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THE STUDY OF THE INTERDEPENDENCIES OF AREAS AND ASPECTS OF SMART CITY IN POLISH CITIES

Tomasz OWCZAREK[1*], Adam SOJDA[2], Maciej WOLNY[3]

[1] Silesian University of Technology, Zabrze; tomasz.owczarek@polsl.pl, ORCID: 0000-0003-2532-4127
[2] Silesian University of Technology, Zabrze; adam.sojda@polsl.pl, ORCID: 0000-0002-3021-4451
[3] Silesian University of Technology, Zabrze; maciej.wolny@polsl.pl, ORCID: 0000-0002-8872-7794
* Correspondence author

Purpose: To determine the interdependencies between Smart City areas as well as the aspects and areas between resident-oriented IT areas of the city.
Design / methodology / approach: The data for the study was collected during a survey of 287 cities for Smart City. The study of interdependence was based on a correlation analysis using: Pearson's correlation coefficient, Cramér's V coefficient, and Kendall's tau. In addition, a PCA analysis was used to reduce variable dimensions.
Findings: The results of the research indicate that the scope of using services within e-office services is more strongly related to functionality than to IT equipment. In turn, the economic area plays a fundamental role in the perception of the city as a Smart City. There was also a clear difference in self-evaluation regarding Smart City areas and IT aspects of the city depending on the size of the city. However, this difference does not translate into declarations regarding the readiness for evaluation in Smart City categories.
Originality/value: presentation of the relationship between the areas defining the concept of Smart City dependence on the basis of an original study addressed to city representatives. The results of the study allow us to look at the Smart City concept from the perspective of the city. The results of the analysis, in addition to scientists dealing with Smart City, may be of interest to city managers in Poland. They show the way of understanding and dependencies between individual areas. They also show those dependencies that need to be strengthened in the context of sustainable development.

Keywords: Smart City, PCA, survey research, dependency analysis.

Category of the paper: research paper**.**

1. Introduction

The idea of a Smart City is multifaceted. On one hand, it refers to people and the quality of their lives, on the other hand, it refers to the development of science and technology, especially information technology (Albino et al., 2015).

The definition of Smart City has a hierarchical structure (Giffinger et al., 2007). The concept of Smart City is separated into areas and sub-areas, and sometimes into more specific categories In the European Smart Cities Ranking (Giffinger, Gudrun, 2010), the Smart City model includes: Smart Economy (which includes: an innovative spirit, entrepreneurship, city image, productivity, a labor market, international integration), Smart Governance (political awareness, public and social services, efficient and transparent administration),Smart Living (cultural and leisure facilities, health conditions, individual security, housing quality, education facilities, tourist attractions, social cohesion), Smart People (education, lifelong learning, ethic plurality, open-mindedness),Smart Environment (air pollution, ecological awareness, sustainable resource management) and Smart Mobility (local transport system, international and national accessibility, ICT-infrastructure, and sustainability of the transport system). The same main areas are considered in The Smart Cities Wheel concept with slightly differently defined subareas (Cohen, 2014). A similar look at Smart City is presented by the Bilbao Smart City Study (Azkuna, 2012). Slightly different areas are presented by the Triple-Helix Model for Smart City (Lombardi, 2011), in which five areas are considered: Governance, Economic Development, Human Capital, Culture and Leisure, Environment. Also, five areas of Smart City are considered in the CITYkeys project (Airaksinen et al., 2017; Bosch et al., 2017): people and quality of life, environment, economy (prosperity), management, and propagation. At the same time, these areas refer not only to cities, but also to projects related to the Smart City concept.

The designation of areas describing Smart City leads to the definition of indicators (criteria) providing information about the maturity of the city in terms of a given category. Next, to assess the extent to which the city is smart (Sharifi, 2020). By its very nature, this assessment is multi-criteria (Halepoto et al., 2015; D'Alpaos, Andreolli, 2020; Ogrodnik, 2020; Carli et al., 2018).

