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High-level model for the design of KPIs for Smart Cities systems

Cezary Orłowski[1], Tomasz Sitek[1], Artur Ziółkowski[1], Paweł Kapłański[1], Aleksander Orłowski[1], Witold Pokrzywnicki[1]

[1] Gdańsk University of Technology, Department of Management and Economics, ul. Narutowicza 11/12, Gdansk, Poland

Abstract

The main goal of the paper is to build a high-level model for the design of KPIs. Currently, the development and processes of cities have been checked by KPI indicators. The authors realized that there is a limited usability of KPIs for both the users and IT specialists who are preparing them. Another observation was that the process of the implementation of Smart Cities systems is very complicated. Due to this the concept of a trigger for organizational-technological changes in the design and implementation of Smart Cities was proposed. A dedicated Model for City Development (MCD) was presented. The paper consists of four main parts. First the structures of both city and business organizations were presented. Based on that, in the second part, the processes existing in cities and business organizations were presented to show how different they are. The third part presents the role of KPIs and their limitations with the example of the IOC. The last part consists of the presentation of the model and its verification based on two city decision-making examples. The proposed design model presented herein takes into account both the city indicators and their aggregate versions for the needs of city models.

Keywords: smart cites, knowledge base, knowledge management, fuzzy logic, process modeling, decision support

1. Introduction

Currently, 54% of the people who live in the world live in city areas. According to the United Nations this is 3,5 billion people and is supposed to grow to 7 billion in 2045. [1]The process might be most visible especially in North America (84% of the population living in urban areas) and Europe (73%).

The data shows that managing city areas is, and is going to be, more important with the growing number of inhabitants and limited area in which the cities might and should (e.g. because of economic reasons) grow. It should be noted that it is not only a process of fast-growing cities, there are many examples (with the best-known: Detroit), where the number of inhabitants is rapidly dropping. In both cases pure managerial decisions have to be taken. There is a need to make managerial decisions but it is not obvious what kind of decisions are going to be taken because a city is a type of organization in which different attitudes to the same problem are seen. This might be illustrated by one of the typical problems: should a city build more highways in the city centers, which is very expensive for the city and devastates the surrounding areas plus increases congestion but is expected by local inhabitants and therefore has a strong political influence?

If there is a need to manage cities more effectively because of the growing number of inhabitants and there are no clear rules/values according to which decisions are taken it seems to be necessary to help cities in the process of effective management. How this can be done and what kind of limitations are observed will be presented in this paper.

2. A city and a business organization

A city and a business organization are two types of organization. An organization is a “formalized intentional structure of roles and positions.”[2] Although they are types of organization there are

several differences between them and in managing them because "Management applies to any kind of organization."[2] These aspects will be presented below.

A business organization (also known as an enterprise) is an entity formed for the purpose of carrying on commercial enterprise. Such an organization is based on systems of law governing contract and exchange, property rights, and incorporation. [3] Management was originally dedicated to business organizations starting from Henry Fayol and Fredric Winslow Taylor at the end of XIX centry. The main goal of a business organization is to generate surplus. While managing the enterprise the interest of owners/shareholders, employees and business partners should be taken into consideration.

The enterprise might offer products or services as the main result and both might be offered either to individuals (B2C) or business customers (B2B). Most current knowledge in management is concentrated on managing business organizations with dedicated models supporting that process, special indicators used for this and many scientific methodologies. Because this is so obvious it will not be presented in this paper.

A city is "an inhabited place of greater size, population, or importance than a town or village."[4] "Cities should be seen in terms of networks stretching in time and space." [5] There are many different attempts at the definition of a city. Here, one might present the idea of "The Ideal-Type City" by Max Weber or the IRN (Inter-Representation Network) Cities.

There are several other descriptions of a city, "The city is a network of networks, embedded in broader networks, and within it are the values flows between network participants."[6] A city can be presented as a social area but also a physically existing area, and it is often also described as a cultural area with socio-economic processes.

The process of analyzing a city from the managerial point of view has a long history. In 1970 the NYC-RAND Institute used urban statistics, modeling and computation developed for wartime and typical corporate management to determine resource allocation, especially for New York City's Fire Department[7]. After more than 40 years the question should be asked, will new technologies help manage cities in a better way? To answer that it seems to be necessary to present the procedures that should be supported by technologies in the current cities.

