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SMART CITY INDEX BASED ON TOPSIS METHOD

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Purpose: The construction of rankings is an important element of city assessment consistent with the Smart City concept. New rankings appear periodically. New sets of variables or concepts for ranking are proposed. The article is part of this trend.
Design/methodology/approach: The article combines the hierarchical structure of areas and indicators used in Smart City assessment with the concept of multidimensional assessment of facilities using the TOPSIS method.
Findings: Assessment of the possibility of using the presented method to evaluate both individual areas of the city operation combined with an overall assessment.
Originality/value: The most important achievement of this article is the proposal of the concept of city evaluation using the TOPSIS (SCI2T) method. An assessment of selected cities based on the proposed method is also presented.

Keywords: Smart City, TOPSIS method, linear ordering.

Category of the paper: Research paper.

1. Introduction

The (United Nations Report, 2018) report predicts that in 2050, 68% of population will live in urban areas. In 2018, 82% of population lives in urban areas in North America. In Europe, this number is 74%. The forecast for Asia and Africa predicts rapid urbanization over the next three decades. Therefore, there is a growing need for proper city management and creating favourable living conditions for residents. In the near future, the Earth will change its face from rural to urban, creating new challenges for cities.

The concept of Smart City – an intelligent city is constantly developed. We are currently talking about Smart City 5.0. (Svítek et al., 2020). The idea of Smart City is multidimensional and goes beyond the concept of a smart city based only on technology. There are two trends in understanding the phenomenon of Smart City. The first is associated with the effective use of technology. Technology is used as a tool to create economic growth and human capital or to ensure higher efficiency of economic activities (Hollands, 2008). The second should be identified with the new paradigm determining the role, significance and development of the city (Giffinger et al., 2007). According to this concept, the development of the city should focus on human and social capital, the environment and education. One of the most complete definitions of Smart City was formulated in a report containing a ranking of smart cities (EC, 2007). Yet another concept defines Smart Cities as those that using technology, change the city into a human-friendly environment in aspects such as mobility, management and the environment (Bakıcı et al., 2013).

Table 1.
Selected Smart City assessment systems

Name	Description
European Smart Cities Ranking	European ranking compiled by an international consortium chaired by the University of Technology in Vienna. It includes, among others: Bydgoszcz, Gdańsk, Katowice, Kraków, Łódź, Lublin, Poznań, Szczecin and Wrocław. It consists of 6 categories and 64 indicators. http://www.smart-cities.eu/ (accessed on: 09.04.2020)
The Smart Cities Wheel	A holistic assessment system, taking into account the key elements that make up a Smart City. A tool to support city benchmarking. Compiled by Boyd Cohen, in collaboration with leading cities around the world. It includes 6 categories and 62 (28) indicators. Boyd Cohen https://www.fastcompany.com/1680538/what-exactly-is-a-smart-city https://www.fastcompany.com/3038818/the-smartest-cities-in-the-world-2015-methodology (accessed on: 09.04.2020)
Bilbao Smart Cities Study	The idea initiated at the world summit in Bilbao, giving an overview of the situation in cities of different regions of the world. Includes, among others, Katowice. It consists of 6 categories and 49 indicators. http://www.uclg-digitalcities.org/app/uploads/2015/06/en_smartcitiesstudy.pdf (accessed on: 09.04.2020)
Triple-helix network model for smart cities performance	Model analysing the links between smart city components, including social relations. It uses a modified triple helix model applied in innovation analysis. It consists of 5 categories and 45 indicators. http://degree.ubvu.vu.nl/repec/vua/wpaper/pdf/20110045.pdf (accessed on: 09.04.2020)
Smart City PROFILES	A set of 21 Smart City indicators, with particular emphasis on climate change and energy efficiency. Indicators include 5 categories. Smart City PROFILES (2013) https://www.smartcities.at/assets/03-Begleitmassnahmen/SmartCity-PDF-INTRO.pdf (accessed on: 10.04.2020)
CITYkeys	An EU project (under the H2020 program) aimed at providing a validated, holistic framework for measuring and assessing Smart Cities. Also in the context of city and project implementation. It consists of 73 indicators in 5 main categories. http://www.citykeys-project.eu/ (accessed on: 10.04.2020)
CIMI (City In Motion Index), IESE Cities in Motion Index	Project implemented by the Business School University of Navarra. 10 key assessment areas and 96 indicators are considered. The concept is being developed. In 2019, 13 more indicators are considered than in the previous year. Of the 174 cities evaluated, there are 2 Polish cities: Warsaw and Wroclaw. https://media.iese.edu/research/pdfs/ST-0509-E.pdf (accessed on: 10.04.2020) DOI: https://dx.doi.org/10.15581/018.ST-509

Source: Compiled on the basis of: (Ahvenniemi et al., 2017; Giffinger et al., 2007; Lombardi et al., 2011; Boasberg et al., 2019).