One of the key elements of the evaluation system are data that can be obtained from publicly available databases (Sojda, Wolny, 2020), own research, expert opinions or from various sources, depending on the evaluation system. Smart City evaluation initiatives are usually related to an objective approach (independent of residents or city authorities) or refer to a survey of the opinion and situation of residents (e.g., the source of the Urban Audit survey). On the other hand, research involving the assessment of Smart City from the perspective of the administration and city authorities is relatively rare (Ligarski, Wolny, 2021).

A separate issue is research related. This is due to the occurrence of interdependencies between areas, sub-areas and categories defining Smart City. There are numerous studies identifying the occurrence of correlations between individual categories (Moustaka et al., 2017, 2018; Theng, Kanokkorn, 2016; Neirotti, 2014, Cagliero et al., 2016). However, there are no results showing the interdependencies directly between the main areas of Smart City.

Researchers generally agree that Smart City development should be sustainable (Honarvar, Sami, 2019; Silva et al., 2018; Khan et al., 2020; Heitlinger et al., 2019), although the difference between a sustainable and a smart city is recognized (Ahvenniemi et al., 2017). Therefore, a sustainable Smart City should be characterized by a significant interdependence between the main areas defining the Smart City.

Taking into account the presented considerations, Smart City research was undertaken from the point of view of the administration and city authorities. The following main areas of Smart City were considered: social, logistic, economic, managerial, technical, IT, ecological, and additionally evaluative (readiness to evaluate Smart City solutions). In addition to the above-mentioned research areas, cities were asked to assess the functioning strictly in IT aspects aimed at residents (functionality of the e-office, scope of use of the e-office, availability of IT infrastructure, IT equipment of the e-city hall, and educational activities related to IT going beyond the curriculum). The main objective of the research was to determine the interdependencies between Smart City areas and between these areas and the IT aspects of the city aimed at residents.

2. Methods

The collected data come from a random sample of 287 Polish cities. The draw was layered, so that each of the voivodships was represented by at least 10 cities. The study was addressed to people responsible for the preparation of strategies and urban development plans. It concerned the assessment of cities in the area of IT infrastructure and the perception of the city in the context of being "smart". Questions related to IT infrastructure covered the following 5 aspects:

- e-office functionality,
- e-office usage,
- access to IT infrastructure for residents,
- e-office equipment,
- IT education.

Questions about the perception of the city as a Smart City related to the following areas:

- social,
- logistical,
- economical,
- managerial,
- technical,
- IT,
- ecological,
- evaluative.

For each question, respondents answered on a 5-point Likert scale. A detailed description of the research sample and the results of the answers to individual questions can be found in (Sojda et al., 2020).

Since the aim of the study was to determine the interdependencies between Smart City areas and between these areas and the IT aspects of the city aimed at residents, it was necessary to select appropriate measures of interdependence.

The first measure was Pearson's linear correlation coefficient defined by the formula:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (1)$$

Due to the fact that this coefficient measures the degree of linear dependence, while the answers were measured on a 5-point ordered scale, it was feared that the values obtained with this coefficient would not be reliable. Taking this into account, it was also decided to determine the Kendall's tau correlation coefficient (Kendall's tau), which measures the monotonic relationship between the two X i Y variables. It can be interpreted as the probability that the X variable Y will also increase as it increases – with this probability being scaled to a range from –1 to 1 (Arndt et al., 1999).

The third measure chosen was Cramér's V-statistic given by the formula:

$$V_{xy} = \sqrt{\frac{\chi_{xy}^2}{n\min\{p-1,s-1\}}}, \quad (2)$$

where χ_{xy}^2 is the value of the chi-squared statistic calculated from the contingency table for variables X i Y with dimensions p and s.

It measures the relationship between nominal variables and takes values from 0 (no dependencies) to 1 (variables are mutually unambiguous) (Rayward-Smith, 2007).

Based on the selected measures, correlation coefficients between the variables were calculated. Then, using the Spearman rank correlation coefficient, the correspondence of the order of strength of the compounds determined by each of these measures was checked. The results are presented in Table 1.

