BIG DATA AND DEVELOPMENT OF SMART CITY

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Abstract:
Phenomenon of Smart City had its around-twenty-year development path influenced by changes in technological, social and business environment. Big Data, together with Internet of Things and Cloud Computing, has tremendous and profound impact on the changes of Smart City, transforming its shape and achievable goals and redefining its requirements and challenges. The aim of this paper is to study the aspects of Big Data within the Smart City concept. We analyze the past and present Smart City pilot projects, giving special attention to the evolution of its traditional applications (traffic, healthcare, power grid, water & waste treatment and public safety) in the context of present technological maturity. We also describe feasible Smart City applications based on Big Data, followed by summary of benefits and main challenges, especially the growing ones, such as security of infrastructure or security of private data. The final result of the study is comprehensive two-dimensional chart (technological maturity of environment vs. stage of adoption of Smart City) with identification of typical development states. The chart may help city planners selecting or creating optimized development plans of their communities.

Keywords:
Smart City, Big Data, Timeline.

1. INTRODUCTION

Broad definition of Smart City includes monitoring and integration of the critical infrastructure, optimization of resources, planning of maintenance activities, monitoring of security while maximizing services to the citizens [1]. The critical infrastructure may involve physical infrastructure (roads, bridges, tunnels, rails, subways, airports, seaports, water, power), IT infrastructure (telecom networks, data centres, access points, terminal devices, available IT services), social infrastructure (schools, hospitals, theatres, media, social clubs, social networks) and business infrastructure (companies, campuses, clusters) [2].

Physical and IT infrastructure is having dominant stake in Smart City agenda from its early age, while social and business infrastructure gain more attention in the recent years. Originating from more than 20 years ago, Smart City applications evolved from SCADA-like solutions to applications covering broad range of aspects of life.

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The four technological layers of Smart City architecture are: 1) sensing layer - sensors or terminal devices, 2) network layer - telecommunication medium and associated services, 3) Operation, Administration, Maintenance and Provisioning, and Security (OAM&P&S) layer - centralized processing or management platform[1] and 4) application layer [3]. All technological layers were subject to dynamic changes and transformation. One of the key drivers of this process is appearance of *Big Data*.

Big Data is a popular term used to describe the exponential growth, availability, and use of information, both structured and unstructured [4]. Smart sensor devices, the primary source of Big Data, became ever-present and affordable both for institutions and individuals. It is considered that 90% of world`s digitized data was captured (or generated) in the last two years. Per Intel and United Nations estimations, the number of connected smart devices will rise from respectful 6 billion in 2006 to astonishing 200 billion in 2020, which will be 26 devices per each human being on Earth [5].

Some characteristics of Big Data are referenced to as the Vs of Big Data management. These include the main 3 Vs (1, 2 and 3) and two additional Vs: 1) Volume: amount of data that has been created from all the sources; 2) Velocity: speed at which data is generated, stored, analyzed and processed, with emphasis on supporting real time Big Data analysis; 3) Variety: various types of data being generated – structured or unstructured; 4) Variability: constant changes of data structure and 5) Value: possible advantage that Big Data can offer to businesses [6].

Big Data, together with Cloud Computing and Internet of Things (IoT), are seen as pillars of future Smart Cities.

2. TIMELINE

Historically, the toddler age of Smart City may be considered in late 80`s with innovations in centralized management over power generation, water processing, first steps in video monitoring and real-time data exchange over those-days telecommunication networks. The earlier appearance of ATMs (in the 70`s) cannot really be related to Smart City phenomenon, although its technical aspects correlate to the essence of Smart City. Situation with traffic lights introduction in the same era is somewhat different: they fit the frame of Smart City applications, but technically they were not really integrated and interconnected.

1 decentralized model is subject of recent research

Development of Smart City was further driven in the 90`s by the progress in available computing power, introduction of web services and roll out of mobile radio networks. Although sensors were still not ``plug-and-play`` and telecom networks were still typically narrowband, it becomes clear that it is possible to connect and integrate remote devices with central processing platform in almost any place and in any time. Smart City starts to grow as feasible and sustainable concept.

Late 2000`s see broadband mobility, initial steps of cloud computing and ever-present and ever-affordable sensors in smart devices. Data centres become critical public and private infrastructure. People and devices get fully connected. Wide population start to benefit from its smart environment and smart applications become everyone`s need.

