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The impact of Big Data on Smart City concepts

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Abstract. The main aim of the paper is to analyse the possibilities of using big data as a part of a smart city and indicate what challenges cities face during big data analytics implementation. The author divided this paper into three, main sections. In the first part, the author has described a concept of smart city, explaining why this concept has become so important and popular in recent years. In the second part of the article, the author has presented the concept of big data, giving the definition, the most important characteristics and general examples allowing a better understanding of this field. Finally, in a key part of the paper, these two concepts have been combined together to indicate fields they should complement each other to positively influence the cities' development and achieving its goals. In the last part of the article, the author gave examples of benefits that cities can see in the implementation of the big data analysis, as well as examples of big data projects combined with the cities in which they have been implemented. Results of a paper show that nowadays, the implementation of big data technology may have a positive impact on smart city development.

Key words: smart city, smart technology, big data, ICT, knowledge management, artificial intelligence

1 Introduction

Cities generate huge amounts of raw data every day. Data are produced by people, applications, systems and much more. The correct collection and use of this data can be extremely beneficial to cities. At the same time for several years we have seen higher interest of the concept of smart cities. We hear and read about cities that are even surpassing themselves in being smarter, doing so on the one hand to benefit and make amenities for their citizens and on the other hand to tackle the growing problems of urbanisation, climate change and so on. The author of this paper decided to bring together two concepts: big data and smart city, and to present what a combination of them can result. The main aim of this paper is to present the potential benefits of using big data in modern cities, as well as to indicate what challenges cities face trying to implement solutions related to big data applications. In the first part of this paper, the author focused on the concept of smart city, explaining its definitions and describing the components, in order to present how many data sources are in modern cities. In the following chapter, the author describes the concept of big data explaining how to effectively use the collected data and giving important

characteristics. In the last part of the paper, the author focuses on both concepts, showing the benefits of their combination and examples of solutions already functioning today. The last part of a paper is about results of using big data solutions in smart cities.

2 Smart City Characteristics

Cities are an increasingly important element of civilization. According to the statistics of United Nations (UN), by 2050, around 68% of the world's population will be living in urban areas. The gradual shift in residence of the human population to urban areas, combined with the growth of the world's population could add about 2.5 billion people to urban areas by 2050. [1] The current number of city dwellers, especially in the largest cities, as well as a perspective of the continued growth of this population, makes the recourses of the cities limited. City government faces new, previously unknown challenges. The problems of the cities can be divided into the following categories: social, economic and organisational. Examples of these problems include communication and transport problems, environmental pollution and ecology or adaptation urban space to modern needs of city dwellers. [2] In literature, urban development concept based on modern technologies and innovative way of managing the city is named smart city. In research and scientific sources, there is not any single appropriate definition of this term as so it can be interpreted in many ways. One of the definitions is that “a smart city is (...) a city which invests in ICT enhanced governance enhanced governance and participatory processes to define appropriate public service and transportation investments that can ensure sustainable socio- economic development, enhanced quality-of-life, and intelligent management of natural resources” [3], however by another definition smart city is “a 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.” [4] It is necessary to consider what characteristics a city must have in order to be called a smart city. The table below shows the components of smart city along with their description.

Tab.1. Components of smart city.

Components	Description
Smart Economy	Means using Information and Communication Technologies (ICT) for business. A smart economy can also mean better flow of information and knowledge, as well as goods and services.
Smart Mobility	Means innovative transport and logistics systems, using ICT to enable the safe and

	<p>efficient movement of people and goods.</p> <p>They can also be used to collect data on the current transport situation and its subsequent use, e.g. for a traffic management.</p>
Smart Environment	<p>Means solutions for controlling emissions and energy consumption.</p> <p>In this area, Information and Communication Technologies can be used for street and building lighting or waste management.</p>
Smart People	<p>Means an appropriate level of education. Smart people are city dwellers who use various intelligent solutions in their everyday activities, both in their private and professional lives.</p>
Smart Living	<p>This component is similar to smart people. Smart living means that smart city dwellers use modern technologies every day. Smart living refers, among other things, to concepts such as smart homes and smart workplaces.</p>
Smart Governance	<p>Means intelligent management of public administration, i.e. integrated management of all subsystems of a city. City dwellers, public benefit organizations and private companies should also participate in the management of these systems.</p>

Table 1. does not indicate all areas of city management that are components of smart cities. In order to better understand the topic of smart cities, three groups of factors that make up a smart city can be identified [5]:

- Technology factors,
- Institutional factors,
- Human factors.