The results clearly indicate a high compatibility of the strength quantity of the compounds determined by each of these measures. The Pearson correlation coefficient showed the greatest consistency with other measures, which is why it was the relationship sizes determined by this measure that were selected for detailed analysis.

Table 1.
Spearman's rang coefficient between three correlation measures

	Pearson's r	**Kendall's tau**	**Cramér's V**
Pearson's r	1.0000	0.9867	0.9488
Kendall's tau	0.9867	1.0000	0.9165
Cramér's V	0.9488	0.9165	1.0000

In addition to correlation analysis, it was also decided to perform a principal component analysis (PCA) to determine the main directions of volatility (the evaluative aspect was omitted as the least correlated with the rest of the variables). Bartlett's test of sphericity was performed, the result of which confirmed the occurrence of correlations between variables and the possibility of PCA analysis ($\chi^2(66) = 3008.86, p < 0.001$). The eigenvalues of the first 10 components obtained with the PCA are represented by figure 1.

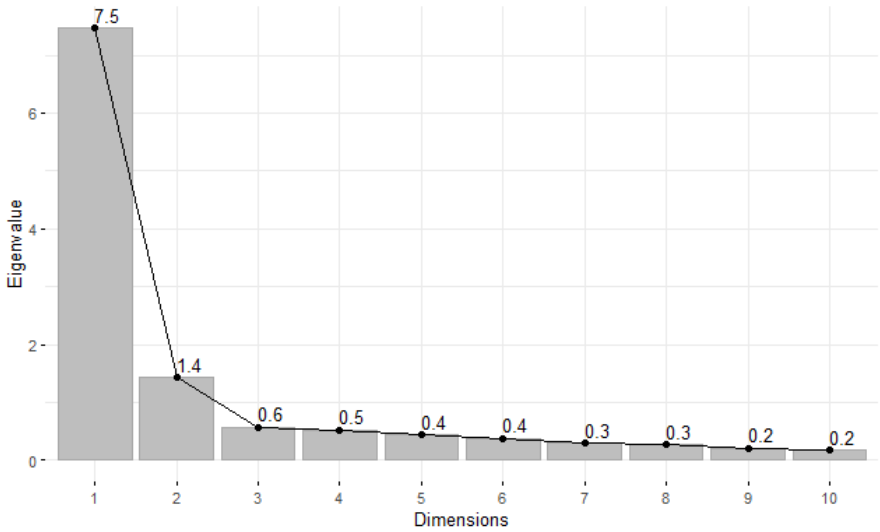

Figure 1. Eigenvalues of first 10 principal components.

Based on the Kaiser criterion and the scree plot, it was decided to choose 2 components that explain 74% of the variability of the entire set.

3. Results

Analysis

Firstly, the correlations between infrastructure aspects were checked. The obtained values are represented by figure 2.

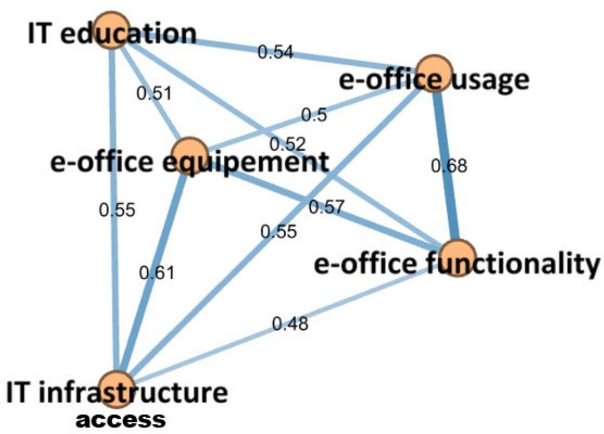

Figure 2. Correlations between the IT infrastructure aspects.

There are positive correlations between all variables, but the strongest is between e-office usage and e-office functionality. The second strongest correlation is between IT infrastructure access and e-office equipment. There are also clear correlations between additional IT education activities and access to IT infrastructure and the scope of using the e-office.

Next, the correlations between the areas of urban perception in Terms of Smart City (figure 3) were checked. All correlations are high here, but among them it is possible to distinguish the strongest and the weakest.

