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SELECTED ASPECTS OF MEASURING PERFORMANCE OF SMART CITIES IN SPATIAL MANAGEMENT

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Abstract. This paper explains the meaning of the term smart in the context of city management through an approach based on relevant scientific literature review as well as official documents of international institutions. It also identifies key elements characterizing a smart city. Furthermore, the study shows how to measure and compare urban smartness for instance using ISO 37120 Standard. The test procedure used taxonomic methods such as Hellwig's synthetic indicator. The main goal of the research is to analyze and evaluate of the smartness cities in Poland. The result of the study is the author's ranking of Polish cities in view of their level of smartness. The most smartness cities proved Polish metropolises (Wrocław, Katowice, Poznań, Kraków), tourist cities (Sopot, Łeba, Jastarnia, Władysławowo), suburban cities (Podkowa Leśna, Zielonka, Pruszcz Gdański) and post-mining cities (Chorzów, Gliwice, Siemianowice Śląskie).

Keywords: smart cities in Poland, ISO 37120, urban development, spatial management, taxonomic methods, Hellwig's synthetic indicator.

JEL Classification: O18; O31.

1. Introduction

In the last three decades, the concept of smart city has become more and more popular in scientific literature and international policies in particular urban spatial management (European Union 2014). Cities play a huge role in social and economic aspects worldwide and have a major impact on the natural environment. Whereas only 10 percent of the world's population lived in cities in 1900, urbanization is a defining phenomenon of the 21st century. Currently cities produce greater than 75 percent of global GDP. The world's urban population will double from 2010 (2.6 billion) to 2050 (5.2 billion) (Lierow 2014; United Nation 2015). The importance of urban area as a global occurrence is confirmed by the diffusion of megacities of more than 20 million people in Asia, Latin America and Africa.

The need for globally comparable data and knowledge on cities has never been greater. The ISO 37120:2014: Sustainable Development of Communities – Indicators for City Services and Quality of Life is the first standard of the International Organization for Standardization concerned with city metrics. It defines and establishes methodologies to be used with a set of indicators which steer and measure the performance of city services and quality of life. ISO 37120:2014 can be applied to any city, municipality or local government, irrespective of size and location.

This study aims to analyze and evaluate the smartness of cities in Poland. The research included 304 cities of Poland. The main result is the author's ranking of Polish cities in view of their level of smartness. The author used statistical data from the Local Data Bank of the Central Statistical Office and reports prepared by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences, the International Organization for Standardization and the European Union. The test procedure covered the taxonomic methods such as Hellwig's synthetic indicator.

2. Background literature

Smart cities are areas of high concentrations of learning and innovation. In such territories creativity, innovation and entrepreneurship, connected with digital infrastructure, aspire to stimulate economic growth, sustainable development and a better quality of life for citizens (Schaffers *et al.* 2011; Shapiro 2006). The smart city has a variety of definitions and interpretations (Chourabi *et al.* 2012; Hernández-Muňoz *et al.* 2011; Ricciardi, Za 2014). The concept of smart city is an attempt to answer problems such as urbanization, aging of social infrastructure, congestion, reduction of CO_2 emissions (Richter *et al.* 2015; Cocchia 2014; Paskaleva 2009). The smart city is concerned primarily with the integration of Information & Communication Technologies with processed performed in the city (those concerning urban infrastructures, including: energy, water, buildings, transportation, communications, administrative services) with the aim to obtain optimal efficiency of these processes (Dameri, Cocchia 2013; Papa *et al.* 2013). This integration results from strategy, planning, and programs developed by ICT companies for municipal authorities, e.g. Toshiba, Ericsson, Cisco, IBM, Siemens, Apple.

