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Structure and dynamics of a public bike-sharing system. Case study of the public transport system in Białystok

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ABSTRACT

The article presents the results of a research project referring to the dynamics of the public bike-sharing system BiKeR (Białystok, Poland) in 2014-2015. Identification of the dynamics of the system permits modifications that lead to the enhancement of the efficiency and help to determine the reasons for the choice of a location for new bicycle stations. The basic methodology used for compiling data were the statistical methods with special emphasis on network analysis and graph theory.

Analysis of the data allowed us to identify the mechanisms of changes in the system affecting its dynamics, especially in the area of network topology changes in conjunction with the location of network nodes (stations). The research and analysis showed the specificity of PBS as a transport network. The PBS network, the process of analysis, the value of network metrics and their distribution differ significantly from other types of transport networks (including municipal). The results improve decision-making processes related to the creation and modification of a PBS network, especially in the field of process support, the choice of station location and the impact of these choices on the networks dynamics (as a prognostic utility).

KEY WORDS

public bike-sharing system (PBS), network dynamics, network analysis

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Introduction

The study of transport networks has a long history. One of the features of this type of research is the interdisciplinarity. In recent years, we have seen a growing interest in this field of study due to the development and implementation of methods for network analysis, mainly, the Internet research. Traditional studies of transport networks took flows of people or cargos as their basis, and these flows were connected with the optimization of costs, maximization of flows and the determination of the shortest transport paths. The main direction of the research was statics network associated with the structure topology. The prevalence of methods of the social networks analysis (SNA) has led to an increased interest in the dynamics of processes in the network associated with changes in time and issues of evolution.

In the case of urban transport networks, the widest representation in the literature includes research of transportation by bus. Due to the relatively short period of existence of urban cycling systems, the study of their dynamics is understood as a variation of the system (organisation) in time and are at an early stage of development. This article is an attempt to fill this gap. The authors examine the changes, which were applied to the urban bike-sharing system BiKeR (Bialystok, Poland) in its first two seasons of operation. The results were compared with studies by other authors on other personal communication systems of both urban and global character (airline network). The comparison of research results was also aimed at identifying tools and research methods that can be applied to urban bike systems.

1. Literature review

In the literature, there are three (or rarely four) generations of PBS (Shaheen & Guzman, 2011). The standard first-generation system is called the White Bicycle system, which originated in Amsterdam in 1965. The system was free-of-charge, which led to numerous thefts and destruction. The implementation of the system was a failure; however, the PBS concept survived.

The introduction of city bikes in Copenhagen in 1995 is considered as the beginning of the second-generation systems. The system involved a fee and worked on a coin-deposit principle. Assumptions of this system have not changed in the next generations of PBS (distinctive design and colour of bicycles, special docking stations serving the basic operations on rent and return, paid rent). Experience in the operation of second-generation systems allowed gaining experience, which is used for systems of the third generation.

The introduction of BIXI in Montreal in 2009 (Faghih-Imani et al., 2014) should be considered as the beginning of the third-generation systems. BIXI offers new solutions and concepts for both technical and organisational sides, which became the basis for the third generation of PBS in Canada and the United States (Mahmoud et al., 2015; Ahillen et al., 2016). Basic features of this generation are the integration between transport and advertising functions, additional features of the docking station (user identification and payment service) and the use of advanced information technology (mobile phones, magnetic stripe cards, smartcards). Most currently operating PBS belong to the third generation. All PBS operating in Polish cities are also the third-generation systems (Klimkiewicz, 2013; Kłos-Adamkiewicz, 2014).

Some authors (Shaheen et al., 2010) postulate the separation of the fourth generation of PBS. It contains all of the features particular to the third-generation systems, but also aims for the integration of cycling with other modes of public transport (especially car sharing). The basic method of integration is common in determining the locations of stations and stops for all modes of transport. It also increases the use of advanced technological solutions (solar systems and bicycles with electric drive in order to promote the principles of sustainable development).

Most publications consider transport networks as static systems. With such a perspective, the main objective is to determine the characteristics of the network structure based on the topology, geometry, morphology and transport flows (Ducruet & Lugo, 2013). Within the static perspective of research on transport networks, two directions of research dominate: at the global level, dealing with the network as a whole and on the local level of the network by separating individual groups of nodes (Lu & Shi, 2007).

Transport networks belong to the broad category of spatial networks because their structure is closely linked to sites connected to the physical infrastructure. The physical infrastructure is determined by the mode of transport. The nature and course of the transport processes affect the durability of the relationship between flows and infrastructure. Regardless of the type of transport, networks have a durable link with nodes in the form of terminals, ports, railway stations or bus stops and their locations. Flows between nodes are dependent on the specification of transport. In the case of urban transport (subway or bus) or rail link with elements of transport, through which the flows go (roads, bridges, railway lines), those links are strict in nature (Ibarra-Rojas et al., 2015). In some modes of transport (maritime, airlines) spatial location of flows is determined by the location of the nodes, whereas the flows between nodes can take place in almost any way (Lillo et al., 2016).

On the global level, most focus is given to the accessibility of a transport network. The planning of transport infrastructure is supported by topographic measures and their impact on the mobility in the city, the suburbs or the region. Transport networks without the physical structure of the route (maritime, airline) analyse systems of cities at different levels (Dobruszkes, 2006).

On a local level, the main objective of the research is to analyse the position of each node in the network and discern node groups (clusters) within the network. Since the analysis of the whole network is complicated in terms of computing (and less useful in terms of pragmatics) there are definitely more papers and articles related to the analysis of the local transport network perspective (Farahani et al., 2013).

The development of a transport network requires analysis and understanding of the complexity and dynamics of the processes that cause changes in the transport system. The literature defines two major research problems: how the spatial organisation of the transport system changes over time and what mechanisms modify the structure. A number of techniques have been found that allow the simulation, and describe the changes (Colizza et al., 2006). A popular tool for the analysis of the network dynamics is an Agent-Based Model (Xie & Levison, 2009). ABM assumes the existence of independent components (called agents) having relationships with each other and the environment. Interactions between agents are based on simple principles and cause complex changes in the networks on the global level. ABM is a good option as a method for the analysis of the dynamics of transport networks enabling the evaluation of the models and a large variety of theoretical approaches.

There are two main procedures for the analysis of dynamics. Generative methods explaining the formation of connections between nodes take the existence of nodes with no connections between them as the initial position, and in the development process of the system, the connections are formed (as a result of action, i.e. the principles of the lowest cost or the optimization of time of transport), (Newman, 2003). The degenerative method for analysis of the initial state considers the existence of the network, in which all nodes are connected to each other. Connections represent all possible variants of paths in the system, while process dynamics change their parameters (Yerra & Levison, 2005).

The literature review allowed us to identify the specificity of urban cycling systems distinguishing them from others. The summary of differences is reported in Table 1.