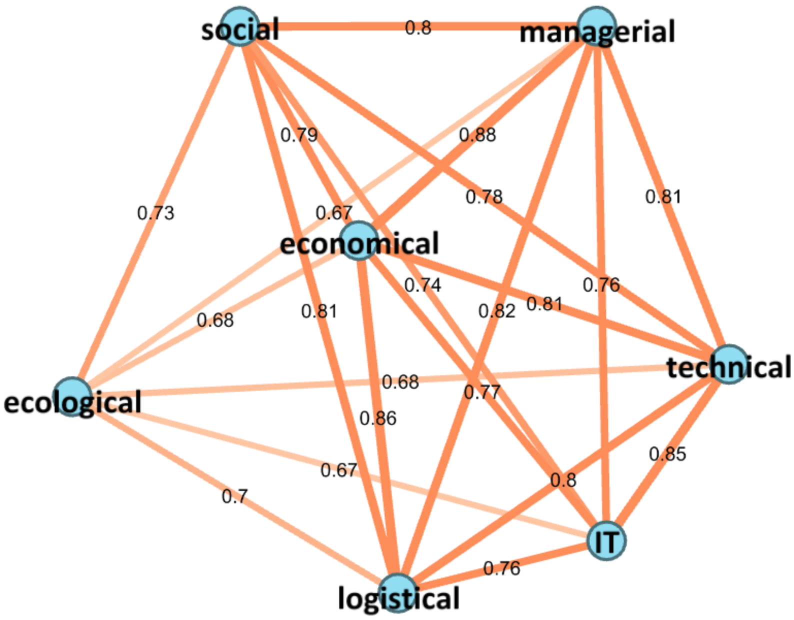

Figure 3. Correlations between the perceived Smart City aspects.

The strongest relationship here is between the economic and managerial areas. High correlations also characterize the economic and logistic area as well as technical and IT areas. The economic area seems to be the most closely related to the others. The weakest relationships occur in the case of an ecological area (it is most strongly related to the social aspect).

The relationships between the Smart City areas and additional IT education and access to IT infrastructure were also checked (figure 4).

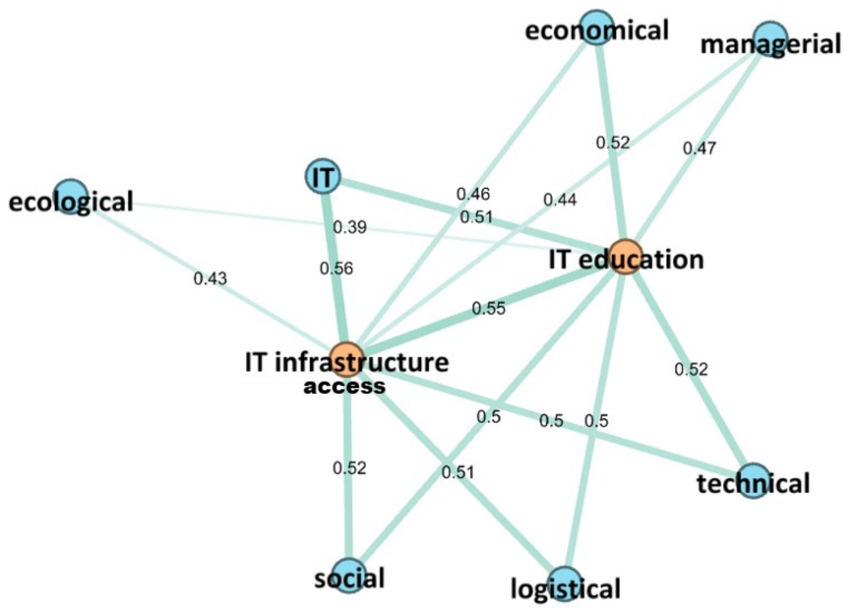

Figure 4. Correlations between ID infrastructure access and IT education with the perceived Smart City aspects.

Both of these areas are most strongly related to the IT aspect, and least to the ecological and managerial area.