City management is normally seen from two perspectives: managing the city hall and managing the whole city. Managing the whole city consists of aspects such as city strategy creation, and the control, coordination and assessment of departments which are implementing the city's strategy and policy.

The result of city management is a city product which is different from a typical commercial product offered by enterprises. The main differences between these two types of products consist of:

- High complexity of the city product
- Limited market influence on the product
- Consumption of the product in one, defined, location
- Very complicated process of pricing parts of the product (social climate, image) which strongly influences how attractive the product is.[8]

It is important to mention that today's developed cities 'are social and technical complex systems characterized by historically unprecedented levels of diversity and temporal and functional integration." [7] There is a growing individual specialization and interdependence which makes large citie 'extremely diverse and crucially relies on fine temporal and spatial integration and on faster and more reliable information flows.' Because of that cities are the economic and cultural engines of all human societies."

3. Types of processes in a city vs processes in a company

As it was presented in previous paragraphs a city and a company while both being types of organization are defined differently. It also means that the processes which are used in both city management and managing a company are different. In this section the differences will be presented.

As a result of every process it is believed that the better it fulfills the process requirements the better the whole organization exists. However, when cities are discussed, an important statement should be referred to: "The world's most vibrant and attractive cities are not usually the same places where buses run impeccably on time. While improvements in infrastructure and urban services are

absolutely necessary for cities to function better, they are not the fundamental sources of social development or economic growth."[7]
Current cities, as described above, are unique examples of organizations. Besides the description, it seems to be important to present how cities work, how they are organized and what type of processes might be observed.

Typical cities in Poland are divided into departments. A department is "a distinct area, division, or branch of an organization over which a manager has authority for the performance of specified activities." While discussing business organizations there might be several types of departments presented (e.g. sales department, production department). Companies try to adapt departmentalization into their main type of business: it might be departmentalization by time (when shifts are in use), departmentalization by geography (when a company tries to adapt to several markets in dfferent geographic locations), customer departmentalization (when different types of customers seem important to be represented in organization structure) or several others. When taking cities into consideration they are typically divided by enterprise functions so there are departments representing functions of the city such as financial department, architecture and urbanistic department, social department, etc. Such departmentalization has several advantages presented in the theory of organization from which it is worth mentioning that it follows the principle of job specialization, simplifies training and seems to be logical and, because of this, easy to create that type of structure.

This type of departmentalization has also disadvantages, from which the most important is that people working in one department have problems with seeing the organization as a whole. It creates 'walls' between departments; employees mostly do not know what is done in other departments.

It is also important to mention wicked problems which are found in city management. The essential character of wicked problems is that they cannot be solved in practice by a central planner. This is based on two types of problems a) the knowledge problem b) the calculation problem."[7] Calculation can be easily done by today's computers but 'the *knowledge* problem refers to the information that a planner would need to map and understand the current state of the system; the city, in our case. While still implausible, it is not impossible to conceive information and communication technologies that would give a planner, sitting in a 'situation room', access to detailed information about every aspect of the infrastructure, services and social lives in a city. Privacy concerns aside, it is conceivable that the lives and physical infrastructure of a large city could be adequately sensed in several million places at fine temporal rates, producing large but potentially manageable rates of information flow by current technology standards' which will mean it is not a problem in city management.

It is also necessary to define when it is possible to conclude that a city is properly managed. In a business organization the results are normally presented in crisp values (such as a financial result at the end of the fiscal year, the growth/drop in the number of sold products, the growth of stock value). When the same question is posed for cities the answer is not clear. From the city mayor's perspective the main indicator of city management is the result of the election. But it cannot be concluded that the results are based only on crisp results of the city (such as city debt, level of infrastructure development, etc.). It is often based only on feelings or personal opinions which might be (and many times are) very different from real results.
Even if the assumption can be made that city managers will not follow political needs (to win the election) but will concentrate on the needs of the city, a similar question might be posed – what are the needs of the city? The needs are defined by different actors (inhabitants, investors, politicians, public organizations). One of the suggestions of how to answer that question is the idea of Smart Cities.