Tab. 1. Network characteristics of an urban bike transport system

Parameter	Traditional public transport systems (bus, Metro)	Public Bike-sharing systems
Means of transport	Group	Individual
The influence of the user on transport move	Negligible	Significant
Route selection	Conditioned by organization and transport network topology	Any (including the possibility of returning to the original station)
Availability (by day)	As timetable	Full
Availability (per year)	Full-year	Limited by climate (usually in the summer period)
Interaction with other modes of transport	Imposed by the transport manager	Shaped by the user
The degree of the impact on user behaviour	Significant	Limited
Main substitutes of urban transport systems	Private cars	Private bikes
Possibility of transport system modification	Limited, dependent on urban infrastructure	Smaller limitations, integration with infrastructure of pedestrian flows

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2. Object of the research – the BiKeR system

The bike-sharing system was established in Bialystok in 2014. The initiative to start the bike transport system came from the city authorities. In the beginning, the city held a contest to name the system. Residents chose the name of the project from among the following options: BIKESTOK, BICIKLO (Esperanto for a single track vehicle) BiKoMobil, BKMBike, BIKER (Bialystok Bicycles Communication). Before the system began to function, two tenders for the operator of the urban bicycle-sharing system were held. Only two companies competed in the first tender. The bids submitted by the two companies were not attractive. In the second tender, only one company, namely Next Bike, made an offer. Next Bike priced its offer at PLN 4.4 million. Although the offer was PLN 1.5 million higher than expected, it was selected.

In Bialystok, on 31 May 2014, the first BSS was launched. In the beginning, 30 stations were in operation with 300 bikes. The locations of stations were established by administrative decisions. The first season of BiKeR lasted until the end of November. Bicycles were hired 347 797 times and the system registered 26 330 users.

The second season began on 24 March 2015. The system was enlarged by additional 15 stations. The locations of the stations were selected by resident votes on the system's website. These stations were equipped with 150 bicycles. The third season began on 1 April 2016. Users could choose from 46 stations and 460 bicycles. In the future, the system is expected to expand by 15 new stations.

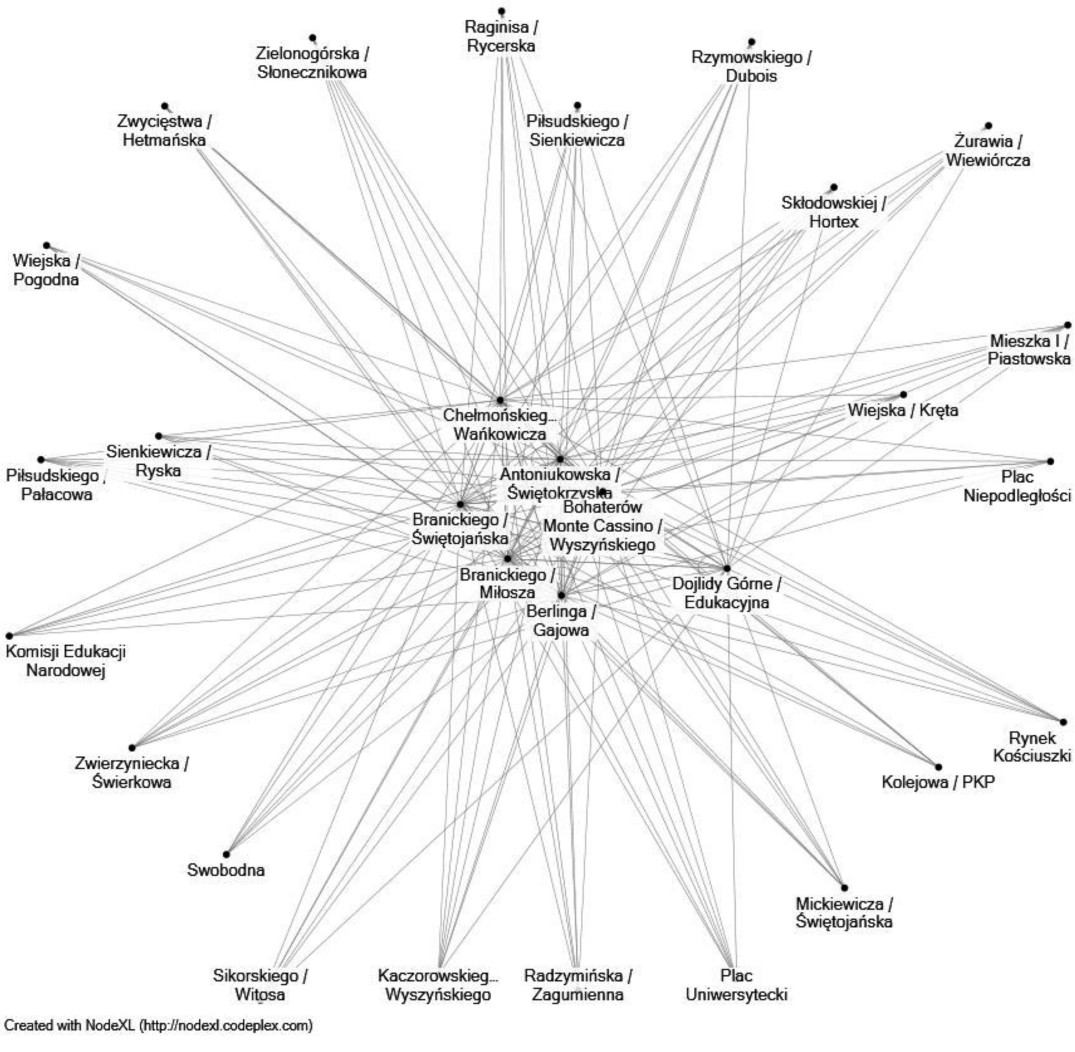

Fig. 1. Topology of the BiKeR system and flows between stations

Figure 1 shows the topology of the network BiKeR and the pattern of flows between stations. The empirical data confirm that this network has connections between two arbitrarily selected nodes (fully connected network topology or complete topology).

3. Research method

Multiple metrics have been developed for the analysis of the dynamics of networks at local and global levels (Rocha, 2016; Tarapata, 2013). The most popular metrics of the global level are:

- Betweenness centrality – the number of possible positions on the shortest path; in research practice, other variants of this measure are also used (e.g. closeness centrality or distance);
- Eccentricity – the number of connections (edges) required to achieve the furthest node in the network (graph);
- Shimbel index (Shimbel distance) – the sum of the lengths of the shortest paths connecting all nodes in the network.

Taking into account the specificities of urban bike network, which results from the analysis of comparative literature in the research part, the BiKeR system was examined mainly from a local perspective. A set of indicators for the analysis at the local level is focused on the issues of the neighbourhood node. Most measures are:

- Degree (or degree centrality) – the number of adjacent neighbouring nodes;
- Hub dependence – the share of the path having the greatest flow in the total flow of the network; it is a measure of the sensitivity of the connections;
- Average nearest neighbour degree characterized by the importance of the nodes adjacent to the analysed node;
- Clustering coefficient: the ratio between the observed nearest threes and the sum of all possible coming of threes; it is a measure of proximity and density.