Analysis of the principal components

For further analysis, the first two components were selected. Due to the positive correlations between all variables, in order to better interpret the obtained dimensions, it was decided to carry out an additional *oblimin* rotation. The factor loadings of the individual variables are shown in Table 2.

Table 2.
Factor loadings between variables and rotated components

variable	principal 1	principal 2
social aspect	**0.862**	0.059
logistical aspect	**0.913**	0.007
economical aspect	**0.936**	-0.022
managerial aspect	**0.972**	-0.088
technical aspect	**0.872**	0.069
IT aspect	**0.790**	0.152
ecological aspect	**0.844**	-0.050
e-office functionality	-0.058	**0.873**
e-office usage	-0.090	**0.901**
e-office equipment	0.251	**0.613**
IT infrastructure access	0.138	**0.696**
IT education	0.159	**0.661**

Factor loadings indicate two clearly separated dimensions of data: the perception of the city in terms of being "smart" (Smart City dimension) and IT infrastructure (IT dimension). These values for individual variables are presented in a two-dimensional space determined by these dimensions (figure 5).

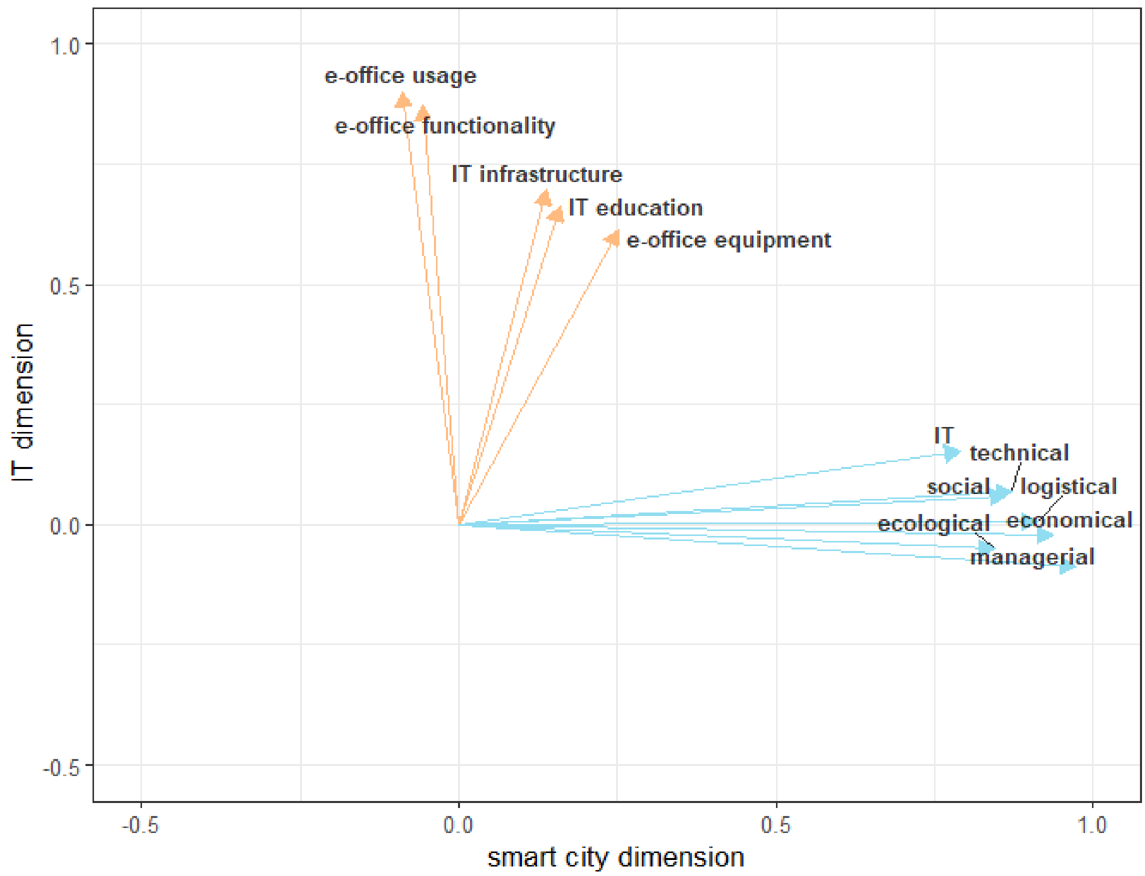

Figure 5. Variables' factor loadings in 2-dimensional space.