The Smart City notion is a concept that started to emerge approximately two decades ago and was originally used to describe a city that applied technological solutions to the everyday problems of the city and its inhabitants, through the intensive use of information and technologies.[9] This can be prested as a definition of smart cities but the question arises as to when the current existing city might be called a smart city. "…when investments in human and social capital, transport and ICT fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participative governance".[10] There are also more general definitions as the one from the European Smart Cities Model that states that a Smart City is a city that performs well in six areas: Economy, Mobility, Environment, People, Quality of Living and Governance.[11] So a Smart City is more than an intelligent city because it creates and uses feedback.

To answer the question of 'how to manage effectively' it is necessary to present the type of methodologies that might support decision making. It seems to be necessary to refer here to the concept of Smart Cities (presented above). These days the Smart Cities 2.0 concept is becoming popular as an idea in which departments are connected through digital strategies which helps to integrate and build bridges between the current 'silos' (represented as different departments).[12]
Because a city cannot be seen as the same type of organization as a company (business organization) it means that it should be managed also in a different way. As presented in previous paragraphs, it has different goals and because of this another logic of existence and the way is it managed. It also means that different tools for supporting management processes should be used. Even if the logic and goals are different and the whole process of managing the city is more complicated than in a typical business organization, it still has to be supported.

Examples of city management processes

As it was presented in the previous section, cities are divided into partly independent departments. This presents just the organizational structure which by itself should not impact directly on city management. It is important to present how different processes organized by each department influence the process of city management. Next, the examples ill be presented.

The process of investing money in the transport infrastructure influences several different areas such as the location of schools, land value, pollution and economic development. One of the major decision-making problems of this kind is the project of Podwale Przedmiejskie Street in Gdansk. Today, Podwale Przedmiejskie Street is seen as a major spatial barrier and a burden to its neighbours. It was built 40 years ago as a transit road through the historical city centre and consequently divided the city. As an effect, one side is still perceived as a high quality district, a popular tourist destination with all the famous landmarks, and functions as a city centre. The other side, however, is considered a dangerous, impoverished district even though it has a lot of valuable, historical urban tissue which - unlike most of the rest of the city - survived the 2nd World War. Because of this there is an idea to rebuild the street, narrow the whole street and build a pedestrian crossing. There are several sides interested in this topic: car owners are against it, city and non-profit organizations hope that it will 'bring back to life' a huge part of the city, and several other factors from different areas have to be taken into consideration (like air pollution, noise but also access to shops and services located in this area and the total cost of constructions). These areas cover the interest of several city departments and in the end the city, as a whole, has to make the decision. The key question is who is going to assess the influence on the different areas and how to calculate the final results from several areas.

Another case is the changes in the network and location of schools in the city. The changes are normally organised by the department of education and are mostly based on data such as demography in the neighbourhood, the market needs, the school facilities (gym, swimming pool). Based on this kind of data, decisions about closing, opening new or relocating schools are made. Several examples might be presented here but one of the most noticeable was a few years ago in one of the cities in Poland. There was a relocation of schools and slight changes in the school timetable made by the department of education. At the same time, the department of transportation noticed high changes in the transportation system of the city (congestion on some bus lines whereas others rapidly became empty) and traffic jams in new places and times. Special research was done and based on the results the department realised that there were changes in the school network made by other departments of the same city.

The examples described above present the main problem existing in the current process of city management – how to support decision-making processes in the whole city (where normally decisions are made at the level of departments).
To answer that question it is necessary to define the proper way of city development. It was defined in the first section of this paper. When it is known in what direction the city should go it is possible to think of how it might be done.

4. Key performance indicators and their significance for estimating cit processes in IOC

In the previous sections the problems of managing cities were presented. Based on the examples, current trends and main problems, it seems to be important from one side, but also complicated, to manage cities efficiently. Besides managing cities, it is important to find a technology that might support that process. The last great technological advancement that reshaped cities was the automobile (and the second in importance was the elevator). In both cases, these technologies reshaped the physical aspects of living in cities – how far a person could travel or how high a building could be. But it did not change the fundaments of the city because it was connected only with technology. Currently, when personal computers, mobile phones and the Internet are in use, there is the ability to influence also the social organization of cities and empower everyday citizens with the knowledge and tools to actively participate in the policy, planning and management of cities.[13] This is what the Smart Cities concept tries to use. Besides having just a concept there is a need to have tools that might be practically used by cities. An example of these tools, which is going to be presented next, is IBM's Intelligent Operations Center for Smarter Cities (IOC).

The IOC is able to receive, transform and use the data gathered from many different sources to support city management processes. It is a big system (big data) that consists of a lot of features and extensions.