The term "smart city" was first used in the 1990s (Tranos, Gertner 2012; Bakici *et al.* 2013; Sainz Pena 2011). At that time, the meaning focused on new information technologies with regard to modern infrastructures within cities. Smart city refers to the interception of data through the use of sensors, meters and appliances and the integration of that data in a computing platform that allows the communication of such information to various city services allowing them to make better operational decisions (Allwinkle, Cruickshank 2011; Dameri 2013; Tachizawa *et al.* 2015). Some years later, scientific institutes and public agencies started criticizing the idea of smart cities as being too technically oriented and claimed that smart city should emphasize the role of human capital. A few years ago researchers started to show the social aspects within the context of a smart city. Within that concept particularly interesting is the inclusion of the quality of life of the citizens of that city (Shapiro 2006; Batagan 2011). Other interpretations suggest that smart implies intelligent, because that smartness is realized only when an intelligent system adapts itself to the users' needs (Leydesdorff, Deakin 2011; Lombardi 2011). In literature it is acknowledged that there is a lack of a consensus on how to classify smart cities. The line between smart cities and similar concepts such as creative and intelligent cities is vague. Thus, there exists a need for a clear definition of the determinants of a smart city which is consensually accepted. Table 1 outlines some of the different definitions and meanings of the concept of a smart city in the chronological order. It also explains that ICT in cities should be used in every subsystem to improve quality of life of citizens.

Table 1. Definitions of a smart cities (Source: own elaboration on the based Hall 2000; Florida 2002; Komninos 2006; Giffinger *et al.* 2007; Hollands 2008; Caragliu *et al*. 2011; Nam, Pardo 2011; Lombardi *et al*. 2012)

Authors	Years	Definitions
Hall	2000	A city that monitors and integrates conditions of all its critical infrastructure, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power, even major buildings, can better optimize its resources, plan its preventive maintenance activities, and monitor security aspects while maximizing services to its citizens
Florida	2002	Applied by city officials, urban planners, businesses and anyone interested in city development today with the goal of redefining the city as a creative center
Komninos	2006	A cities are territories with high capacity for learning and innovation, which is built in the creativity of their population, their institutions of knowledge creation and their digital infrastructure for communication and knowledge management
Giffinger *et al.*	2007	A digital platform on which a complex ecosystem of multiple agents (including administration, companies and citizens) is development, equipped with sensors and capable of offering, through the processing of all the information acquired by the sensor network, the best services possible at every moment
Hollands	2008	It is the implementation and deployment of information and communication technology infrastructures to support social and urban growth through improving the economy, citizens' involvement efficiency
Caragliu *et al.*	2011	Safe, secure, environmental and efficient urban centre of the future with advanced infrastructures such as sensors, electronic devices and networks to stimulate sustainable economic growth and a high quality of life
Nam, Pardo	2011	A smart city infuses information into its physical infrastructure to improve conveniences, facilitate mobility, add efficiencies, conserve energy, improve the quality of air and water, identify problems and fix them quickly, recover rapidly from disasters, collect data to make better decisions, deploy resources effectively, and share data to enable collaboration across entities and domains
Lombardi *et al.*	2012	The application of information and communications technology with effects on human capital/education, social and relational capital, and environmental issues is often indicted by the notion of smart city

Researchers emphasize the importance of the integration of a city's various systems such as transportation, energy, education, health care, technical infrastructure, public safety in creating a smart city (Papa *et al.* 2013). Giffinger and Gudrum identified six main components of a smart city. These elements include a smart economy, smart mobility, a smart environment, smart people, smart living, and smart governance (Giffinger, Gudrun 2010). In this area scientists rely on traditional theories of urban growth and development: regional competitiveness, transport and ICT economics, natural resources, quality of life. However, many researchers argue that the last component does not represent a separate dimension of a smart city because all the operations performed in other areas should have the objective of raising the quality of life. Lombardi *et al.* have linked these components with different aspects of urban life. For instance, smart economy has been connected with the presence of ICT enterprises (Lombardi *et al.* 2012). Nam and Pardo mark out technology, people (creativity, diversity, education) and institutions (governance, policy) (Nam, Pardo 2011). A city becomes truly smart when investment in human and social capital, together with ICT infrastructure, creates sustainable development. The Table 2 presents components of a smart city.