The choice of a set of measures of the transport network is largely conditioned by the specificity of transport. The authors of the publication freely choose indicators depending on the purpose of research, so that the choice of indicators can vary considerably (e.g. for maritime (Wei-Bing et al., 2009), airlines (Wang et al., 2011) and the overall transport network (Sienkiewicz & Hołyst, 2005; Eagle et al., 2010). The dynamics of the bike system will be dealt with on a local level, the identification of this dynamic requires a selection of indicators grouped giving a deeper insight into this problem.

4. Results

Basic data concerning the operations of bike hire and return in Bialystok urban agglomeration for the respective seasons of 2014 and 2015 were obtained directly from the system BiKeR. Geographic data (location of stations) have been developed independently by the authors.

In this section, we present the results of statistical analysis of data on two levels of networks: local and global. At the local level, two features were considered: node-degree distribution and node clustering coefficient.

Figure 2 shows a graph of the validity of distribution network nodes of BiKeR, presented in a double logarithmic scale (note: individual points of the graph should be treated as multiple points). The distribution shows considerable differences in relation to similar ones calculated for other transport networks (can be compared with the distributions for the urban bus network (Chattterjee, 2005, Fig. 12) or airline network (Li et al., 2006, Fig. 2).

In Figure 2, the phenomenon of heavy-tailed characteristics can be seen. The chart does not pre-

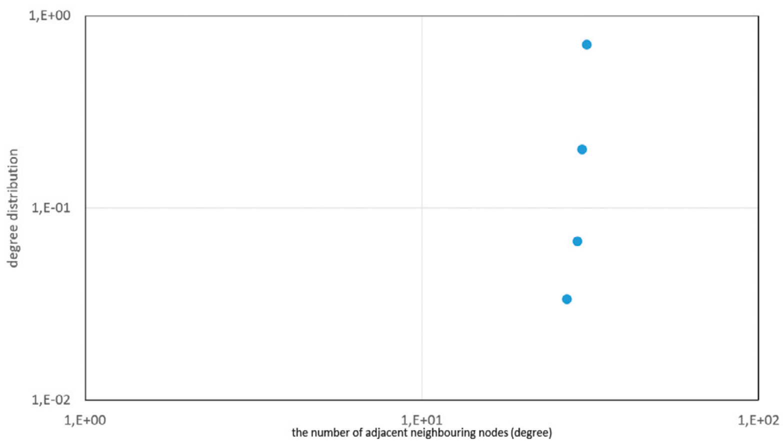

Fig. 2. Degree-distribution in the BiKeR network (double logarithmic scale)

serve the principle of power-law distribution[1]. In the discussions found in the literature, transport networks in the real world follow the principle of slower decaying distributions. Typical class networks have exponential or power law tails. The graph in Figure 2 is not compatible with any of these rules. A noticeable difference of a general nature is also a gap for the degree in the range from 0 to 10^1, not found in similar graphs for other modes of transport.

Figure 3 shows a variation factor of clustering in relation to the validity of nodes (the chart was also

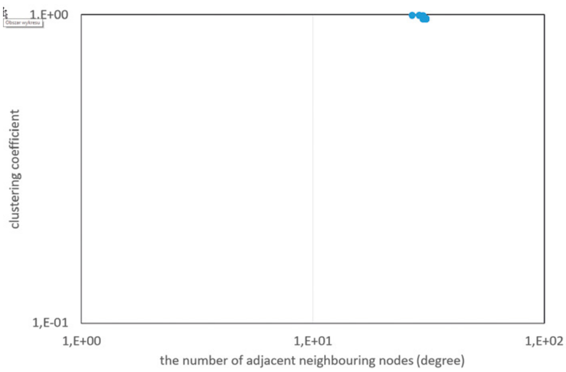

Fig. 3. Variation in clustering coefficient with the node degree in the BiKeR network (double logarithmic scale)

drawn up to a double logarithmic scale, and individual points are to be treated as multiple). There is no similarity between the graphs of these parameters prepared for other modes of transport (e.g. urban bus (Li, 2006, Fig. 15). The chart reflects the hierarchical structure of the network. The nodes with a high degree of validity serve as hubs focusing transport flows both on a local level and in general. The nodes of the lower level of importance formulate usual local clusters, concentrating flows of a local nature. Usually, transport networks existing in the real world have both types of nodes. In the BiKeR system, hub stations (nodes) dominate, which are central agents that focus the flows and interact with each other.

For the analysis of transport networks on the global level (topology), the most common indicators are node centrality and connectivity. Figure 4 shows the distributions of two indicators: betweenness and closeness centralities (the results can be compared with the same indicators for the urban bus network (Chatterjee, 2015, Fig. 12).

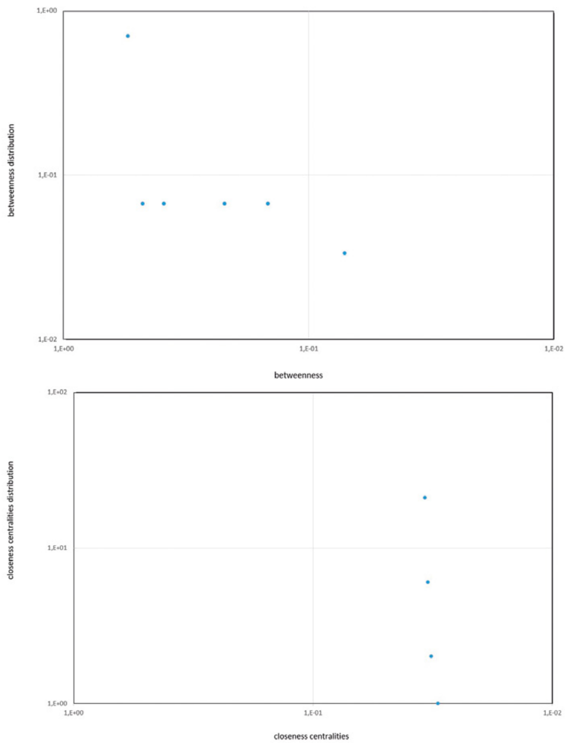

Fig. 4. Betweenness and closeness centralities for the BiKeR network (double logarithmic scale)

5. Discussion of the results

The studies analysed the properties of the urban bike network using statistical methods. The analyses revealed significant differences between the characteristics of a bike network and networks of other modes of transport. The bike networks show similarities to other transport networks. From the geographical perspective, they belong to urban (agglomeration) transport, which suggests a resemblance to bus networks. From the perspective of the infrastructure functionality, bike networks should have characteristics that are similar to networks of sea or air transport (fixed hub locations, the ability to change routes between hubs). The comparison of characteristics of the network and their distributions (degree distribution, clustering coefficient, betweenness and closeness centralities) showed significant differences between cycling networks and other types of transport networks. The main observed differences:

- Lack of hubs in bike networks with a small number of connections (low degree coefficient); bike networks are almost exclusively hub nodes that generate a connection not only with neighbouring nodes (stations) but also with more additional stations (greater distances); the characteristic of

1 In statistics, a power law is a functional relationship between two quantities, where a relative change in one quantity results in a proportional relative change in the other quantity, independent of the initial size of those quantities: one quantity varies as a power of another.

the bicycle network is the creation of complete networks, in which the nodes are interconnected;
- In bike networks, we do not observe the typical distributions characteristic of other networks; in transport networks, two types of distributions dominate: the exponential and Poisson distributions; distribution network indicators in bicycle transport are chaotic in nature;
- Nodes (stations) in the bike network tend to create a smaller number of strong clusters (steady state – low dynamics);
- The dynamics of the network bikes is degenerative; the choice of the location of a station is made by administrative decision or by voting (e.g. a plebiscite); new nodes form connections with all existing nodes.