The selection of appropriate indicators (Lombardi et al., 2011; Szczech-Pietkiewicz, 2015) to describe a city as a Smart City is of key importance for its assessment. The variety of emerging rankings means that the problem of choosing indicators is still valid (Huovila et al., 2017; Aletà et al., 2017; Boasberg et al., 2019; Bosch et al., 2017).

The categories, areas in which we perceive Smart Cities include: smart economy ECO, intelligent population PEO, smart management GOV, intelligent mobility MOB, intelligent environment ENV, intelligent living conditions LIV.

The construction and ranking of smart cities is time consuming, as relevant data must be collected. Access to a reliable data source is very important. The EUROSTAT database should be considered a reliable source of data. This database resources include an area related to Urban Audit urban areas (Szczech-Pietkiewicz, 2015; Sojda, 2018).

2. Data and Methods

2.1. Data

Analysis data comes from the Eurostat database. The database includes the 1990-2019 information about 1,822 cities from 32 countries. There were 572 indicators used to distinguish the cities. Most of them are objective. Indicators that refer to the residents' feedback are especially valuable. In most cases, a five-point Likert scale was used or the percentage of matching answers was provided.

For data expressed on the Likert scale, switching to one synthetic indicator using the following weight system was suggested. Weights (-2;-1;0; 1; 2) are assigned to the response: (strongly disagree, very unsatisfied; somewhat disagree, rather unsatisfied; do not know/no answer, somewhat agree, rather satisfied; strongly agree, very satisfied).

Variables and indicators are expressed in different units, which assume values of various orders of magnitude. In order to allow comparison of these quantities, a standardization process was performed (Kukuła, 2012; Sojda, & Wolny, 2020).

Table 2.
Indicators in ranking

INDIC	NAME	MD	SD
ECO O1	Activity rate	1	S
ECO O2	All companies per 1000 population	2	S
ECO O3	Unemployment rate	0	D
ECO S1	In this city, it is easy to find a good job	0	S
ECO S2	Most important in my city: Unemployment	0	D
ECO S3	You have difficulty paying your bills at the end of the month	0	D
ENV O1	Annual average concentration of NO2 (µg/m³)	0	D
ENV O2	Annual average concentration of PM10 (µg/m³)	1	D
ENV O3	Number of days particulate matter PM10 concentrations exceed 50 µg/m³	0	D

Cont. table 2.

ENV S1	Most important in my city: air pollution	0	D
ENV S2	The cleanliness in the city	0	S
ENV S3	This city is committed to the fight against climate change (e.g.; reducing energy consumption in housing or promoting alternatives to transport by car)	0	S
PEO O1	Employment (jobs) in professional, scientific and technical activities; administrative and support service activities (NACE Rev. 2, M and N)	0	S
PEO O2	Median population age	3	D
PEO O3	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards	2	S
PEO S1	Foreigners who live in this city are well integrated	0	S
PEO S2	Most people in my neighbourhood can be trusted	0	S
PEO S3	Schools in the city	0	S
LIV O1	Infant mortality rate (per 1000 live births)	0	D
LIV O2	Number of deaths per year under 65 due to diseases of the circulatory or respiratory systems per 1000 population	0	D
LIV O3	Number of murders and violent deaths per 1000 population	8	D
LIV S1	Health care services offered by doctors and hospitals in this city	0	S
LIV S2	Most important in my city: social services	0	D
LIV S3	You feel safe in this city	0	S
MOB O1	Cost of a combined monthly ticket (all modes of public transport) for 5-10 km in the central zone – EUR	2	D
MOB O2	Number of registered cars per 1000 population	3	S
MOB O3	Share of journeys to work by public transport (rail, metro, bus, tram) – %	8	S
MOB S1	Means of transport primarily used to go to work/training place: public transport	0	S
MOB S2	Most important in my city: public transport	0	D
MOB S3	Public transport in the city, for example bus, tram or metro	0	S

The selection of indicators also included country capitals. Due to missing data in the database, not all European capitals are represented in the study. The following missing data imputation procedure was used. The lack of data was supplemented by the last value found in the database. If the value did not exist and the city was described by most indicators (with no fewer than three missing), the worst value of the other objects – cities was assigned.