Table 2. Components of a smart city (Source: own elaboration on the based Eger 2009; Giffinger, Gudrun 2010; Nam, Pardo 2011; Kourtit, Nijkamp 2012; ISO 37120:2014)

Authors	Years	Components
Eger	2009	technology, economic development, job growth, quality of life
Giffinger, Gudrum	2010	economy, mobility, environment, people, living, governance
Nam, Pardo	2011	economic socio-political issues of the city, economic-technical-social issue of the environment, interconnection, instrumentation, integration, applications, innovations
Kourtit, Nijkamp	2012	human capital, infrastructural capital, social capital, entrepreneurial capital
ISO 37120	2014	city services: education, finance, fire and emergency response, governance, health, recreation, safety, solid, transportation, urban planning, wastewater, water quality of life: economy, environment, shelter, telecommunication and innovation

Various methods and measurement indices were created according to the several meanings of the concept of a smart city. Rating systems using synthetic quantitative indicators are receiving increasing attention among city managers and policy makers and are to utilized to decide where to focus resources, as well as how to enhance the city's performance. Nowadays every city needs indices to measure its performance but existing indicators are usually not standardized, inconsistent and incomparable. The ISO 37120 standard is a set of standardized indicators which provide a uniform approach to what is measured and how that measurement is performed (Steele 2014). In general, ISO 37120 defines indicators divided into 17 themes (Tillie 2014; Lynch 2015). These indicators can be used to track and monitor progress of a city's sustainable development. Planning for future needs must take into consideration current effectiveness of resource use (McCarney 2015). The indicators have been developed in order to help cities learn from one another by allowing comparisons across a wide range of performance measures and sharing best practices.

3. Research methodology

Classification of Polish cities from point of view of their smartness was examined using Z. Hellwig's method, based on the synthetic indicators. Hellwig's taxonomic method is based on the construction of an abstract object P_o, called the pattern of development (Strahl 1978; Nowak 1990). In this study, the meter was used to organize Polish cities according to the attained level of smartness. Included diagnostic variablles are first subjected to standardization. In the next stage characteristics of the variables taken into account were specified, among with stimulants and destimulants of development were distinguished. The pattern of development has been defined as an object characterized by the highest values for stimulants and smallest for destimulants. The distance between the cities and the object P_o is calculated as Euclidean distance.

The test procedure consisted of the following steps (Strahl 1978; Nowak 1990; Grabiński 1992; Młodak 2006, 2012; Panek 2009; Olszewska 2014):

- normalizing of the set of variables using the following formula:

$$z_{ij} = \frac{x_{ij} - \overline{x_j}}{s_j}, \qquad (1)$$

where: z_{ij} – the standardized value of the *j*-th variable on object *i*;

x_{ij} – the value of the *j*-th variable on object *i*;

$\overline{x_j}$ – the mean value of the *j*-th variable;

s_j – the standard deviation of the *j*-th variable;

- calculating Euclidean distance c_{io} appllying the following formula:

$$c_{io} = \begin{cases} \sqrt{\sum_{i=1}^{n}\left(x_{ij} - x_{\max}\right)^2} & \text{for stimulants} \\ \sqrt{\sum_{i=1}^{n}\left(x_{ij} - x_{\min}\right)^2} & \text{for destimulants} \end{cases}, \quad (2)$$

where: $x_{\max}$ – the maximum value of the *j*-th variable;

$x_{\min}$ – the minimum value of the *j*-th variable;

- count the critical distance between objects and the "ideal object" c_o using the following formula:

$$c_o = \frac{1}{n}\sum_{i=1}^{n} c_{io} \; 2 \; \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(c_{io} - \overline{c_o}\right)^2}, \quad (3)$$

- count the synthetic measure of development proposed by Hellwig d_i by the following formula:

$$d_i = 1 - \frac{c_{io}}{c_o}, \quad (4)$$

where: d_i – the taxonomic measure of development proposed by Hellwig;

c_o – the critical distance between objects and the "ideal object";

- grouping on the based value of the synthetic measure all the cities into four groups:

I class	if the synthetic measure is $d_i > \overline{d_i} + S_{di}$
II class	if the synthetic measure is $\overline{d_i} \le d_i < \overline{d_i} + S_{di}$
III class	if the synthetic measure is $\overline{d_i} - S_{di} \le d_i < \overline{d_i}$
IV class	if the synthetic measure is $d_i \le \overline{d_i} - S_{di}$

where: $\overline{d_i}$ the average of the taxonomic measure d_i;

S_{di} – the standard deviation of the taxonomic measure d_i.