Conclusions

The study by the authors allowed reviewing the current state of knowledge about bike networks, tools used for the analysis and the determination of the network characteristics. Despite a significant increase in the interest of the problems PBS face and a significant increase in publications on the subject, this research area requires a greater exploration. The research enables the development of a series of demands regarding the future research.

The dynamics of the systems are related to their variation in time. PBS are a new phenomenon in the context of transport networks, historical data about their functioning only dates back to a few years at the most (in the case of the BiKeR system, the maximum period of two years, i.e. from 2014 to 2015, can be considered, which is similar to the situation in other Polish cities). The initial stages of the development of PBS are also characterized by changes in the infrastructure (adding new stations), which cause temporary disturbances in the network and variations in the characteristics. At the initial stage of development, the PBS network has a small number of nodes (stations).

Network analysis tools (especially in the dynamically developing field of social network analysis) focus on the issues of topology (configuration) of the surveyed network. The strength of connections (flow volume) between nodes is usually a secondary issue. The conducted analysis, as well as the value and distributions of the network characteristics, indicate the need for tool identification for a deeper analysis of bike networks. It appears that in the case of PBS, it is necessary to use weighted indicators.

The analysis of transport networks is a prerequisite for their modifications and changes. The primary objective of the authors is to strive for the optimal configuration of transport networks. The results of the analysis should also be applied in field-level user support and serve for the improvement of the service. Previous work focused on the supply side (transport infrastructure); however, the demand side (users) requires a deeper and broader analysis.

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Assessment of urban transport – a comparative analysis of selected cities by taxonomic methods

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ABSTRACT

This paper aims to perform comparative analysis of urban transport in selected global cities and to verify the existence of clusters. It was based on data source from the World Organization Data Urban. It used Indicators proposed in ISO 37120 Sustainable Community Development.

The test procedure exploited taxonomic methods as Ward's hierarchical analysis and the deagglomerating k-means analysis. The empirical analysis comprises four indicators: (I) high capacity public transport system, (II) light passenger public transport system, (III) annual number of public transport trips and (IV) number of personal automobiles.

Main results are the classification of selected global cities, identification and characterization of trends in the field of urban transport in each group. The empirical analysis confirms a substantial diversity of urban transport in selected cities. These differences arise from their past, geographical location, size, different reactions to the transition process and the different economic structures. The taxonomic analysis of the urban transport in selected cities separated five independent classes typological. This elaboration aims to examine the role of urban transport in city management based on a literature review, databases and reports of the European Union.

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urban transport, ISO 37120, smart city, taxonomic, city management

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Introduction

Urban transport is a significant component of city management used worldwide. Sustainable public transport prevents social exclusion, congestion, and air pollution in cities. However, so far there has been no standardized method to measure the quality of life and delivery of public services in cities. ISO 37120 Sustainable Community Development provides a uniform and consistent approach to measurement methods of city performance. Urban transport is one of 17 thematic areas.

The main goal of the study is to determine trends in the field of urban transport, to classify global cities and to verify the existence of clusters. The article consists of four sections. The first part includes deliberations of the scientist concerning urban transport.

The next sections present the data and research methods. The last two parts of the study contain results and conclusions of the examination. The elaboration was based on literature studies and taxonomic analysis. The data obtained from the database of the Central Statistical Office – Local Data Bank, Eurostat Regional Statistics and the World Organization Data Urban.

1. Literature review

A constantly growing number of urban residents makes access to public service more difficult and, consequently, reduces the quality of life (Mucha, 2012). Currently, 54% of the world's population resides in cities, whereas forecasts indicate an increase of up to 66% in 2050 (United Nations, 2015). Approximately 85% of the EU's GDP is generated in cities (Dobbs et al., 2012). The increase in road traffic as well as passenger and freight transport, cause congestion and air pollution. Urban transport became an important component of city management in international documents in the last decade (Table 1). Forecasts of the European Commission show that the intensity of freight transport will increase by 40% by 2030, and by more than 80% by 2050, when compared to 2005. At the same time, it is expected that passenger transport will also increase by about 34% by 2030, and by more than 50% by 2050, in comparison to 2005 (White Paper, 2011). Based on the result of a study conducted in seven major Polish cities, it is estimated that in 2013, costs related to congestion will reach PLN 3.5 billion (average of 2.905 per driver). Additionally, external costs of accidents in urban areas are estimated at EUR 80 billion per year, and the external costs of noise – at EUR 40 billion per year. Furthermore, CO_2 emissions in urban areas amount to 280 million tons per year (Rzepnikowska et al., 2014).

City management in the field of urban logistics is influenced by the regulations at the European Union level (Table 1). The European Commission has developed several documents imposing on the cities the obligation to take action towards the improvement of passenger and freight traffic in the city and to reduce environmental degradation. One of the requirements of the EU towards the member states is the necessity to develop sustainable mobility strategies, including passenger and freight transport. Unfortunately, many cities have not prepared this document (Allen et al., 2015; Przybyłowski, 2014).

Tab. 1. Transport on the background of domains of city management in international documents

Documents	Domains of city management
Pact of Amsterdam, 2016	Inclusion of migrants and refugees; Air quality; Urban poverty; Housing; Circular economy; Jobs and skills in the local economy; Climate adaptation (including green infrastructure solutions); Energy transition; Sustainable use of land and Nature-Based solutions; **Urban mobility**; Digital transition; Innovative and responsible public procurement
ISO 37120, 2015	Economy, Education, Energy; Finance; Environment; Fire and emergency response; Governance; Health; Recreation; Safety; Shelter; Solid waste; Telecommunication; **Transportation**; Urban planning; Wastewater; Water sanitation
Leipzig Charter, 2007	Energy efficiency; Environment; Labor market; Education; **Urban transport**
Bristol Accord, 2005	Well run; **Well connected**; Well served; Environmentally sensitive; Thriving; Well designed and build; Fair for everyone; Active, inclusive and safe

Source: author's elaboration based on (*Urban Agenda* ..., 2016; ISO 37120 ..., 2015; *Leipzig Charter* ..., 2007; Bristol Accord ..., 2005).

