges implemented in many cities.

Smart public transport uses technology to provide public transport users with a better user experience [32]. Use of sensors and GPS technology can provide real time data on arrivals and departures of public transport vehicles.

Smart ticketing solutions may use smart cards or mobile phones equipped with Near Field Communication (NFC) to make ticketing more efficient from a user point of view [33].

Online route planners may help users choose the most efficient route from one location to another location.

The data collected from smart public transport can be used for real time situation reports and may also be used by public transport planners to adjust time tables, change routes, create new routes, and adjust fares.

Social media may be mined to find citizen perceptions of the public transport system.

 ISBN: 978-1-61208-615-6

D. *Smart Traffic*

Smart traffic is about using technology to ensure more efficient traffic management. Traffic management may use road lights and signs to optimize traffic flow in real time [34]. Commercial car navigation systems provide information on fastest and shortest routes. Some navigation systems collect information from other cars real time to detect bottlenecks and provide alternative routes.

Data may come from sensors embedded in the roads. The most common technique is to detect traffic density by embedding coils under the road surface to pick up passing cars. Alternatives are to use camera or radar technology to detect traffic.

Data may also come from the vehicles themselves, by using radio transmissions or a cellular network [35].

The data collected may be used by the city-administration for road-planning, adjusting intervals of traffic lights. Data can also be used by transport companies to decide on best schedules for pick-ups and deliveries.

Mining social media may provide some information on how citizens experience traffic situation.

E. *Air Quality Monitoring*

Monitoring air quality and other environmental parameters is important for decision-making. Some cities are enforcing restrictions on traffic when pollution levels reach a certain threshold [36].

In most cases, the air quality monitoring is done by fixed monitoring stations located throughout the city, but may also be done by mobile handheld units, or units installed in cars.

Measurements include gases: CO, CO_2, NO_X, and dust particles, normally 2,5 PM and 10 PM.

Collected data can be combined with other data sources, e.g., meteorological data, to provide real time situation reports and make forecasts for future pollution levels. Data can be visualized and be made available to the public. Such data is particularly valuable for citizens with respiratory problems.

Social media may be mined to find citizen perceptions of air quality.

F. *Energy Management*

Smart power grids contribute to better energy management and reduced environmental footprint. An essential part of the smart grid is smart meters. Smart meters are devices that continuously measure power consumption of households and buildings. Household appliances can communicate with the smart meter to schedule activities when the load on the power grid is low. The smart meters also communicate with energy management systems to optimize energy consumption [37]. Buildings can also take part in energy production through use of solar panels and other alternative energy sources.

Sensor data may be combined with location data and open data sources to make forecasts. Social media data plays a minor role in the context of energy management.

G. *Waste Handling*

Sorting waste materials for recycling has become common practice. Garbage collection can be improved by only collecting waste when necessary. "Intelligent" waste containers can report their state of becoming full and get included in the schedule of trucks collecting the waste [38][39][40].

The recycling process itself can provide valuable data on types and amounts.

Data from the waste collection process can be used to decide on container size and pick-up patterns. Data may also be made public to show timeliness and efficiency of the waste handling, from garbage collection through recycling.

Social media data mining can be used to detect sentiments about the garbage collection.

H. *Crime Prevention*

Crime prevention is about allocating police resources to areas most likely to get victims of crime, but also to find out where to establish surveillance by video cameras and other means.

Data used for crime prevention will mostly be former reported crimes combined with open data sources, e.g., demographic data, property values, income levels of citizens, street light coverage, etc. [41][42].

Social media may be mined to find indications of unreported crimes.

TABLE II. MAPPING APPLICATIONS TO DATA SOURCES

Application areas	**Data sources**			
	Sensor data	**Location data**	**Open data**	**Social media data**
Smart parking	X	X	-	-
Speed monitoring	X	x	-	-
Smart public transport	X	X	-	x
Smart traffic	X	x	-	x
Air quality monitoring	X	x	X	x
Energy management	x	x	x	-
Waste handling	X	X	-	x
Crime prevention	-	X	X	x

X major data source
x minor data source
- not applicable

V. ANALYTICAL FRAMEWORK

The purpose of our case studies is to examine data sources and methods used to analyze data. Seven examples of smart city applications show the importance of sensor data, but also the opportunities of using open data sets combined with sensor data to improve analysis and enable forecasting. Web mining and social media has limited use in these cases, but can be used to alert city administration about potential problems and sentiments.