The first of them, technology factors, are digital solutions that improve the functioning of the city's subsystems. The next of them, institutional factors, concern activities carried out by city administrations and politicians. This factor includes all legal acts, regulations, and institutions, whose task is to support the development of smart cities. Third, human factor, includes an educated society that is willing to use new technologies and responsive to changes.

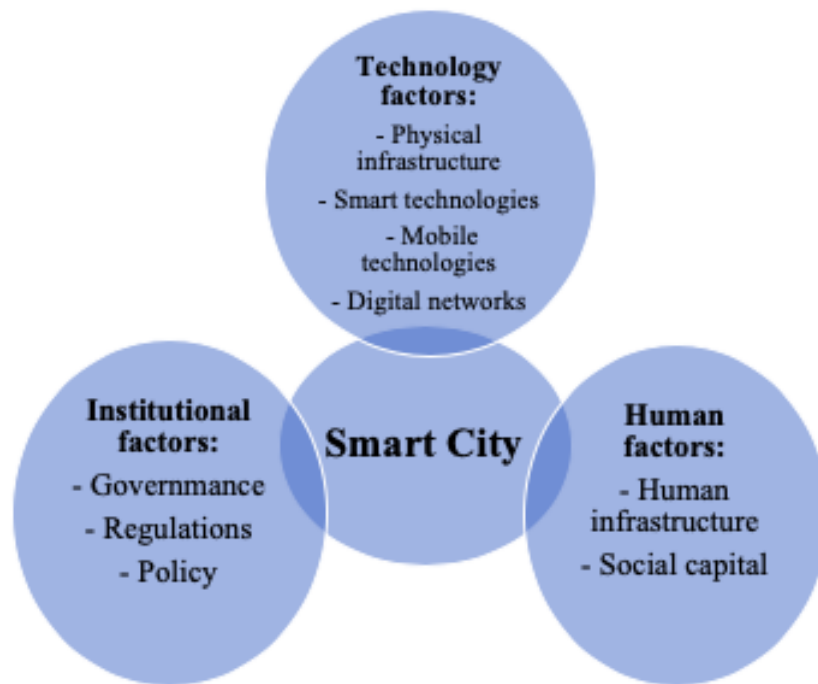


Fig.1 Factors of smart city.

An essential element of smart city is knowledge. However, before we can gain access to knowledge, we need to analyze the sources of data that allow us to obtain it. Examples of such sources include: [6]

- data from public registers: population register, real estate register, business activity register etc.
- local development plans,
- database of topographical objects,
- data from waste management systems, paid parking zones, cultural institutions,
- data collected by various sensors and sensors monitoring infrastructure and the urban environment, e.g. in the field of energy: air and water quality, traffic volume,
- crowdsourcing - data obtained directly from residents and communities,

- data made available by city dwellers using social media applications e.g. applications for monitoring physical activity,
- aerial and satellite images,
- financial data, including local taxes and charges
- data collected by companies for their operations, which can be used by cities, e.g. data from mobile operators.

3 Big Data Assumptions

Today and every day, people collect, analyze and store huge amount of data. From a historical perspective, big data is not something totally new. Data was already stored in data warehouses in the 1990s, but they were not as extensive as they are now. So what does big data mean nowadays? Watson characterize big data as having:

- High volume – the amount or quantity of data,
- High velocity – the rate at which data is created,
- High variety – the different types of data. [7]

In the extended version of this definition, Watson explains that “Big data is a term that is used to describe data that is high volume, high velocity, and/or high variety; requires new technologies and techniques to capture, store, and analyze it; and is used to enhance decision making, provide insight and discovery, and support and optimize processes”.