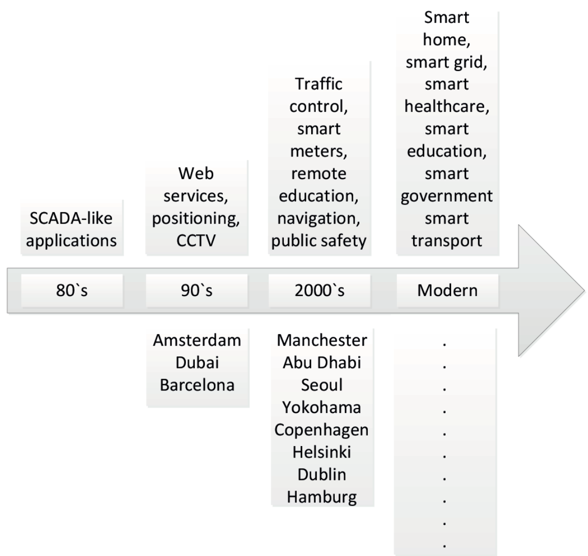

Fig. 1. Smart City Evolution Timeline

As shown in Fig. 1, today almost all cities claim to be more or less smart *with an underlying self-congratulatory tendency, obviously with regard to a different level of technological embeddedness or due to the existing intelligent capacity that a city holds* [7].

The proliferation of digital data usually referred to as Big Data, and flood of processing improvements based on artificial intelligence dictate the ambitious plans and futuristic vision of Smart City. Applications with Big Data analytics in various domains of Smart City enable data storage for large amounts of data and processing of such data for building advanced Smart City services. Big Data platforms, usually hosted on clouds, may perform parallel processing and analysis of such large volume of data. The results of this process are beyond results of traditional applications in terms of very existence, response speed and certainty. All mentioned illustrate how Big Data and accompanying phenomena has tremendous and profound impact on the changes of Smart City, transforming its shape and achievable goals and redefining its requirements and challenges.

Some historical aspects of the evolution of technological layers of Smart Cities are shown in Table I.

Table 1. Evolution of Smart City technological layers

	Centralized platform	*Telecommunication medium*	*Smart devices*	*Application*
80`s	Mainframes, dedicated SW	Narrowband, restricted for public use	Expensive sensors, restricted for public use	SCADA, industry
90`s	Server farms, first public interfaces	More bandwidth, access available	More affordable, market driven	Web services, positioning, CCTV
2000`s	Data centres, more processing power	Fixed broadband, mobile	Very affordable, ``plug-and-play`` type	Traffic control, smart meters, remote education, navigation, public safety
Modern	Cloud computing, artificial intelligence, Big Data, IoT, ideas about decentralization	Fixed and mobile broadband	Smart and autonomous, ever-present	Smart: home, grid, health, education, government, transport, neighborhoods…

3. SMART CITY APPLICATIONS AND CHALLENGES

We will analyse the traditional Smart City applications: traffic management, healthcare, power grid, water & waste management and public safety.

Traffic Management

Traffic Management is one of the first Smart City applications which set foot on ground. Traffic flow, congestion detection, parking availability, real time traffic monitoring, accident prevention and accident response were early seen as sustainable objectives of Smart City. Potential of return-of-investment in traffic applications sparked long ago the interest of city governments, decision makers and solution providers.

The applications are ranging from simple traffic lights control and CCTV to intelligent traffic routing, assisted parking, integrated multi-modal transport and smart video analytics. Challenges related to traffic management are numerous – they are mostly driven by the trend of increase of number of vehicles in urban environment. Enabling traffic flow even in peak hours, keeping traffic participants safe during heavy traffic periods, fitting the stringent and developing ecological demands without compromising traffic efficiency are present challenges that every city in the world has to deal with. Furthermore, traffic management includes interaction with citizens – therefore those applications need to be tailored with human nature taken in to account.

Appearance of smart self-driven cars will have profound impact on the form of traffic in urban environment, partly solving some of the existing problems (traffic security, traffic control), while creating some others (cyber security in traffic, readiness of traditional infrastructure and processes).

Examples:[2]

Zaragoza traffic monitoring system (Spain) [8],

Dublin Road Congestion System (Ireland) [8],

Eindhoven Traffic Flow System (the Netherlands) [8],

Enschede Vehicle Inductive Profile (the Netherlands) [8],

Thessaloniki Mobility Project (Greece) [8],

Toulouse Social Media Analytics (France) [9],

Singapore CityMIND Platform (Singapore) [9],

LA Merge Platform (Los Angeles, USA) [9],

Zhejiang City (China) [9].