The indicators were standardized and then converted into stimulants. An increase in the value of the indicator is responsible for an ordered increase in the value of the phenomenon.

The MD column shows how many values of the variable had to be supplemented with the minimum value. The SD column shows whether the indicator is considered to be a stimulant (S) or a destimulant (D).

Table 3.
Cities in ranking

CAPITAL	MD	POPULATION
Vienna	2	1,766,746
Brussels	0	1,205,492
Sofia	0	1,238,438
Prague	2	1,324,277
Berlin	0	3,613,495
Copenhagen	0	559,440
Tallinn	0	430,805
Athens	3	664,046
Madrid	1	3,223,334
Paris	0	9,803,494

Cont. table 3.

Helsinki	0	643,272
Budapest	2	1,749,734
Dublin	2	516,255
Rome	1	2,872,800
London	2	8,866,541
Vilnius	0	547,484
Luxembourg	2	115,227
Riga	0	632,479
Amsterdam	0	960,402
Oslo	0	623,966
Warsaw	3	1,735,442
Lisbon	1	507,220
Bucharest	4	2,131,034
Stockholm	0	949,761
Ljubljana	0	288,919
Bratislava	1	432,864
Zagreb	4	804,049

Basic statistical parameters were determined for the transformed variables.

Table 4.
Statistical parameters of indicators after standardisation

INDIC	Range	IQR	Quartile 1	Quartile 2	Quartile 3	Skewness	Kurtosis
ECO O1	3.46	1.57	-0.85	0.08	0.72	-0.20	-0.97
ECO O2	3.94	1.20	-0.62	-0.14	0.58	0.39	0.02
ECO O3	3.93	1.33	-0.67	0.18	0.66	-0.61	-0.12
ECO S1	3.72	1.33	-0.58	0.26	0.76	-0.79	-0.32
ECO S2	3.63	1.37	-0.50	-0.06	0.87	-0.56	-0.06
ECO S3	4.11	1.39	-0.76	-0.08	0.63	0.70	0.42
ENV O1	3.95	1.31	-0.71	0.22	0.60	-0.49	-0.17
ENV O2	3.79	0.86	-0.29	0.12	0.57	-0.94	0.82
ENV O3	3.96	1.07	-0.31	0.25	0.77	-1.64	2.65
ENV S1	3.68	1.06	-0.34	0.02	0.71	-0.80	0.06
ENV S2	4.02	1.62	-0.86	0.19	0.76	-0.18	-0.66
ENV S3	3.49	1.36	-0.63	0.09	0.73	-0.05	-0.88
PEO O1	3.58	0.88	-0.67	-0.40	0.20	1.66	1.90
PEO O2	3.56	0.99	-0.35	-0.06	0.64	-0.33	-0.34
PEO O3	4.14	1.07	-0.36	0.09	0.71	-0.33	0.23
PEO S1	4.53	1.25	-0.46	-0.07	0.79	-0.60	0.90
PEO S2	3.50	1.25	-0.58	-0.02	0.67	0.08	-0.80
PEO S3	3.18	1.81	-1.02	0.08	0.79	0.00	-1.30
LIV O1	4.90	1.06	-0.42	0.14	0.64	-1.94	6.48
LIV O2	4.57	0.42	0.08	0.38	0.49	-3.02	10.16
LIV O3	2.45	2.11	-1.33	0.42	0.78	-0.51	-1.58
LIV S1	3.09	1.81	-0.90	-0.02	0.91	-0.16	-1.36
LIV S2	3.74	1.43	-0.69	0.20	0.73	-0.16	-0.81
LIV S3	3.57	1.40	-0.57	0.07	0.83	-0.71	-0.02
MOB O1	3.23	1.28	-0.43	-0.08	0.85	-0.60	-0.45
MOB O2	3.42	1.10	-0.72	-0.08	0.38	0.64	-0.28
MOB O3	4.07	1.69	-1.10	0.06	0.59	0.81	1.30
MOB S1	3.76	1.65	-0.84	0.04	0.81	0.11	-0.81
MOB S2	3.89	1.42	-0.59	0.02	0.83	-0.49	-0.34
MOB S3	4.99	0.85	-0.32	0.14	0.53	-0.91	2.27

The values of the statistical parameters indicate the differentiation between variables. There is no variable that could unambiguously distort the results of the ranking. Variables can be considered as appropriately selected.