Integrated city management requires specific knowledge of how to take effective strategic decisions. Effective city management is based on information that can be obtained through quick access to reliable data. A smart city should be built through the implementation of goals and decisions based on reliable data. ISO 37120 should be used to measure the city performance. The standard value does not include evaluation data and quantitative limits; it only provides a framework for the sustainable development of the city and its monitoring. It allows to compare cities in a global perspective and to benefit from the knowledge and skills of the leading urban centres. This is the right tool for reporting the state of city development. There are four levels of accreditation certificate. The minimum limit is to collect data for 30 obligatory indicators. World Organization Data Urban disseminates a new international standard for cities and coordinates efforts to obtain accreditation by sharing city data. It publishes information regarding 30 cities.

Sustainable urban transport improves the quality of life in urban areas. The results are a wide range of advantages, such as a more attractive public space, improvement in the city's image and increase in competitiveness, health improvement, better road safety, lower air pollution and reduced noise emissions (Komisja Europejska, 2014). Improving the quality of urban space can be achieved through the promotion of public transport and alternative forms of movements within the cities (Ministerstwo Infrastruktury i Rozwoju, 2015). It may help to inhibit the process of suburbanization and revitalize city centres. Road investments should mainly focus on the construction of a basic transport system of the city and its functional area, which will enable the removal of excessive traffic through the ring roads of the city and exit routes to national roads. It is necessary to modernize the existing road system by eliminating bottlenecks and improving traffic safety, which is the priority of public transport and cycling.

Improvement of urban mobility can also be achieved through the appropriate coordination of timetables among different means of transport. The integration of railways, subways, buses, and trams requires, among other things, a rhythmic timetable, dynamic passenger information, and proper interchanges locations. This solution constitutes a part of the category of a multi-modal trip, which is to leave the personal means of transport in the car park and to continue the onward journey to the city centre by public transport. It is also worth mentioning here the existence of an Intelligent Transportation Systems, which allows for the management of road traffic, rail, public transport, fleet and cargo transport. These are devices that can investigate and inform drivers about traffic jams or vacant parking spaces.

The public transport measurement is rather challenging because of a diversified approach to this matter in the substantive literature and various international and national strategic documents (European Commission, 2013). However, it is possible to determine and select the indicators that are commonly and repeatedly applied in the very approach to the measurement of the progress of implementation of public transport. The quantitative approach of the measurement applicable to the transport phenomena is generally easier to measure directly. Quantitative data refer to information measured numerically (Mingardo, 2008; Pindea, 2016). Quantitative data are recognized as more objective and easier to be analysed, e.g. the speed of moving vehicles and their communication delays. The qualitative approach measurement of specific phenomena of transport is more difficult to estimate. The qualitative data are related to a different type of information, e.g. convenience, comfort, and dynamism in the opinion of users (Nieuwenhuijsen, 2016). Qualitative data can be expressed as quantitative, using a rating system or different evaluation techniques used in economics. Another division of indicators is reflecting the economic, social and environmental influences. Economic dimension indicates the profitability of transport, as the cost per unit of travel (Fielbaum et al., 2016; Taylor, 2008; Medda et al., 2003). The social dimension reflects the relative mobility and financial burden of the population in connection with the use of transport. The environmental dimension shows different emissions caused by transport and field requirements (Table 2).

The great challenge in the field of urban transport is to reduce the use of cars in favour of alternative forms of movement, which have a positive environmental impact, such as a cycling or walking. Furthermore, alternative forms of movement reduce congestion, at the same time improving health and physical condition of travellers. Poles have about 9 million bicycles but in large cities, cycling remains at a low level, constituting 1–3% of total journeys. To compare, in some European cities, such as Kuopio, Cambridge, Stralsund, cycling amounts to 30% of total journeys (Fig. 1).

Tab. 2. Approach and domains of urban transport in scientific literature

<table>
<tr><th colspan="2">Approach based on quantitative data</th><th colspan="2">Approach based on qualitative data</th></tr>
<tr><td colspan="2">– user preferences
– convenience and comfort
– the dynamics of community
– aesthetic qualities</td><td colspan="2">– length of linear infrastructure
– the number of kilometres travelled per vehicle and per person
– traffic accidents and fatalities
– expenses and revenues</td></tr>
<tr><th>Mobile dimension</th><th>Economic dimension</th><th>Social dimension</th><th>Environmental dimension</th></tr>
<tr><td>– the supply of transport service
– the organisation of mobility inside city</td><td>– cost incurred by community</td><td>– the number of vehicles in the household
– the distance flown individually
– expenditure by households on transport</td><td>– annual energy consumption and emissions of CO_2, CO, NO_x, hydrocarbons, particulate matter
– se of public space for parking and transport infrastructure
– noise
– risk of accidents</td></tr>
</table>

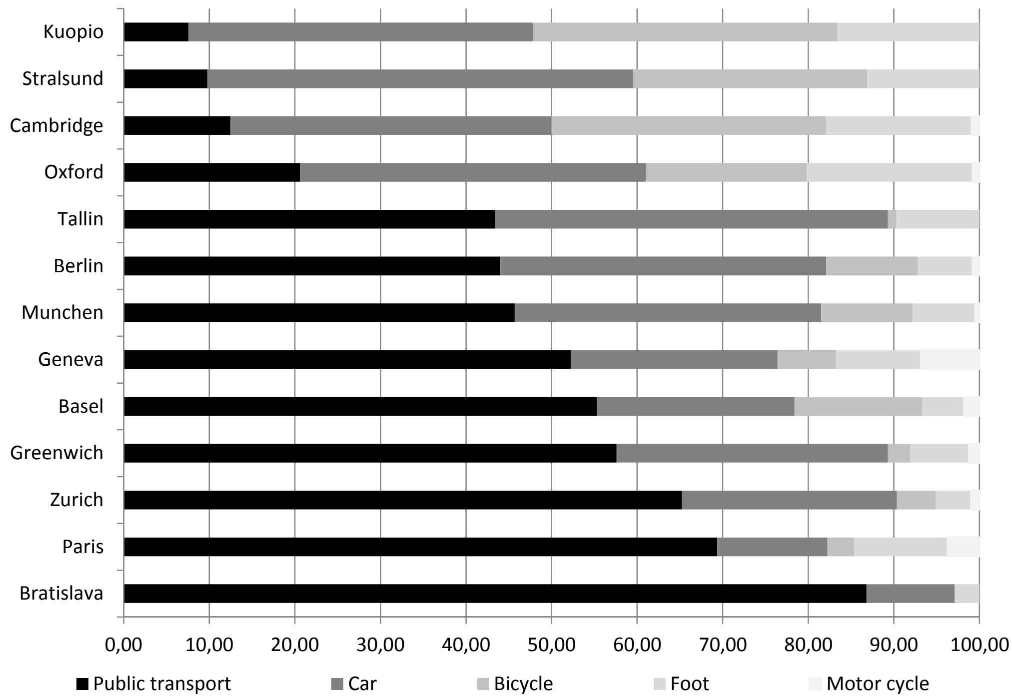

Fig. 1. Share of the use of transportation modes in European cities [%]
Source: author's elaboration based on (Eurostat, 2016).