Healthcare

Healthcare is the area where Smart City is yet to prove its potential. Medical call centres and networked medical institutions with unified patient records were seen in the past decade. More efficient work of field emergency medical teams is consequence of usage of

2 some cities – Dubai, Tianjin, Brisbane, Amsterdam, Barcelona correspond to almost all applications, so they are not usually mentioned

Geographic Information Systems (GIS) and navigation services, supported with availability of mobile broadband telecommunication. Smart health and telecare services offer remote telematic support to citizens, typically elderly people. However, jump to the foreseen healthcare application is yet to be seen.

Deployment of home-based diagnostics solutions, artificial intelligence based diagnostics, robot assisted surgeries is ahead. However, human-related aspect of healthcare may cause significant delays in deployment of those solutions.

Challenges of smart healthcare are related to: 1) availability to all citizens – the issue of finances, social justification, government type; 2) responsibility for the results of treatment shared between medical staff and Smart City services and infrastructure and 3) education of medical staff and citizens to deploy and use futuristic healthcare services.

Examples:
Amsterdam Health Lab (the Netherlands) [8],
Forum Virium Helsinki (Finland) [8].

Power Grid

Smart power Grid applications attract lot of attention as all stakeholders benefit from their deployment: electricity companies optimize their operation and attain more control over the system; citizens get better and cheaper energy with opportunity to actively tailor and control their consumer profiles; society in general get cost-efficient and reliable infrastructure; environmentalist achieve higher ecological standards etc. Hence power grid may develop itself within or without Smart City initiatives. Also smart power grid may easily be deployed in the area larger than the city - regional level, for example.

Smart power grid application may range from smart metering and smart lighting to smart energy management.

Typical challenge of the smart power grid is handling the unprecedented quantity of data in real time. Every successful smart power grid project is actually also the successful Big Data case.

Examples:
Ontario Smart Metering (Canada) [9],
Power matching city (Denmark) [9],
GRID4EU (Reken -Germany, Uppsala -Sweden, Castellon -Spain, Forli Cezena -Italy, Virchlabi -Czech Republic, Carros -France) [9],
Smart electric Lyon (France) [9],
Korea Electric Power Corp (Korea) [9],
Pacific Northwest Smart Grid (USA) [9],
Smart Meter by Tata, Delhi (India) [9],
Barcelona Smart Grid (Spain) [8],
Smart Power Hamburg (Germany) [8],
Copenhagen wind power and Smart grid system (Denmark) [8],
Mannheim E Energy (Germany) [8],
Gothenburg managed Celsius project (Germany) [8].

Water & Waste Management

Water & Waste Management attract lot of attention as well, but the attention comes mostly from city governments, responsible for the reliable services and from environmental organizations, interested in ecological aspects of using water resources and management of waste.

Challenges in this field are mostly related to the pace of growth of cities` population and the pace of growth of waste generated per capita.

Examples:
Dongtan (South Korea) [9],
Tianjin (China) [9],
Cape Town (South Africa) [9],
Copenhagen waste water management (Denmark) [8],
Aarhus City Water Balance (Denmark) [8].

Public Safety

Public Safety due to its nature and *raison d’être* is one of the first spheres to use the technological benefits within Smart City framework. Urban areas are most common target of terrorist attacks or attempts of attacks. Prevention of security incidents or enabling first responders to better handle problematic situations by using modern communication methods and databases is fitting nicely into Smart City agenda. Video surveillance is ever-present system in all the cities of the world; however those systems became only recently upgradeable to use smart video analytics and processing in real time. Empowering citizens to report security problems in real-time (with photo/video sharing), controlling potential spread of diseases or enhancing food security are some of the additional applications related to the public safety aspects of Smart City. Smart City seen through the eyes of public safety professionals becomes Safe City.

Some studies showed that security technology is seen as the most important and essential part of Smart City technology roadmap [10].

Challenges of public safety applications are typically handling of massive amount of data and keeping citizen privacy. Sensitivity of those challenges is defining a bit different ambience for deployment of public safety applications.

4. BIG DATA BENEFITS AND CHALLENGES WITHIN SMART CITY FRAMEWORK

Data mass in Smart City arena will grow rapidly (exponentially) in all areas, from personal and municipal level to global. The data will come from plethora of devices and sources available in the market and it will have various forms: structured, semi-structured and unstructured. We may witness the shift from the realm of traditional desktop computing to an increasingly sophisticated computing [11]. It is already utterly important to understand data sets and organize them carefully.