The crime prevention case does not rely on sensor data, but on reports of crimes. Combining different open data sets can provide better insight related to crime prevention. The reported crimes can provide patterns, but combining data sets may shed light on underlying factors, like property values, incomes, absence of street lights and other factors.

In this study, we have examined mainly the instrumentation and interconnection layers, finding a set of data sources used in different smart city application areas, as shown in Table 2.

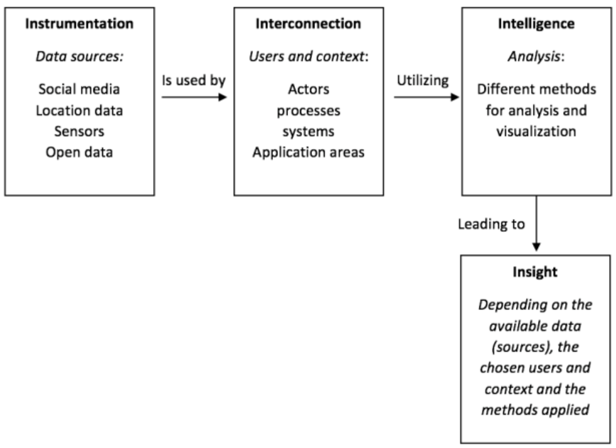

Figure 3. Analytical framework.

When we map these finings to the three layers in Table 1, we have the outline of an analytical framework as shown in Figure 3. The resulting analytical framework may guide future research efforts in the field. Existing research and white papers provide examples of how big data can be applied for decision making, but as our framework shows, there is a need for both synthesizing existing studies as well as conducting new empirical studies to create a roadmap for decision-makers. This roadmap would list relevant data sources and analytical techniques for different users and contexts. The framework forms a possible foundation for future studies in this area.

VI. Conclusion, Limitations and Future Work

In this paper, we used eight typical application areas of smart cities to explore their use of data. We examined relevant data sources, and their use. Data collected from sensors are very important for seven of the chosen application areas. Open data is often a valuable supplement to collected data. In some cases, location data are combined with other types of data. Social media data mining may play a role to show user perceptions and sentiments.

The collected data need to be processed and analyzed to be useful for decision-making.

Data will often be used for automatic decision-making. In seven of the chosen application areas, we found examples of data used for automatic decision-making:

- Smart parking: Automatic update of displays directing drivers to available parking spots.
- Speed monitoring: Automatic regulation of traffic lights, or even photographing speeding vehicle to issue a speed ticket.
- Smart public transport: Automatic updates of screens showing arrival and departure times.
- Smart traffic: Automatic control of signs and traffic lights to redirect traffic.
- Air quality monitoring: Automatic alerts to citizens in the areas, through signs or SMS service.
- Energy management: Automatic start of household appliances, based on grid load.
- Waste handling: Automatic updates of garbage truck schedules based on amount of garbage in each container.

For strategic and long-term decisions done by humans, the results of the processing and analysis need to be visualized in a meaningful way, e.g., through graphs, bar charts, pie charts often combined with a map or even embedded in a Geographic Information System (GIS) front-end.

This paper studied application areas of smart cities to examine use of (big) data. The study is not exhaustive. We used example of application areas from literature, but as “smart cities” have ambiguous definitions, we may have overlooked some areas. Further, as we had to start examining white papers from industry it is likely we have missed interesting data from relevant sources even after our rigorous search in the most well-known big data/analytics companies.

In the future, we intend to investigate how data can be analyzed using different methods and techniques, so that we can present a comprehensive model of possible combinations of data sources, actors and contexts, and analytical techniques.

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