The collective public transport uses several systems of transport: bus, tram, railway, trolleybus, and metro. In relation to passenger cars, it brings two important advantages – reduces traffic congestion and environmental impact. Compared to individual transport, a bus emits five times less pollution, requires three times less energy per passenger, and twenty times less road surface. A particularly advantageous solution in this respect is bus lanes. 24 Polish cities with powiat status have 196 km of bus lanes allocated for public transport vehicles (Table 3).

Tab. 3. Cities with powiat status with the greatest length of bus lanes

Cities	Length of bus lines	Number of buses	Buses lines per 100 buses
Kielce	15.3	576	2.66
Olsztyn	13.3	657	2.02
Białystok	12.8	857	1.49
Łódź	18.9	1 363	1.39
Kraków	25.2	2 458	1.03
Wrocław	21.5	2 129	1.01

Source: author's elaboration based on (Bank Danych ..., 2016).

Moreover, many scientists analyse transport in a national and regional approach (Czech & Lewczuk, 2016). There are only few publications that compare transport in cities. Urban transport often appears in case studies (Paradowska, 2012; Zimon & Gosik, 2015), analyses of the key success factors (Iwan, 2015) or benchmarking (Chojnacka, 2012; Szymczak & Sienkiewicz-Małyjurek, 2011; Kiba-Janiak, 2016). Scientists use the latest future-oriented methods to evaluate transport (Ejdys et al., 2015).

2. Research methods

The presented research focused on the assessment of urban transport. The scope of research has three steps: selection, evaluation, and classification (Fig. 2). Four indicators were selected from ISO 37120:2014, namely: (X_1) kilometres of high capacity public transport system per 100000 population; (X_2) kilometres of light passenger public transport system per 100000 population; (X_3) the annual number of public transport trips per capita; and (X_4) the number of personal automobiles per capita.

The study included 25 cities (Table 4) with different levels of certification according to ISO 37120:2014, i.e. aspiring (the cities), gold (three cities), and platinum (12 cities). They represent each continent: six cities were European, ten – North American, one –

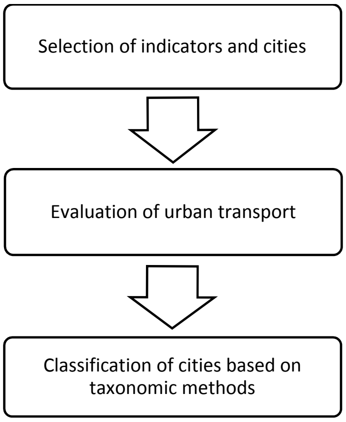

Fig. 2. Scope of the research process

South American, five – Asian, two – Australian, and one – African. Data for each city were collected from the website of the World Organization Data Urban (World Council …, 2016).

Tab. 4. Certification level of cities per ISO 37120:2014

Level of certification in ISO 37120:2014	Cities and abbreviations
Aspiring	ES1 Barcelona; NL2 Rotterdam; US2 Los Angeles; CA1 Surrey; CA4 Toronto; CA5 Vaughan; AU1 Greater Melbourne; AE1 Dubai; VN1 Haiphong; TW1 Amman
Gold	NL1 Amsterdam; PT1 Porto; CA3 Shawinigan
Platinum	UK1 London; ES2 Valencia; US1 Boston; US3 San Diego; CA2 Saint-Augustin-de-Desmaures; MX1 Guadalajara; MX2 Leon; AR1 Bueno Aires; AU2 Melbourne; PH1 Makati; JO1 Taipei; SA1 Makkah.

Abbreviations of cities based on ISO 3166.

Source: author's elaboration based on (World Council …, 2016).

Each indicator was determined by measuring the position (arithmetic mean,) and variability (standard deviation, S_X; variation coefficient, V). Indicators were standardized based on formula . The Pearson's correlation coefficient matrix was used to determine the correspondence among indicators and to eliminated strongly correlated indicators. The classification of cities applied the Ward's hierarchical analysis for the Euclidean distance based on formula. The number of classes was determined by using a graph of distance bond with respect to binding steps. Each aggregation was characterized based on the deagglomerating k-means method.

3. Research results

The most differentiated indicator (177.82%) is the length of high capacity public transport system. While the least differentiated variable (48.93%) is the number of public transport trips. Melbourne has the longest public transport system. Bueno Aires has the largest number of personal automobiles per capita (Table 5).

Tab. 5. Selected statistics of urban transport indicators

	X_1	X_2	X_3	X_4
	11.64	121.54	316.22	0.42
S_X	20.70	90.35	454.65	0.21
V	177.82	74.34	143.77	48.93
Max	AU2 102.87	AU2 293.57	PH1 2097.25	AR1 0.75
Min	CA1 CA2 PH1 TW1 SA1 0.00	PH1 3.25	TW1 2.29	VN1 0.01

Source: author's elaboration based on (World Council …, 2016).

Correlation among indicators was determined based on the Pearson's correlation coefficient (Table 6).

Tab. 6. Pearson's correlation matrix of urban transport indicators

	X_1	X_2	X_3
X_2	0.385836		
X_3	0.341173	-0.057860	
X_4	0.437447	0.348036	-0.162726

Source: author's elaboration based on (World Council …, 2016).

Values of the correlation coefficient were positive except for two pairs. The strongest correlation was between the length of high capacity public transport system with the number of personal automobiles. Negative values of the correlation coefficient were observed in the following relations: the length of light passenger public transport system vs. the annual number of public transport trips as well as the annual number of public transport trips vs. the number of personal automobiles.

Using agglomeration Ward's method for the Euclidean distance, 25 cities were divided into five classes. Applying the chart that compares the binding distance chart to binding levels, the limiting distance was established at the level of 5.0. The taxonomic analysis of the urban transport in selected cities separated five independent typological classes. First and