Benefits of Big Data

Foreseen quantity of sensor or smart devices in all Smart City applications drives the necessity of aligning with Big Data principles. Congestion management systems will not be able to operate through conditions of unprecedented sizes of cities, where dozens of millions of people live, work and commute, without using Big Data for analytics. Europe with its 240 million smart meters in 2020 will be an excellent example of networked and optimized Smart Grid which everybody will benefit from, but only in case it will be capable of digesting the Big Data created. Face recognition and tracking of the suspects via urban video surveillance is the dream of the public safety professionals – the dream that can only became reality if the challenges of Big Data are handled.

Big Data is offering and bringing immense advances to applications of urban life. Actually, it is *conditio sine qua non* for Smart City of the future.

Big Data Challenges

Big data will enable new data-driven services to upgrade processes and enable innovation of products and business models. In the era of advanced digitization of the society, the potential benefits and challenges associated with big data are important topics for decision-makers [12].

Challenges related to Big Data may be grouped in the following way, as given in [13]:

1. Data sources and characteristics – related to the format of data; to be tackled by technological improvements.
2. Data and information sharing – related to the ``ownership`` of data and protocols of sharing; to be tackled by hierarchical organization of sharing with strict rules and procedures.
3. Data quality – related to the heterogeneity of data and its subsequent (un)certainty; to be tackled by technological improvements.
4. Cost – related to whether the citizens should pay for deployment of advanced application based on Big Data or not;
5. Smart City population – related to growth of population and growth of generated data per capita; to be tackled by technological improvements.
6. Security and Privacy – related to security policies and mechanisms to protect the data against unauthorized use and malicious attacks. There is a great amount of danger which originates from the process of digitization and exchange of data, especially in the Big Data environment. Small scale and large scale cyber-attacks are becoming reality and the potential resulting damage is rapidly growing. Even well-planned Big Data applications, such as Cassandra and Hadoop suffer from a lack of cyber security mechanisms. The way to tackle this issue is: 1) establishing and following strict security procedures and 2) establishing and operating cyber emergency response teams (CERTs).

5. DEVELOPMENT OF SMART CITY VS MATURITY OF ENVIRONMENT

Anthopoulos and Fitsilis in [14][15] did an analysis of the types of Smart City services and came out with nine smart service groups (SG):

- SG1: e-Government services
- SG2: e-democracy services
- SG3: smart business services
- SG4: smart health and tele-care services
- SG5: smart security services
- SG6: smart environmental services
- SG7: intelligent transportation
- SG8: typical telecommunication services

- SG9: smart education services.

They observed when a shift from a service group to another happened, which drives a shift to a different smart city class. Technology roadmapping for these smart service groups shows that the smart city evolution did not pass through all classes, neither cities have evolved from all classes to all the others. The authors Anthopoulos and Fitsilis tried to explain the results with a theory that a *smart city evolves in order to sustain against radical changes, coming both from internal (e.g., service demand, political willing etc.) and external sources (e.g., city competition, climate change etc.)* [14].

On the other hand, Park, del Pobil and Kwon studied Smart City technology roadmapping related to IoT [10]. They analyzed and classified Smart City applications based on importance and essentiality. One of their conclusions was that the sustainable urban environment may be feasible only with a data-oriented smart city infrastructure in place.

In this paper we have analyzed Smart City development over different axis compared to Anthopoulos and Fitsilis, with simplified states in order to achieve a clearer picture. We were not addressing importance and essentiality.

The horizontal axis is the timeline represented by five quasi-historical stages related to Smart City: 1) *no* (corresponding to rare cities with almost no smart applications), 2) *early* (cities with smart city application in its early stage, such as those from 80`s and 90`s), 3) *developing* (cities with developing smart city infrastructure, such as those from late 2000`s), 4) *mature* (modern cities, disposing several Smart City applications) and 5) *future* (a few cities with futuristic state of Smart City).

The vertical axis is the technological maturity of environment, represented by three simple states: 1) *low*, 2) *medium* and 3) *high*. The technological maturity of environment can be defined in many ways – here for the cause of simplicity the following criteria has been adopted: *low* means that the power supply system within urban area is not of high quality (variation of voltage, frequency) or not of high availability (not rare power cuts); *medium* means that broadband connectivity (4G, fiber optics) is not available in every corner of the urban area; *high* means that power supply is very stable, 4G and fiber optics is available everywhere within the city limits. The last criterion may be considered a precondition for Big Data applications.