Figure 6 shows the component coefficients of all cities broken down by city size. X points indicate group centers (i.e., average values obtained by cities of a given size). It is clear that the largest cities (over 100,000 inhabitants) perform best due to the two analyzed dimensions, while the lowest are cities with a size of up to 10,000 inhabitants.

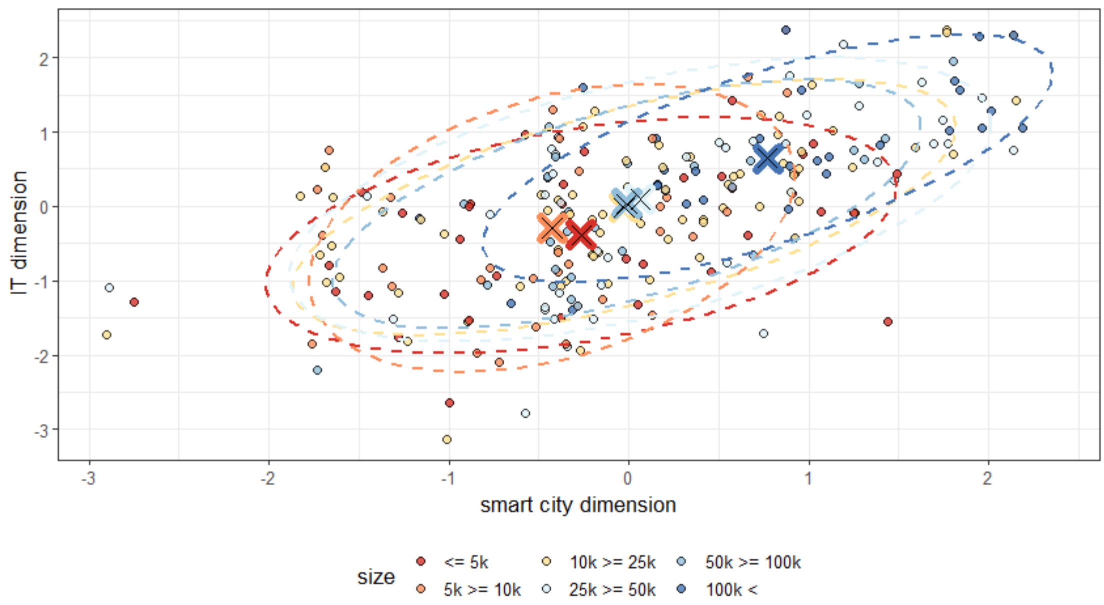

Figure 6. Cities' results according to their size.

The next figure shows the coefficients of cities broken down according to the answers given to the question about the evaluation aspect, i.e., conducting a self-assessment in the field of smart solutions (figure 7). A clearly positive relationship can be seen between the answers given and the values obtained in the two analyzed dimensions.