4. Results and discussion

To evaluate the level of smartness of Polish cities Hellwig's method was applied. Analysis data was supplied by the Local Data Bank of the Central Statistical Office for the year 2014 covering 304 Polish urban gminas. Seventy of these cities have full coverage planning. Polish cities are covered in 55.7 percent by local plans (Śleszyński *et al.* 2015). Based on the review of literature mentioned above, the author adopted the following indicators as thirteen diagnostic variables. For each city thirteen indicators which represent different components of the ISO 37120 Standard have been calculated. Nine variables represent city services and four variables apply to the quality of life. Two variables are destimulants (X_3, X_6) and remaining eleven variables are stimulants. All statistical analyses in this article were performed using the Microsoft Office Excel 2010 software. The Table 3 outlines indicators of a smart city and components of ISO 37120 Standard.

Classification by synthetic measure calculated by Hellwig, based on thirteen selected features, identified as the most smartness cities in 2014 Krynica Morska and a synthetic index amounts 0.28. This city has the highest total revenue reaching 23,897.38 PLN per capita. Calculated synthetic smartness indicator allowed the isolation of groups of cities characterized by a similar level of smartness. In this way, four classes of cities were identified:

- Group I: the cities with the highest smartness,
- Group II: the cities with the middle rate of smartness,
- Group III: the cities with a low rate of smartness,
- Group IV: the cities with the lowest rate of smartness.

The group with the highest smartness includes 42 cities and a synthetic index amounts $d_i > 0.11$. This class includes most Polish metropolitan cities (Wrocław, Katowice, Poznań, Kraków), tourist cities (Sopot, Łeba, Jastarnia, Władysławowo), suburban cities (Podkowa Leśna, Zielonka, Pruszcz Gdański) and post-mining cities (Chorzów, Gliwice, Siemianowice Śląskie). The capital of Poland ranks a distant fifth position within this group. This class is characterized by the smallest area covered by local plans. Karpacz has the largest number of entities entered in the REGON register at 7692 per 10 thousand of population. Józefów has the largest share of newly-registered creative sector entities within the total number of newly-registered entities reaching 13.4 percent.

Table 3. Indicators of a smart city vs. components of ISO 37120 Standard (Source: own elaboration on the based the Local Data Bank of the Central Statistical Office (2014), the World Council on City Data (2014) and Standard ISO 37120: 2014)

Variables	Components of ISO 37120	Indicators
X_1	urban planning	share of the area covered by local plans in the total city area in percent
X_2	finance	total revenue per capita
X_3	solid waste	mixed municipal waste collected during the year per capita
X_4	transportation	urban transportation routes bus per 100 hectares of area
X_5	education	number of pupils per 1 computer with broadband Internet access
X_6	water	consumption of water for needs of the national economy and population during the year per capita
X_7	recreation	share of green areas in the total area in percent
X_8	health	health out-patient departments per 10 thousand population
X_9	wastewater	share of population connected to municipal wastewater treatment plants
X_{10}	governance	share of woman of total elected to city-level office
–	energy	none
–	fire & emergency response	none
–	safety	none
–	shelter	none
X_{11}	economy	entities entered in the REGON register per 10 thousand population
X_{12}	environment	share of legal protected in total area in percent
X_{13}	telecommunication & innovation	share of new-registered creative sector entities in the total number of new-registered entities

The group with the middle rate of smartness consists of 91 cities and a synthetic index amounts $0.07 < d_i \leq 0.11$. The low ranking of the city of Toruń, the largest regional city, should be noted (it is 64 position). This class is characterized by the highest share of area covered by local plans and the highest computerization rate in primary and secondary schools.