Initial chart layout, with all theoretically possible system states, is shown in Fig.2.

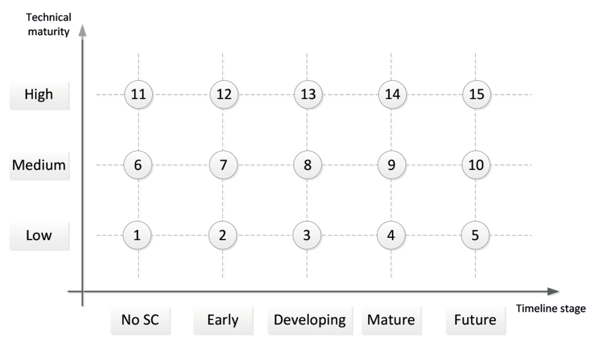

Fig. 2. Initial chart layout

Considering Timeline stages and Technical maturity, it is obvious that only system states 14 and 15 may have conditions for real Big Data applications.

Chart optimization is performed by eliminating system states 4, 5, 6, 10, 11 and 12. States 4, 5 and 10 are not technically possible, while states 6, 11 and 12 are considered rare exemptions, if existing at all.

The remaining states and possible (feasible, sustainable) state shifts are shown in Fig. 3. Horizontal shifts indicate efforts of Smart City planners to improve or broaden Smart City services. Vertical shifts indicate efforts of the whole society to improve overall technical environment in the city (simplified herein to telecommunication environment). Finally, diagonal shifts indicate ambitious efforts of all relevant institutions to enhance both general conditions and Smart City status.

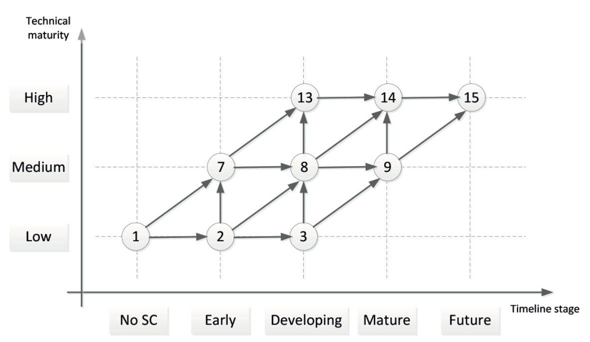

Fig. 3. Optimized chart layout with possible state shifts

The optimized chart may be used to detect a city`s status and indicate realistic perspective, thus assisting the Smart City development planning.

Example of Belgrade

City of Belgrade has very turbulent past, including the recent period. Certain city aspects (geographical and operational) are underdeveloped, while some others (public safety, culture) are in a relatively good shape.

Deployment of Smart City applications may help with bridging the problems the city has. Since Belgrade has already got some Smart City applications in place (e.g. traffic control, public safety, e-government apps), the current Smart City state may be tagged *Developing* on the horizontal axis. On the other hand, having the stable power grid and not having broadband connectivity everywhere, it may be tagged *Medium* on the vertical axis, taking state 8 as its current point.

Shifts to states 9, 13 and 14 are possible depending on the following considerations:

1. If it is considered that the overall technical environment will not progress (due to lack of initiatives or due to economical limitations or for some other reason), the planners may pursue shift to state 9. The shift might be done with initiatives on the Belgrade City level that could introduce realm of field-proven Smart City applications.
2. If it is considered that the Smart City state in Belgrade will not progress (due to lack of support or due to economical limitations), the planners may follow the shift to state 13. The shift might be done with initiatives on the country level only (Serbian Government). In this simplified model, those initiatives would be related to improvement of telecommunication infrastructure and services.
3. If it is considered that both the overall technical environment and Smart City state may progress simultaneously, the planners may pursue shift to state 14. The shift might be done only with initiatives on both Belgrade City and country level (Serbian Government). The shift would bring Belgrade to Big Data age.

6. CONCLUSIONS

The aim of this paper was to study the aspects of impact of Big Data on the Smart City concept. We presented the past and present Smart City projects, especially their traditional applications (traffic, healthcare, power grid, water & waste treatment and public safety). We described main challenges of traditional and advanced Smart City applications, especially the growing ones, such as data sharing or security of private data. The final result of the study is comprehensive two-dimensional chart (technological maturity of environment vs. stage of adoption of Smart City) with identification of typical development states and potential shifts. The chart may be used by the city or government planners to select or create optimized development plans of their communities.

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