The main element of the IOC are Key Performance Indicators (KPIs). A KPI "is a measurable value that demonstrates how effectively a company is achieving key business objectives. Organizations use KPIto evaluate their success at reaching targets."[14] KPIs include Data Source, Model and KPI itself. They help an organization define and measure progress towards organizational goals. Here the key question should appear: what is the main goal of the city?

Several answers might be given here:

- Build 2 new roads
- Reduce the unemployment rate in the city by x percent
- Build 3 new schools

This reflects the discussion presented in the first part of this paper in trying to answer the question of what a successful city looks like. Based on the current knowledge, it is a mix of socio-economic aspects. Here the second feature of KPIs should be presented: every KPI must be measurable. Several examples of KPIs used in business might be presented:

- A business may have as one of its Key Performance Indicators the percentage of its income that comes from return customers.
- A Customer Service Department may have it as a percentage of customer calls answered in the first minute.[15]

KPIs are mostly used in managing organizations but it seems to be important to check if they can be used for city management. In systems like the IOC hundreds of KPIs should be taken into consideration. In current cities the amount of collected data is significant. Based on this the KPIs are built and might be presented to the system operators. But still this concentrates only on measurable crisp values, which skips many socio-economic aspects very important for the city.

The authors prepared two types of models: a model which will help in organizing the KPIs in the IOC (by dividing the KPIs into categories) and a model of city management processes (MCMP) which will present another view on the problem analysis in the IOC.

5. High-level model for the design of kpis for smart cities

The starting point for the construction of a high-level model for the design of indicators (WMPW) was to assess the management processes of cities and organizations described in the previous section. It was assumed that this differentiation in the processes of a city and an organization shows a limited application and design of KPIs with a bottom-up approach. Also the integrated KPI models that are presented in a different submitted paper indicate that they can be designed in conditions in which while managing a team of designers one is aware of a high-level use of indicators. While the paper entitled "Designing aggregate KPIs as a method of implementing decision-making processes in the management of Smart Cities" discusses the design of aggregate indicators with a view to the aggregation of these indicators, this work discuss the need for the design of indicators with the model of city processes at its basis. The research presented in this paper also shows that the indicators can/should be designed from the top according to a top-down approach unlike that presented in the

previously quoted paper. These two different approaches can be used depending on the maturity of the project team and the representatives of cities.

In a situation in which this maturity is high, the indicator design process using a bottom-up method appears to be more efficient. However, when taking a top-down approach, the maturity of the team may be low, provided, however, that both teams are familiar with detailed models of the city while building the metaphor of the system.

Therefore, this paper proposes an extended approach to building KPIs based on models depicting how the city functions. It was assumed that the adoption of such a model for implementation forms the basis for the design of indicators as well as for their integration. It was also assumed that the adoption of such a model also acts as a metaphor of the (constantly developing) city processes, readable for users of city systems and also for system designers. Hence, the development of a high-levl model for the design of indicators (WMPK) may provide a kind of trigger for changes in the organization of cities and in the method of evaluating processes and their importance for decision making.

The starting point for the design of indicators was the analysis of models of city processes. Indeed it was assumed that the scope and number of these models will indicate to what extent the approach to these models is important or integrated (attempt at their aggregation) or to treat these models as independent entities and use them as design patterns on the basis of defined KPIs. The top-dow approach was deliberately used to indicate the importance of knowing the vision of the operation processes of the city before the defining of indicators for this vision. This approach is commonly used in the design processes of corporate architectures and can constitute a methodological component used in the design of KPIs.

The analysis of city processes indicates that the number of models of the operation processes of cities is limited. City processes and the need for their use and credibility in the design of Smart Cities systems indicates that the suitability of these models for KPI design processes must be evaluated in order to then generalize this process to assume an approach under which initially (along with the city) a model of the operation processes of the city is adopted and then KPIs are designed bearing in mind the possibility of their aggregation for the needs of this model.

Figure 1 presents WMPW where there are three visible layers (city models, aggregate indicators and KPIs, which are the basis for measuring those processes of the city that are important from the point of view of city models). The feedback vector visible in this figure and the controller on the right-hand side indicates the direction and area of the design processes. This city model represents specific kind of data necessary for the design of indicators. Based on the city models, processes are selected and measurements are assigned to these processes. Then the aggregation of indicators takes place based on the processes isolated within the models and they are assigned to the corresponding measurements.