The third group with a low rate of smartness includes 143 cities and a synthetic index amounts $0.036 < d_i \leq 0.072$.

The fourth group consists of 28 cities and a synthetic index amounts $d_i \leq 0.036$. The last position on the list of cities belongs to Konin. This city has the largest consumption of water for needs of the national economy and population reaching 17,904.1 m^3 per capita because of the location of its power plant Pątnów-Adamów-Konin. The Table 4 presents the ranking of Polish cities.

Table 4. Cities ranking base on synthetic variable (Source: own calculations on the based the Local Data Bank of the Central Statistical Office (2014))

Ranking	Level of smartness	Criterion	Cities
I	High	di > 0.108	Krynica Morska, Podkowa Leśna, *Sopot*, Karpacz, <u>Warszawa</u>, <u>Wrocław</u>, <u>Katowice</u>, <u>Poznań</u>, Łeba, <u>Kraków</u>, Jastarnia, *Chorzów*, Zamość, Kołobrzeg, Władysławowo, *Gliwice*, <u>Białystok</u>, <u>Lublin</u>, <u>Łódź</u>, Ustroń, <u>Opole</u>, Świeradów Zdr., <u>Gdańsk</u>, Wisła, Zielonka, <u>Kielce</u>, <u>Olsztyn</u>, *Siemianowice Śl.,* Ciechocinek, *Siedlce*, Józefów, Pruszcz Gd., *Świnoujście*, *Krosno*, *Bielsko Biała*, Tarnowskie Góry, Człuchów, *Gdynia*, <u>Zielona Góra</u>, Szczawno Zdr., *Leszno*, *Słupsk*, Ustka
II	Middle	0.072 < di ≤ 0.108	Cieszyn, <u>Rzeszów</u>, Zakopane, Maków Maz., Puszczykowo, Lidzbark Warm., Polanica Zdr., *Kalisz*, *Dąbrowa Górn.,* <u>Bydgoszcz</u>, <u>Szczecin</u>, *Tychy*, Górowo Iławieckie, Milanówek, *Koszalin*, Ostróda, *Płock*, <u>Gorzów Wielk.</u>, Jelenia Góra, *Częstochowa*, <u>Toruń</u>, *Nowy Sącz*, Piastów, Kościan, Żyrardów, Szklarska Poręba, *Przemyśl*, Tomaszów Lubelski, *Grudziądz*, Mikołów, Legionowo, Świdnica, Żywiec, *Sosnowiec*, Bochnia, Ząbki, *Legnica*, *Tarnów*, Wągrowiec, Mszana Dln., *Chełm*, Będzin, Limanowa, Piotrków Tryb., Szczyrk, Giżycko, Otwock, *Radom*, Radzionków, Pruszków, Przasnysz, *Bytom*, Bolesławiec, Koło, Łomża, *Zabrze*, Luboń, Sulejówek, *Rybnik*, Kętrzyn, Rawa Maz., Skierniewice, *Włocławek*, Czeladź, Puck, Sandomierz, Malbork, Płońsk, Złotów, Brzeziny, *Biała Podl., Tarnobrzeg*, Nowe Miasto Lubawskie, Słupca, Lębork, Wysokie Maz., Sucha Beskidzka, Marki, Brzeg, Kłodzko, Rumia, Gubin, Głogów, Czarnków, Łańcut, Nowy Targ, Szczecinek, *Suwałki*, Chodzież
III	Low	0.036 < di ≤ 0.072	Dusznik Zdr., Kraśnik, Pabianice, Hel, Łowicz, Oświęcim, *Piekary Śl.*, *Mysłowice*, Ostrów Wielk., Garwolin, Darłowo, Zawiercie, Zgierz, *Elbląg*, Mrągowo, Tczew, *Ruda Śl.,* Ciechanów, Stoczek Łukowski, Świdnik, Kobyłka, Zduńska Wola, Puławy, Golice, Biłgoraj, Szczytno, Bełchatów, Świdwin, Lubliniec, Zgorzelec, Ełk, Wejherowo, Inowrocław, Żary, Kutno, Radlin, Dzierżoniów, Bartoszyce, Chojnice, Piła, Łęknica, *Wałbrzych*, *Jaworzno*, Złotoryja, Kwidzyn, Chojnów, Łęczyca, Chełmno, Wojkowice, Przeworsk, Knurów, Sokołów Podl., Jordanów, Reda, Mińsk