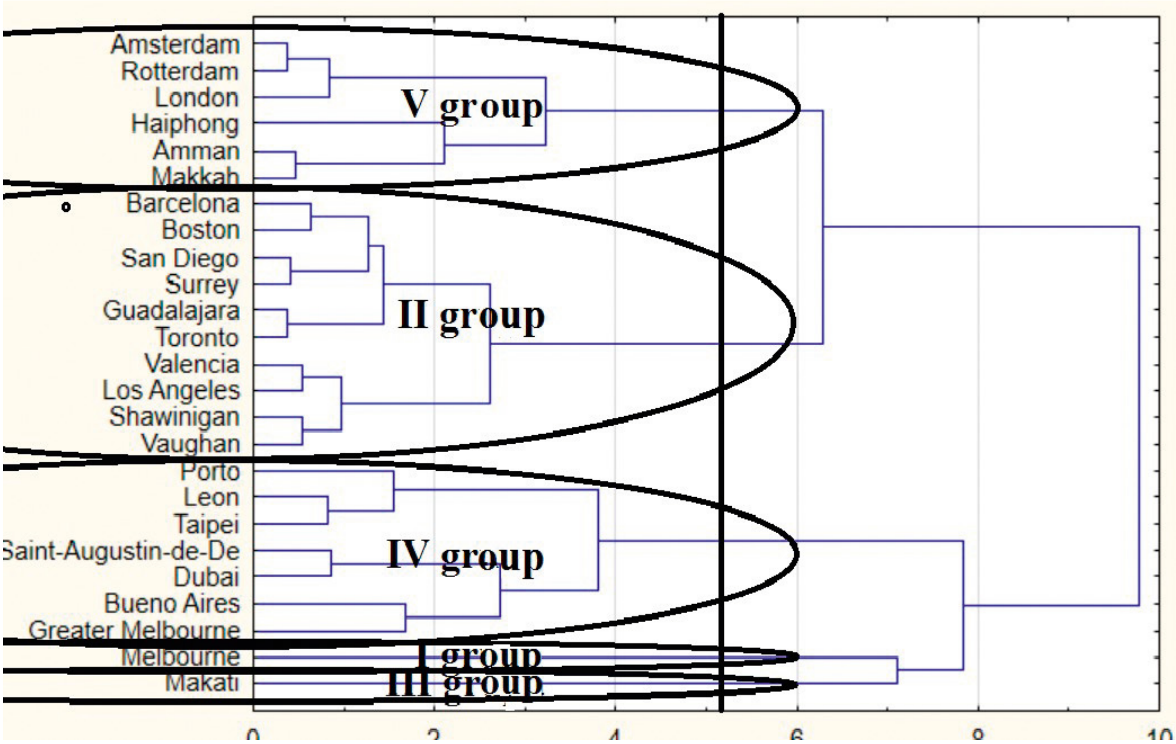

Fig. 3. Scheme of the cluster analyses

third class are constituted by a single element. The second group consists of ten mostly American and Canadian cities. The majority of European cities fall in the fifth class. The fourth cluster includes seven cities (Fig. 3).

Classes have been characterized using k-means methods. The first group has the highest capacity value of the public transport system, while the third cluster has the lowest. The first group has the highest value of the light passenger public transport system, while the third cluster has the lowest. The third cluster has the highest value of the annual number of public transport trips, while the second cluster has the lowest. The first group has the highest number of personal automobiles, while the third cluster has the lowest.

4. Discussion of the results

The first group consists of one-element. Melbourne has a public transport system characterized by high levels of capacity. However, transport in Melbourne consists of an extensive network and a wide variety of transport services. The second class has ten objects, such as Barcelona, Valencia, Boston, San Diego, Los Angeles, Surrey, Shawinigan, Toronto, Vaughan, and Guadalajara. The cities have the lowest value for the light passenger public transport system. The third cluster consists of one element. Makati is characterized by high levels of the annual number of public transport trips because of jeepneys (they were introduced after the World War II and made from leftover US military jeeps in the Philippines). The fourth class includes seven objects, namely Porto, Leon, Taipei, Saint-Augustin-de-Desmaures, Dubai, Bueno Aires, and Greater Melbourne. These cities are characterized by the average value of all indicators. The fifth group consists of six objects: Rotterdam, Amsterdam, London, Haiphong, Amman, and Makkah. These cities are characterized by the average value of all indicators (Table 7).

Tab. 7. Average values of urban transport indicators for each group

	X_1	X_2	X_3	X_4
Unites	km	Km	capita/yr	-
GI	102.87	293.57	1009.18	0.72
GII	6.49	88.56	146.70	0.51
GIII	1.10	3.24	2097.25	0.06
GIV	11.47	220.94	314.03	0.49
GV	6.99	51.58	188.98	0.21

Source: author's elaboration based on (World Council ..., 2016).

Conclusions

An efficient and effectively functioning transport in the city is important for residents and enterprises. As a part of the production and consumption, it is an integral part of the modern economy and society. However, apart from the positive impact transport also amounts to numerous social costs, including congestion, accidents, and negative impacts on the environmental.

The results obtained in this research show that selected cities are characterized by great diversity in the field of urban transport. These differences arise from their past, geographical location, size, different reactions to the transition process, and different economic structures. The taxonomic analysis of the urban transport in selected cities separated three independent typological classes (beyond the first and the third group, consisting of one element, respectively, Melbourne and Makai).

The author understands that due to the small sample and the huge variety of cities, generalised conclusions are hardly possible. However, the results of this study can be treated as guidance for reflection and further research.

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Multidimensional assessment of the European Union transport development in the light of implemented normalization methods

Artur Czech, Jerzy Lewczuk, Artur Bołtromiuk

A B S T R A C T
Transport is considered a basis for socio-economic development. It is closely connected with the process of movement of products and humans. The main aim of the paper is to investigate the influence of different order normalization methods in the synthetic measure construction implemented in the assessment of the development of European Union member states in the area of logistic, especially transportation system. Moreover, the article attempts to investigate the influence of such methods on linear ordering in multi-criteria taxonomic approach.
The source of information in the research is the data drawn from Eurostat, the statistical office of the European Union. The main method in this study is the order synthetic measure constructed with Weber median in different forms due to implemented normalization methods.
The main result of the carried out analysis indicated that the development level of three main branches of a transportation system correlates with the socio-economic development of particular member states. Furthermore, the assessment process based on the synthetic measure construction can lead to differences in linear ordering due to the implemented normalization methods. The research on the transport development can bring a better understanding of the socio-economic development of particular areas of the European Union. Hence, the results can be helpful to European policy makers for the allocation of support funds.

K E Y W O R D S
transport, European Union member states, synthetic measure, normalization

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Introduction

As a European Union member state, Poland is a part of the structural policy. The main imperative of its activity is to increase the state, regional and local cohesion. It is caused by the fact that excessive spatial disproportions are considered a factor of negative external effects for the whole European Union. Moreover, it becomes much more important in the face of globalization effects because the world economy has changed significantly and globalization needs new logistic dynamics (Kherbash & Mocan, 2015). Hence, transport plays an important role in the management process of logistics and has already been considered one of the cornerstones of the globalization process (Kumar & Hoffmann, 2002).

The economic growth and foreign trade determine the level and structure of transportation demand (Proniewski et al., 2005). Going further, the Gross Domestic Product, consumption level, the structure of household expenditures, technology innovations, fuel prices and other phenomena are considered factors of transportation demand. On the other hand, transport influences the economic growth and job creation (White Paper, 2011), which results in the demand for many products and services. The relationships in the area of transport and their links with economy and society are mutual and very hard to quantify. Thus, transport is considered as a complex phenomenon where different and directly unobservable interactions play a key role. Hence, the studies in that area are especially sophisticated and require special tools. Taxonomy brings many opportunities to improve the assessment process that ought to have a positive impact on the transportation policy. Nevertheless, multidimensional statistical analysis, such as linear ordering, is ballasted with arbitrary aspects. The properly constructed synthetic measure depends on the data set selection, normalization methods, distance measure, statistical measures, etc.