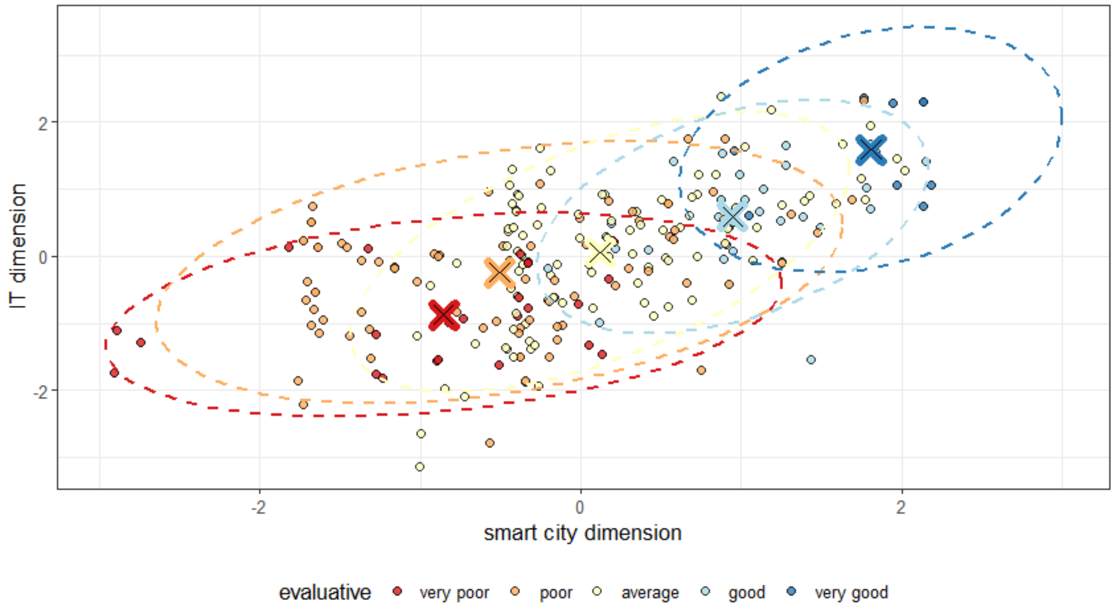

Figure 7. Cities' results according to self-evaluative aspect.

Figure 8 presents the results of cities depending on the answer to the question about interest in the overall evaluation of the city in terms of Smart City evaluation.

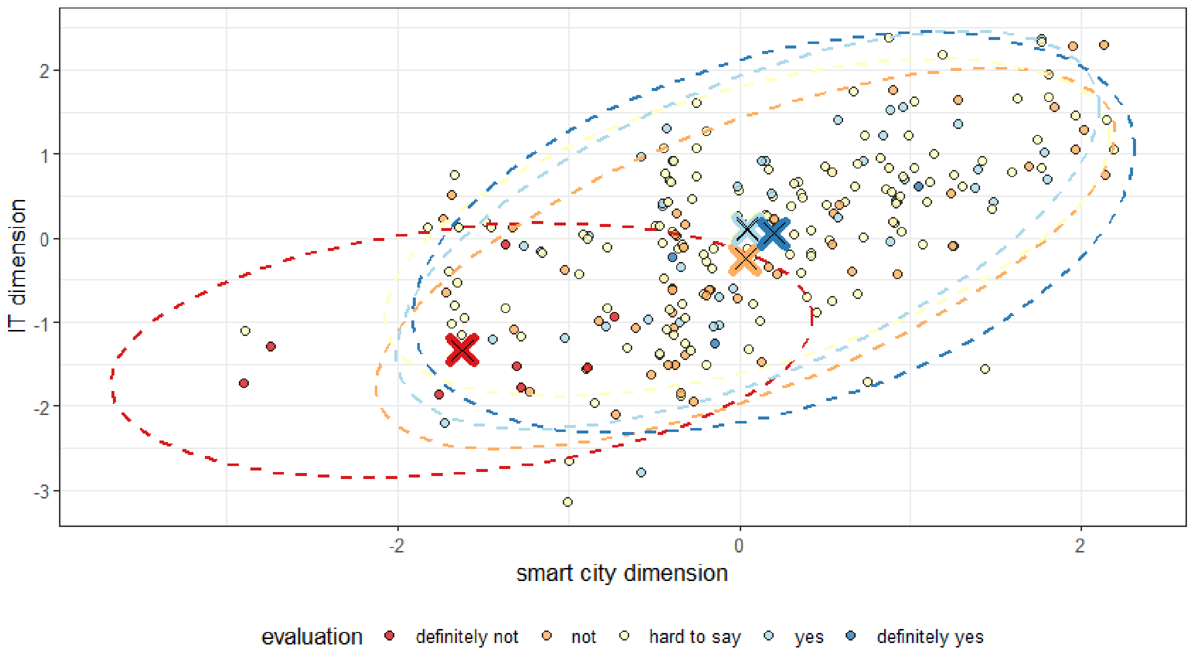

Figure 8. Cities’ results according to their interest in evaluation of being “smart”.