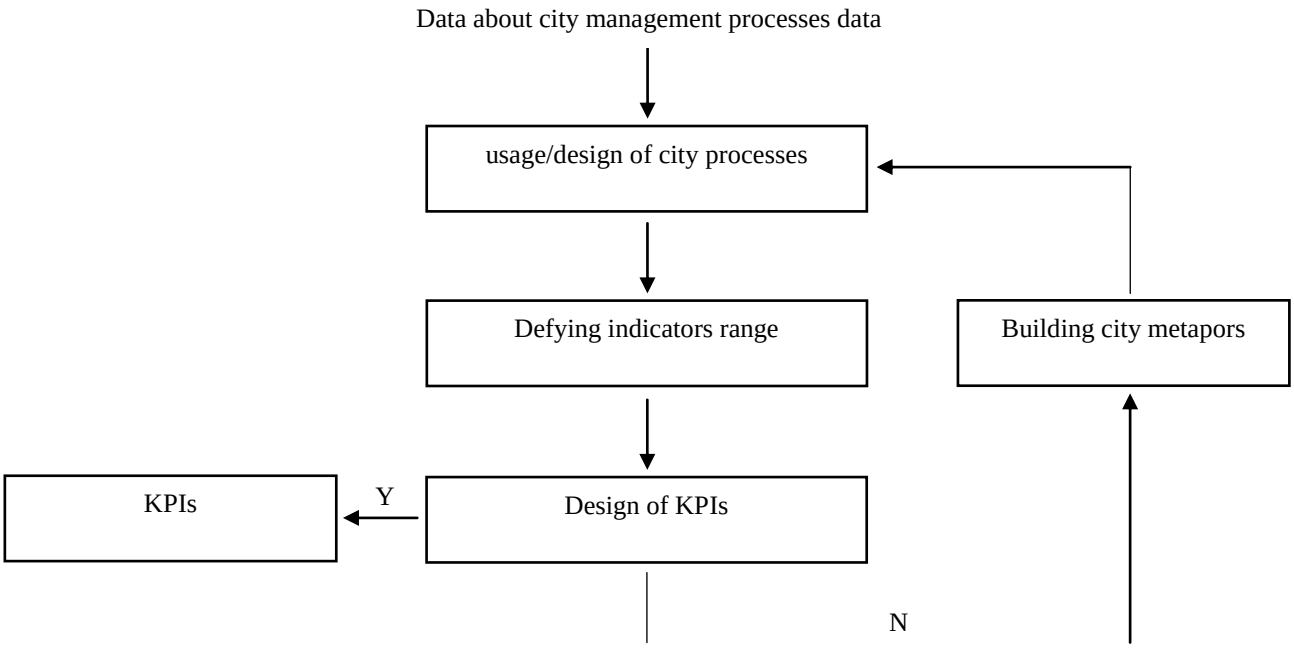

Fig. 1 High-level KPI design model (WMPW) for the needs of smart cities

Because of the situation presented above there are currently thousands of KPIs in the IOC system. Some of these are pure business KPIs (which cannot be used in the city management process), the others might be used, all are put together and the new KPIs are added in the same way. The authors propose to add extra levels to the extent in which all data representation in the IOC is based on KPIs. It is suggested to first to add aggregate KPIs which will accumulate KPIs in order to meet important issues. This idea is presented in detail in the next paper and therefore will not be presented here. The authors suggest adding one more level: models of city management processes (fig 2.), which will be presented further.

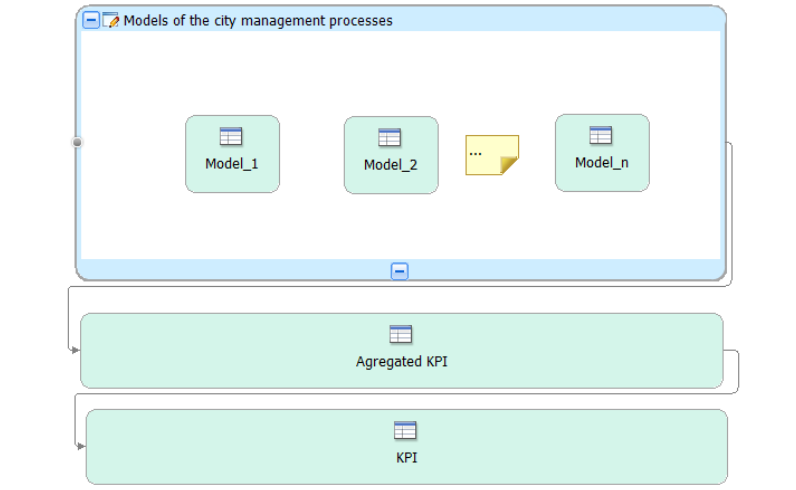

Fig. 2 Three layer architecture of the KPI design (additional layer of the city management processes models)