2.2. Methods

The TOPSIS method was proposed to build the ranking (Yoon, & Hwang, 1995; Li et al., 2020; Gutiérrez et al., 2020).

We assume that we have to evaluate m objects described by n variables. First, a standardization procedure is carried out. For the stimulant, the variable is determined by the formula (1) and for the destimulant by the formula (2)

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \tag{1}$$

$$z_{ij} = -\frac{x_{ij} - \bar{x}_j}{s_j} \tag{2}$$

where:

x_{ij}– observation of the j-th indicator, for the i-th object,

$\bar{x}_j$– the average value for j-th indicator,

s_j– standard deviation value for j-th indicator.

TOPSIS method

The TOPSIS method uses two reference points (pattern and anti-pattern) in relation to which the object distance is determined.

Step 1 – Determination of the pattern (3) and anti-pattern (4).

$$z_{0j}^{+} = \max\{z_{ij}\} \tag{3}$$

$$z_{0j}^{-} = \min\{z_{ij}\} \tag{4}$$

Step 2 – Determination of distance from the pattern (5) and anti-pattern (6).

$$d_{0i}^{+} = \sqrt{\sum_j (z_{0j}^{+} - z_{ij})^2} \tag{5}$$

$$d_{0i}^{-} = \sqrt{\sum_j (z_{0j}^{-} - z_{ij})^2} \tag{6}$$

Step 3 – Determining the aggregate variable value (7).

$$q_{\mathrm{i}} = \frac{d_{0i}^{-}}{d_{0i}^{-} + d_{0i}^{+}} \tag{7}$$

In the TOPSIS method, the higher the values of the aggregated variable, the better the object.

Smart City TOPSIS (SCI2T) Index

The higher the values of the aggregated variable, the better the object.

$$\mathrm{SCI2T} = TOPSIS(I_{TOPSIS_i}) \qquad (13)$$

for the area

$$I_{TOPSIS_i} = TOPSIS(\{I_{ij}\}) \qquad (14)$$

where

I_{ij} – value of the j-th variable, a measure included in the i-th area,

$TOPSIS()$ – application of the TOPSIS method to a group of indicators describing the objects,

I_{TOPSIS_i} – aggregate variable values for the i-th area.

The TOPSIS method is used twice to determine the ranking. It is used the first time for footnotes for specific area indicators. The second time, for the aggregated values obtained in individual areas.

3. Results and discussion

Based on the proposed method and TOPSIS, the following city ranking was obtained.

Table 5.
Ranking results

CAPITAL	SCI2T:	ECO	ENV	PEO	LIV	MOB	TOPSIS
Helsinki	1	12	2	8	4	12	2
Stockholm	2	11	3	9	2	22	4
Tallinn	3	3	1	12	13	6	1
Oslo	4	7	13	2	1	18	3
Copenhagen	5	17	6	6	3	23	9
Amsterdam	6	9	9	7	10	13	5
Vilnius	7	1	5	5	23	20	6
Luxembourg	8	20	7	4	15	8	8
London	9	8	12	18	5	15	10
Dublin	10	21	8	3	11	24	11
Vienna	11	19	4	21	17	4	12
Prague	12	2	19	15	16	2	7
Berlin	13	16	11	25	9	9	13
Ljubljana	14	26	10	1	26	16	15
Riga	15	5	14	23	20	19	17
Paris	16	14	23	11	6	5	14
Brussels	17	22	16	14	7	17	18
Warsaw	18	13	18	16	18	7	16
Bratislava	19	6	17	24	22	10	19
Budapest	20	10	21	13	24	11	20
Lisbon	21	15	15	20	12	27	23
Madrid	22	27	20	19	8	3	22

Cont. table 5.