- Big data is characterized by the following methods of information analysis:
- possibility of analyzing very large data sets,
 - ability to analyze disordered data,
 - the searching for relations between effects and causes.

The characteristics described above indicate that big data analyses differ from classical information analyzes. In big data analyses, any data set, even the smallest one, can be of great importance. With the use of big data technology, the decision-making process, based on bug data sets is supported, and many people, both from the world of science and business, see this potential, not only in the storage of information but, what is more important, in its analysis.

There are many sources of big data. Examples of data sources are shown in Figure 2.

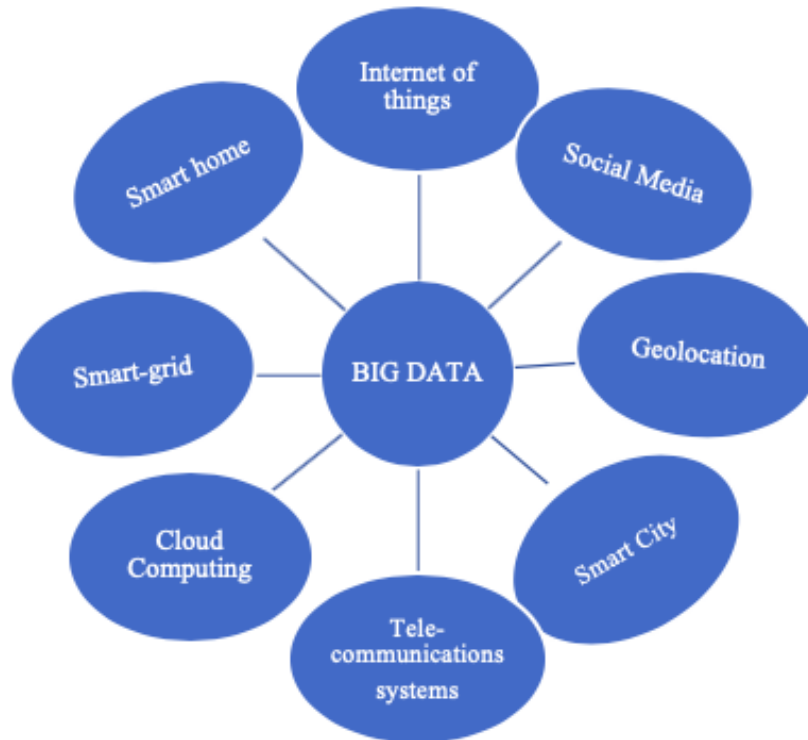


Fig.2. Examples of data sources.

The process of building useful data using big data analyzes can be divided into the following parts [8]:

- Data creation,
- Collecting data,
- Creating ideas,
- Processed data,
- Inference,
- Implementation,
- Utilization.

The first of these stages concerns the creation of data by various sources. They can be produced consciously or only accompany specific phenomena. The next stage, that is data collection, may take place in various ways. Information may be collected voluntarily or compulsorily, some of them spontaneously, and others according to a specific key. The next stage is creating the idea. Based on it, a data analysis algorithm will be created from a specific source. Its result is a data processing step, the aim of which is to develop a model of a given phenomenon. Inference is the stage of

extracting knowledge from the information collected, and the transfer of this knowledge to real use is an implementation that consists in creating a system based on previously acquired knowledge. In the end, there is a utilization, which is based on the current use of the implemented system.