As presented in Figure 2 the top part is the model of city management processes. The model represents the main idea to be implemented in the city (for example a model for sustainable development or a model for effective transportation). So first the model is described. Next to that model aggregate KPIs are assigned which will represent the main areas of interest of the model (such as all important aspects of transportation in the transportation model). The aggregate KPIs consist of many individual KPIs necessary to describe the model. Every KPI that will be created will be assigned to one or many models so there will be no 'independent' KPIs which are not assigned to any model (which would mean it is not used). It solves one of the main current problems in the current existing systems: lots of data is measured but not used which is expensive, time-consuming and makes the process of finding proper data more complicated. Because of that, it is also very complicated to implement the system in other cities – because there is no knowledge of which KPIs are necessary to answer the main problems (which are presented in the models).

As it was stated above, currently there might be billions of KPIs defined for every city. In view of this it seems necessary to organize them to make it possible not only to manage them. Because a city is a fast changing organization, managing current existing KPIs might be seen from different perspectives:

- Some KPIs after some time might not be needed any more (and due to this it will be necessary to delete them which lowers the cost and gives order.
- When a new decision-making process is going to be made, very often it is possible to base it on current existing KPIs. As there are very many of them in the city, it is required to make it possible to find them.

- When the aggregate KPIs are built, they should cover all KPIs from the necessary area. Due to this, proper organization of KPIs is required.

The authors propose the creation of a dedicated model, a model for the organization of KPIs (WMPW) which will help to organize KPIs. This will be based on the function of eery KPI and will be used in the creation of the process of solving city problems. The main idea of the model is based on the document prepared by the United Nations Conference on Sustainable Development. In the created Agenda 21 (chapter 40)[16] the importance of information in the decision-making process (on the level of country government) was discussed. According to the United Nations 'there is a general lack of capacity (..) for the collection and assessment of data, for their transformation into useful information and for their dissemination."[16] Based on long-term experiments a model was proposed for the sustainable development of cities, which consists of 130 factors divided into three areas: causes of the problem, current state of the process and proposed reaction. The authors suggest using a similar idea for organizing KPIs in the city management processes (fig. 3).

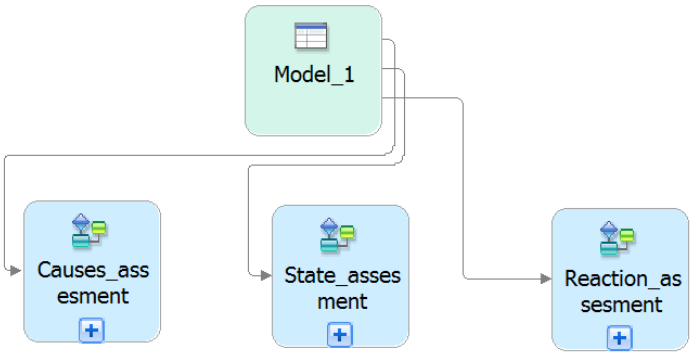

Fig. 3 Model of the city management processes

The main idea of the model for the organization of KPIs is to solve the problems presented above. In this respect the model is divided into three parts: causes, state and reaction.

The proposed construction will not only help organizing the KPIs (their place in the system) but mostly should help in the main process for which KPIs are used: building the procedure in the decision-making process. As presented in the first section of the paper, there are different needs placed by different groups in cities. The first level of the model (Causes) will help in defining the potential needs/problems proposed by different groups in the city. When the needs are seen (and measured, for example, how important the need is) the KPIs from Causes will lead us to the State part in which the KPIs presenting different areas of the city are presented. Here all the everyday measures are presented (e.g. traffic, pollution, budget). For the declared needs one (or a group) of KPIs will reflect the current state of the city in the area in which the problem might occur. This will lead the user to the third part called Reaction. It will consist of the KPIs that will measure the potential reaction of the city to the presented problem, taking into consideration the current state.