Sofia	*23*	*4*	*25*	*17*	*21*	*1*	*21*
Zagreb	24	25	22	10	19	21	24
Rome	25	24	24	27	14	26	25
Bucharest	26	18	27	22	27	25	27
Athens	27	23	26	26	25	14	26

The method allows assessment of the city within each of the defined areas plus an overall assessment. The high position of Scandinavian cities is associated with a high rating in areas related to living conditions and the natural environment. Tallinn, in the third place on the ranking list, also owes its position to two areas in which it received high ratings. The relatively low position of the cities hitherto considered to be leaders may be caused by the inclusion of subjective ranking measures. The smaller the city, the smaller the problems of its inhabitants may seem. Possible problems are easier to solve. Cultural differences may also cause that this group of cities with a similar geographical location achieved a similar result.

The analysis of the differences between the rankings and the SCI2T ranking shows that there are no fundamental differences between the presented new ranking method and the general TOPSIS method. The maximum shift in the ranking is 5 places.

Table 6.
Ranking results – comparison to SCI2T results

CAPITAL	ECO	ENV	PEO	LIV	MOB	TOPSIS
Helsinki	-11	-1	-7	-3	-11	-1
Stockholm	-9	-1	-7	0	-20	-2
Tallinn	0	2	-9	-10	-3	2
Oslo	-3	-9	2	3	-14	1
Copenhagen	-12	-1	-1	2	-18	-4
Amsterdam	-3	-3	-1	-4	-7	1
Vilnius	6	2	2	-16	-13	1
Luxembourg	-12	1	4	-7	0	0
London	1	-3	-9	4	-6	-1
Dublin	-11	2	7	-1	-14	-1
Vienna	-8	7	-10	-6	7	-1
Prague	10	-7	-3	-4	10	5
Berlin	-3	2	-12	4	4	0
Ljubljana	-12	4	13	-12	-2	-1
Riga	10	1	-8	-5	-4	-2
Paris	2	-7	5	10	11	2
Brussels	-5	1	3	10	0	-1
Warsaw	5	0	2	0	11	2
Bratislava	13	2	-5	-3	9	0
Budapest	10	-1	7	-4	9	0
Lisbon	6	6	1	9	-6	-2
Madrid	-5	2	3	14	19	0
Sofia	19	-2	6	2	22	2
Zagreb	-1	2	14	5	3	0
Rome	1	1	-2	11	-1	0
Bucharest	8	-1	4	-1	1	-1
Athens	4	1	1	2	13	1

There are clear differences between the overall rating and the ratings in individual areas. The differences cover even 22 places in the rankings.

Table 7.
Pearson's linear correlation coefficients between values and ranks

	SCI2T:	ECO	ENV	PEO	LIV	MOB	TOPSIS
SCI2T:		0.42*	0.90*	0.63*	0.59*	0.04	0.98*
ECO	0.49*		0.22	0.06	0.02	0.24	0.50*
ENV	0.83*	0.18		0.52*	0.42*	-0.04	0.83*
PEO	0.66*	0.13	0.49*		0.28	-0.10	0.63*
LIV	0.61*	0.06	0.50*	0.27		-0.06	0.54*
MOB	0.32	0.22	-0.01	0.09	-0.07		0.18
TOPSIS	0.98*	0.41*	0.89*	0.69*	0.64*	0.19	

* Significant correlation at 0.05 (bilateral).

Table 7 presents Pearson's linear correlation coefficients between the rankings obtained (values below the main diagonal) and the values of the relevant aggregates (values above the main diagonal). SCI2T and TOPSIS rankings show the strongest mutual correlation. The positions in the ranking differ the least from all analysed. The position in the ranking is most strongly influenced by the position in the ENV area. PEO and LIV area-related positions show comparable effects. The next areas in order of impact are ECO and MOB.

4. Conclusion

The proposed concept of determining the city ranking not only allows the assessment of the city but also its assessment in individual areas. Therefore, it is a better proposition than the basic TOPSIS method. Interestingly, Scandinavian capitals are positioned in the best places. On the one hand, we should remember that the assessment was built based on the residents' survey results. It is possible that the impact of these assessments should be limited by introducing the possibility of including weights in the method. At the moment, the method is consistent with the weights for sustainable development, where their equality is assumed. Further work should focus on the possibility of introducing weights and showing their impact on the ranking order. Determining the impact on the ranking of subjective ratings will be significant.

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