4 Big Data in a context of smart city

Mining for knowledge from big data is challenging. There are many challenges related to the design, development and implementation of big data applications for smart city. Below are some of them [9]:

- As shown in the first part of the article, data comes from many different sources. In order to use them properly, they should be structured using advanced database systems. When considering the implementation of urban applications that will use big data, it is important to keep in mind the many problems that may be associated with this and relate to both data collection and its future organisation.
- city dwellers should be aware of how to use smart urban solutions. Their active participation may contribute to the improvement of the quality of collected data, which will positively influence the improvement of the functioning and selection of appropriate directions of the city development.
- security and privacy issues. Databases can collect confidential and private information that should not be processed or require a high level of security. Examples of such data are medical records, bank records, etc. The borderline between what data can and should not be collected is sometimes very thin. It may also prove difficult to ensure adequate anonymity. Many individuals and organisations believe that such data should not be transferred or used under any circumstances. Although the use of big data can bring many positive benefits to cities, the effects of inadequate protection of the information collected can be irreversible and disastrous.

These challenges have different impacts on the performance of smart city applications and create different levels of difficulty. Moreover, different applications have different requirements for data usage.

Data, generated from multiple sources, can be catalogued and stored in different locations, owned by different actors. There are many opportunities to use big data to solve problems, through data analysis, data intelligence and data mining. To facilitate this huge demand for resources to support big data analysis, the Cloud was used. The Cloud is a suitable platform for applications with a high demand for resources, enabling active cooperation between different applications. Through the use of cloud computing, cities have gained access to a huge amount of computing power.

„Currently, many cities compete to be smart cities in hopes of reaping some of their benefits economically, environmentally and socially”. Examples of benefits of transforming a city into a smart city include:

- Efficient resource utilization: at a time when resources are shrinking at a very rapid rate, it is essential to know how to allocate available resources so that their consumption is as low as possible. “In addition, one of the important aspects of smart city applications is that they are designed for interconnectivity and data collections which can also facilitate better collaboration across applications and services.”
- better quality of life: primarily the result of better urban areas planning, more efficient and city dwellers-friendly transport systems and better and faster services.
- better access to information: this benefit makes access to information easier for all city-dwellers and the share of knowledge will become obvious.

These and other benefits can only be achieved if cities invest in more technology and the successful use of big data analysis. Innovation technology can be very useful when considering city resource management and decision making.

Implementation of big data application in smart cities requires a lot of support from information and communication technology (ICT). This technology provides ways to solve many of the problems that smart cities face. There are many examples indicating that the role of big data in smart city is very important. Some of them are indicated below:

- Smart education: analysis of big data has an impact on education, increasing the efficiency and productivity of education processes using smart education services. Smart education applications can engage people in an active learning environment. By analyzing big data education institutions can control whether they are using their resources properly.
- Smart grid [10]: electricity delivery system, which effectively responds to the behavior of all connected entities (generator, customer/prosumer, network operator), integrated with information and communication technology, enhanced grid operations, customer services, and environmental benefits. Smart grid continuously controls what happens at different stages of the energy flow, allowing the possibility of controlling this process.
- Smart healthcare [11]: the application of big data analytics in healthcare has a lot of positive outcomes. Big data refers to huge amounts of information that are consolidated and analyzed by specific technologies. When used in healthcare, they will use specific data on the health status of a population or individual and help to treat diseases, reduce costs or prevent epidemics.

According to the Smart City Maturity Model proposed by IDC Government Insights [12], we can identify five stages of a smart city maturity: Ad hoc, Opportunistic, Repeatable, Managed, Optimized. In the context of the use of data generated in the city, this classification may be as follows:

- Ad hoc stage: In cities at the lowest level, data use and integration are limited. Data is used primarily to provide a specific service. There may be issues related to data integrity quality, security and privacy

- **Opportunistic stage:** At this level we can see the first attempts at advanced data analysis, there are single applications for this analysis. The data may be published for use by other entities.
- **Repeatable stage:** On the third level, cities consciously use data. They invest in advanced data management, data collection, analysis and big data applications. A wide range of open data is published with the strategic intention to use it to stimulate innovation. City dwellers create and share data in key areas.
- **Managed stage:** The next level is a fully managed system. Cities use extended data collection and analysis that leads to better decision making and service design. City dwellers are aware of the benefits of data analysis and are willing to engage in new initiatives.
- **Optimized stage:** The most developed cities in the world are on the last level. Many big data applications are created. They use data analytics to dynamically, automatically predict and preventively improve their services. It is possible to react in real time.