It is suggested that:

- 'Causes' consists of all KPIs which are defined as people's needs; pressure on several processes that should happen according to people's beliefs. These KPIs will measure those needs.
- 'State' consists of KPIs presenting the current values of processes (all measured in the city).
- Reaction should consist of the reaction to negative trends that might appear, also for that, KPIs are necessary.

The proposed construction of the model supports the model of city management processes presented in the first part of this section. The presented organization of KPIs supports the process of building

aggregate KPIs because the potential user can easily find the KPIs needed for the aggregation. It also shows that KPIs do not have to be described (and assigned) to the categories based only on the area in which they exist (such as management, pollution, transportation).

6. Verification of city models

In the previous section the idea of the model was presented. This section will present the verification of the presented model

The usage of the model will be verified on the example of a model built for sustainable development for Warsaw. Therefore, it is the model for sustainable development for Warsaw that consists of four aggregate KPIs (urban/environment, economic, social, management/political). Each of the aggregate KPIs consists of a certain number of KPIs. For better understanding there was a sub-category added and called Area (each aggregate KPI consists of a certain number of KPIs which are grouped into Areas in view of their main goal).

Aggregate KPI	Area	Number of KPIs
Urban/environment	Water management Waste water management Rubbish management Green areas management Land management	74
Economic	Number of companies/unemployment Structure of companies Availability of services/media agriculture	42
Social	Demography Labor market Housing Culture and tourism Education and science Environmental protection	73
Management/political	Management Budget (income) Budget (expenses)	108
Total		297

o present the sustainability of the city there must be in total 297 KPIs taken into consideration. These represent several different areas. Keeping in mind that this is just one model (out of many others in the city) it shows the scale of usage of KPIs in the city. Because every KPI is assigned to a model in which it is used, it is possible to verify and maintain the usage of every KPI (which also means the need to monitor the factors used in each KPI). It helps to avoid the situation in which there are KPIs which are not used at all (not used in any model). Even more important seems to be the fact that because of the structure it is possible to easier implement the IOC in another city – copying the model means that there is a list of necessary KPIs to be used to make it possible to receive the necessary model.

7. Conslusions

This paper presents a high-level model of the design of indicators for smart cities. The starting point for their design was the negative experience of the authors in the design of indicators for the evaluation of individual processes of city management. It was proposed to use, in the design of indicators, city operating models for which areas for the aggregation of indicators are determined in order to, on this basis, design individual indicators for city processes.

The paper presents the main issues connected with managing cities and the problems due to

different factors when compared with managing business organizations. First the differences between a city and a business organization were presented. Next the processes in both types of organization were presented. Based on the processes it was possible to present the KPIs which measure and represent the processes. There is also an important difference in the type of KPI used in a business organization and in cities. Because of this the authors proposed to create a dedicated model which will help in adapting to the needs of cities. In the last section the model was verified.

The proposed model organizes the KPIs by adding two extra levels in the structure. It helps cities to better manage the KPIs (those which are not used) and makes it possible to easily implement the system in other cities. The model was verified based on the case representing the idea of sustainable development in Warsaw.

Now it is necessary to implement the proposed changes into the software (IOC) and verify it based on the bigger amount of data.

The proposed solution can be applied for cities in which city management models are used. Then, the design process is a top-down one as described in the paper. In the absence of these models it is necessary to create them or use those existing in a high-level management model of other cities. Then city models become a specific kind of component used in the design process.

Because of this it seems expedient to modify the design processes of indicators in the IOC, a departure from the typical indicators of an organization, and the introduction of those which respond to city management processes set out in the models of city processes. This approach can be applied both at te level of tools supporting the IOC such as the Business Modeler or the Advanced version or also directly in the IOC. Then, the system designer has the ability to provide an ongoing relationship between indicators, their aggregation and the indicators necessary for the evaluation of the city processes included in the models of city processes.

It seems also to be necessary for the design process to be supported by metaphors of processes and their indicators contained in the libraries both of tools supporting the design process as well as of the IOC. Then, due to the low level of the maturity of city processes it will be possible to acquire those indicators from the libraries and directly introduce them for use in the evaluation of the processes of cities models.

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