It points to clear differences between the cities that have strongly refused to be the subject of such evaluations and the others.

4. Discussion

The following conclusions can be drawn from the presented research results. Firstly, the scope of using the services made available as part of the e-city hall is strongly related to their functionality, and to a lesser extent to the IT equipment of the office itself (figure 2). The degree of use of the services offered by the e-office is clearly related to the additional education of residents in the field of IT. Both of these areas are strongly linked to access to IT infrastructure by residents. This indicates a complex relationship between the studied areas in terms of IT infrastructure of cities. This corresponds with the conclusions of (Kashnar et al., 2021), who recommend treating the entire smart cities infrastructure as an "emergent socio-technological topic", which can only be well understood using a holistic and comprehensive approach.

Secondly, the economic area seems to play a major role in the context of being smart. It is located at the center of the network of connections with all other components of Smart City (figure 3). The management area is most closely related to this area. Therefore, it can be hypothesized that efficient management has a positive effect on the economic results of being “smart”, which in turn translates into other areas. Similar results are presented in the work (Giovannella et al., 2014). The management area is strongly correlated with other smart city areas. On the other hand, the economic area is most strongly correlated with the management area. The impact of the economic aspect on other areas of smart cities is similarly recognized in (Jonek-Kowalska, Wolniak, 2021).

Thirdly, the IT aspect is strongly linked both to access to infrastructure, but also to education in the use of this infrastructure (figure 4). Both of these aspects should therefore be developed simultaneously. This confirms the extreme relevance of education in the context of smart cities, which has been highlighted before (Garg et al., 2017; Molnar, 2021).

Fourthly, the awareness of being "smart" is clearly correlated with the size of cities (figure 6) and self-esteem in the field of "smart" solutions (figure 7). In terms of city size, similar results are provided by the PCA from the study (Giovannella et al., 2014), where the second principal component distinguishes large cities and shows the impact of city size on the assessment of being "smart". It is interesting, however, that the interest declared by the representatives in the overall external evaluation of the city in terms of Smart City evaluation does not seem to be related to how cities perceive themselves. For example, among the cities that have chosen the answer "not" there are both cities from leading positions in both dimensions, as well as those below the average value (figure 8).

5. Summary

The Smart City concept is related to the development of cities, which means that it is constantly being developed. It is a utilitarian concept aimed at indicating the areas in which the city should develop. The overwhelming number of research/works tries to assess the city with objective measures based on indicators of its development. In a few studies you can see the use of residents' opinions. There was a lack of investigation of Smart City from the perspective of city managers.

The paper uses the results of surveys from a sample of 287 cities relating to five aspects of IT infrastructure and eight areas defined within the Smart City concept itself. The survey was addressed to people responsible for preparing the city's development strategy. A detailed description of the research sample and the results of the answers to individual questions can be found in (Sojda et al., 2020).

Based on the answers, dependency measures based on the linear correlation coefficient of Pearson's, Kendall's tau, Cramér's V-statistic were determined. All the meters gave similar results. The Pearson correlation coefficient was the most consistent with the other measures. The PCA analysis indicated the main directions of volatility.

On the basis of the correlation analysis, positive relationships between aspects of the IT infrastructure (figure 2) were found. Positive relationships were observed for the areas of understanding the Smart City concept (figure 3). The study of the relationship between IT aspects and Smart City areas showed the existence of positive relationships between them (figure 4).

Analysis of the main components (PCA) allowed to distinguish two components (figure 1, 5). In addition, the dependence of individual components on the size of the city (figure 6) and the willingness to evaluate in the field of Smart City (figure 8) were checked.

It can be concluded that the scope of using services within the e-office is more strongly related to functionality than to IT equipment. The economic area plays a fundamental role in the perception of the city as a Smart City. The IT aspect is related to the infrastructure and education of how to use this structure.

The presented research results allows us to look at the smart city concept from an individual's perspective managing the city and therefore deciding on the directions of its development.

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