In this section, some of the example use cases of big-data analytics in a smart-city context are presented. These examples can serve as inspiration for creating solutions using big data analysis to improve the quality of life of big city dwellers. As we can see below big data analyzes are helping cities around the world:

Tab. 2. Big data projects in smart cities.

Smart City Component	Big Data Projects	Location
Smart Transport	The city of Nanjing, China, has installed sensors in taxis, buses and one million private cars. The data is transmitted daily to the Nanjing Information Center, where experts are able to analyze traffic data and traffic locations and peak times to then send updates to commuters on their smartphones. With this information, government officials have created new traffic routes by avoiding traffic jams and suggesting the best routes at the moment without spending money on new roads. [13]	Nanjing, China
Smart Transport, Smart Living	The main Italian railway operator has installed sensors in all its trains and now receives real-time updates of the mechanical condition of each train and forecasts for future repairs and maintenance. This data makes it possible to plan actions before trains fail, which would cause many problems for travelers. These technological innovations provide passengers with a reliable system and services, while avoiding major disruptions to cities.	Italy

Smart Living, Smart People	Wroclaw, Poland has introduced a system in which city dwellers can submit their ideas for using the city budget. The administrators of this system collect all the submitted ideas, both those implemented and those rejected, creating a database of the greatest needs of the residents. Based on these data, projects and improvements are implemented in the city, as well as repair works. The ideas gathered in the system concern education, infrastructure, culture and many others.	Wroclaw, Poland (and many others polish cities)
Smart Living, Smart Mobility	The project created by several universities combined data from mobile phone networks, traffic monitoring systems and vehicle tracking systems. In addition to providing information on the situation on the roads and traffic, it allows to plan the city's infrastructure by analysing the collected data. The application is also used for mass events.	Czech Republic
Smart Transport, Smart Mobility	In Amsterdam, almost all car parks are managed digitally using an application. Anyone who wants to book a parking space enters their vehicle registration number. The digital platform connected to the application recognizes	Amsterdam, Rotterdam, The Netherlands

	<p>the vehicle.</p> <p>In Rotterdam, sensors are installed to guide the drivers to free spaces.</p>	
Smart Environment	<p>Los Angeles is replacing traditional streetlights with the new LEDs. The new lights will be an interconnected system that will inform the city administration of each bulb's status. If one malfunctions, it can be identified and fixed immediately.</p>	Los Angeles, United States

In conclusion, it would be appropriate to reconsider the issues that should be addressed in future studies. Many of them are the result of the previously presented examples of using big data in smart city. The most important are data security, privacy and information protection. Another important issue is also the growing need for highly educated people who will be able to design and operate intelligent platforms and applications operating from the city. Another need is to establish common rules for the control of intelligent solutions in the city. In a smart city it is required to monitor and control initiatives and implementations using various tools and techniques to ensure the correctness, effectiveness and quality of the implemented applications. All these needs should be taken into account when analyzing the use of big data in smart city.

Conclusion

The article presents a role of big data in smart cities. Both smart city and big data are two modern and increasingly popular concepts in recent years. The article presents the potential of using big data in smart city development. Combining these two concepts and building intelligent urban applications can positively affect the achievement of a better quality of life for residents and intelligent management of urban resources. Progress in the field of big data has enabled cities to access information that has never been available before, and a well-developed strategy for data analysis gives cities the opportunity to access extremely important knowledge and easily gain significant, practical insights. When a city can monitor desired indicators in real time, the level of its innovation can quickly increase. Big data offers endless possibilities to make better decisions. Building and implementing smart cities based on big data will require challenges and open issues, the use of professional design and development models, well-trained human resources, and being prepared

and well supported by management units. With all success factors and a better understanding of the concept, making a smart city will be possible, and a further improvement in smarter solutions will be realizable. The ability to collect and use city data is what makes city smart.

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