Maz., Iława, Żagań, *Żory*, Kędzierzyn-Koźle, Węgrów, Lubawa, Bukowno, Imielin, Gniezno, *Ostrołęka*, Brodnica, Lubań Mielec, Wałcz, Lubin, Kościerzyna, Radomsko, Sochaczew, Kudowa-Zdrój, Brańsk, Racibórz, Ostrów Maz., Świętochłowice, Białogard, Konstantynów Łódz., Siemiatycze, Nowy Dwór Maz., Międzyrzec Podl., Stargard Szczec., Jarosław, Bielsk Podl., Działdowo, Lubartów, Oleśnica, Golub-Dobrzyń, *Starachowice*, Lipno, Hrubieszów, Sanok, Łuków, Tomaszów Maz., Rydułtowy, Krasnystaw, Oława, Ostowiec Święt., Kostrzyn n. Odrą, Sieradz, Mława, Wąbrzeźno, Sławków, Hajnówka, Leżajsk, Świebodzice, Skarżysko-Kamienna, Nowa Sól, Jasło, Augustów, Radzyń Podl., Bielawa, Jedlina Zdr., Łaskarzew, Bieruń, Dębica, Wodzisław Śl., Myszków, *Jastrzębie Zdr.*, Łaziska Grn., Włodawa, Sejny, Rypin, Lubaczów, Radziejów, Dynów, Stalowa Wola, Raciąż, Lędziny, Ozorków, Turek, Aleksandrów Kuj., Kowary, Niszawa, Starogard Gd., Sierpc, Grajewo, Braniewo, Pyskowice, Jawor
IV	Very low	di ≤ 0.036	Zambrów, Sławno, Głowno, Piechowice, Skórcz, Kamienna Góra, Terespol, Chełmża, Nowa Ruda, Dęblin, Grybów, Kalety, Obrzycko, Wojcieszów, Kolno, Miasteczko Śl., Gostynin, Pszów, Rejowiec Fabr., Boguszów-Gorce, Orzesze, Poręba, Radymno, Sulmierzyce, Piława Grn., Zawidów, Gozdnica, *Konin*

<u>Wrocław</u>	voivodeship cities
Świnoujście	cities with poviat status

5. Conclusions

The literature review in the context of urban spatial management shows that the concept of a smart city is a popular subject of scientific research. There are a lot of definitions and classification of components of a smart city. The most practical methods to measure a city's performance is through the use of the ISO 37120 Standard. One of the dimension of a smart city is urban planning. Smart cities should implement good quality local spatial development plans.

Through the application of the taxonomic method using Hellwig's composite measure of development Polish cities were compared using thirteen indicators. The author divided the cities of Poland into four independent classes. The results obtained were used to rank the analyzed cities in terms of their levels of smartness. The most smartness cities proved Polish metropolises (Wrocław, Katowice, Poznań, Kraków), tourist cities (Sopot, Łeba, Jastarnia, Władysławowo), suburban cities (Podkowa Leśna, Zielonka, Pruszcz Gdański) and post-mining cities (Chorzów, Gliwice, Siemianowice Śląskie). The analysis presented a need to improve city services and the quality of life in cities falling into the fourth class.

Possible areas for future research may include issues such as business models for smart city organizations. Finally, the author hopes that this study will encourage policy makers and city managers to implement the ISO 37120 Standard in their urban systems which will facilitate the monitoring of city services.

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