The aim of the paper is to investigate the influence of order normalization methods in the synthetic measure construction implemented in the assessment process of transportation development in chosen European Union member states. Moreover, the article aims to investigate the influence of such methods on linear ordering in multi-criteria taxonomic approach to compare and improve the previous research in that area.

1. Literature review

The literature review showed that transport as a logistic branch is in the spotlight of different scientific fields and the analyses are carried out with many research tools. However, transport plays a key role in the process of reducing regional and social disparities in the European Union by strengthening economic and social cohesion (López et al., 2008).

On the one hand, transport is analysed because of its impact in the form of external effects on the environment and sustainable consumption (Gratiela & Viorela-Georgiana, 2013; Gratiela, 2013a, 2013b). Going further, the process of adaptation of the Polish transport system to the requirements of the European Union includes consideration of congestion, air pollution, impact on the environment, etc. (Wojewódzka-Król, 2015).

Moreover, transport disadvantages are strictly correlated with social exclusion and well-being (Currie et al., 2010). Transport plays an important role in the strategy development for cross-border regions (Lewczuk & Ustinovichius, 2015). Furthermore, a transportation system has already been analysed with future-oriented methods like foresight (Ejdys et al., 2015). In addition, the same research technique has been used by an interdisciplinary research team in the process of the prediction of the development of future-oriented road technologies in the context of environmental protection (Radziszewski et al., 2016).

Infrastructure adaptation is considered the most important thing in the achievement of social and economic goals, which have to improve the competitiveness of Europe and its regions. This phenomenon is very complex because of technical, economic, and environmental barriers and limitations. Hence, multi-criteria methods play a more significant role in the decision-making process in the development and modernization of transport infrastructure (Pawłowska & Koźlak, 2014).

As one of the research fields of logistics, transport causes many difficulties because of its multidimensional and multi-criteria character. This sophisticated feature disables the clear-cut evaluation process of research objects. Taxonomy can be considered a solution because the implementation of these methods simplifies the assessment process of research objects described by many variables and creates a possibility for support in the logistics policy (Figura, 2013). The author argues that it can be performed by implementing the ordering and classification procedures.

As a result of literature research in the area of taxonomy, two main approaches emerged in the synthetic measure construction in the field of ordering methods due to implemented statistical measures.

One of them is known as a classical approach and uses arithmetic mean and standard deviation in its construction. It was introduced presented by Hellwig and implemented into the research in different fields (Hellwig, 1968). In the scope of transport development, empirical assessment has already been performed in relation to roads and voivodships (Cheba, 2011). Furthermore, the taxonomic development level has already been introduced into transport research in the context of sustainable development, where particular synthetic measures were constructed in the areas of four orders, that is environmental, social, economic, and transport investment (Przybydłowski, 2014).

On the other hand, international evaluation of the European Union transport development was presented as well (Tarka, 2012; Kauf & Tłuczuk, 2014). Most of the evaluations are mainly based on non-pattern methods of the synthetic measure construction and classical statistical measures like arithmetic mean and standard deviation.

The other attitude is called the order and implements the multidimensional median vector and *mad* (the median absolute deviation), (Lira et al., 2002). It was implemented for the first time in the area of logistics for the assessment of road transport development in voivodships (Czech & Lewczuk, 2016a). The further analyses are connected with three main modes of the European Union transport, i.e. roads, railways and air (Czech & Lewczuk, 2016b). Both analyses use the multidimensional Weber median account for interactions in the set of diagnostic variables and among three means of transport. It is worth mentioning that the issue of including indirect impacts is very important for transport, for example in the project appraisal (Ward et al., 2016; Hayashi & Morisugi, 2000). Moreover, this issue is widely discussed among experts, and a consensus has not yet been reached (Vörös et al., 2015).

The review of literature proved that available taxonomic analyses of transport development are usually based on normalization in the shape of standardization. Also, there are other linear transformations, such as unitraization or ratio transformation (Jajuga & Walesiak, 2000; Walesiak, 2011; Dębkowska & Jarocka, 2013). Nevertheless, the research is mainly based on the classical normalization methods.

In the light of literature review findings, the order version of normalization can be implemented not only in the form of standardization but as unitarization and ratio transformation (Młodak, 2006). The Weber median transformation methods have already been introduced into indirect consumption research (Czech, 2014).

To sum up, there is a lack of taxonomic analysis with other normalization methods, besides standardization, which accounts for the sophisticated character of the transportation system and mutual interactions among its elements. It should be emphasized that the research gap is also connected with the multi-criteria taxonomic analysis, which is based on the order synthetic measure construction. Hence, the analysis of synthetic measure construction with the implementation of different normalization methods could have an influence on the correctness of taxonomic analysis in the field of logistic evaluation, especially in the area of transportation.

2. Theoretical basis of implemented research methods and the selection of the data set

The final set of diagnostic variables, which is implemented in the process of synthetic measure construction usually must be transformed to bring particular features into comparability. This process is called normalization and is implemented in the case of classification methods, multidimensional calibration or linear ordering. There are three main normalization methods, namely standardization, unitarization, and ratio transformation, which can be used in the construction process of different classical and order statistic measures. This situation may cause a problem in clear taxonomic assessment with the synthetic measure construction. Therefore, it would be helpful to investigate chosen normalization methods in the process of evaluation of the European Union transportation system.

In reality, transport is considered a complex phenomenon where mutual directly unobservable interactions have a crucial impact on the research field. That is why the wide range of normalization methods will be limited to those that implement the multidimensional Weber median.

Standardization, in its original order version, implements the median and *mad* (the median absolute deviation). It was first presented by a Poznań statistician, and the normalization process is expressed by the following formula (Lira et al., 2002):

$$z_{ij} = \frac{x_j - \theta_j}{1{,}4826 * mad(X_j)} \quad (1)$$

where θ_j is considered the Weber median vector and *mad* (the median absolute deviation) is expressed:

$$mad(X_j) = \underset{i=1,2,\ldots,n}{med} \left| x_j - \theta_j \right| \quad (2)$$

The history of the Weber median and its construction is widely discussed in the literature (Młodak, 2009).

On the other hand, there are other versions of the normalization process. It is worth mentioning that all forms of transformations were proposed by Młodak (2006).

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Another form of order standardization uses only the median absolute deviation, and the transformation process is in accordance with the following formula:

$$z_{ij} = \frac{x_j}{mad(X_j)} \quad (3)$$

Unitization is considered as the next form of normalization. The basis for this transformation is a range of a variable, and the order version of it is expressed by the following formula:

$$z_{ij} = \frac{x_j - \theta_j}{R(X)} \quad (4)$$

where *R(X)* stands for the range of a variable that is the difference between the higher and smaller value in the distribution of a particular feature. Besides, the presented form of order unitarization, there are other untypical forms expressed by the two following formulas:

$$z_{ij} = \frac{x_j - \theta_j}{\max\left|x_j - \bar{x}\right|} \quad (5)$$

$$z_{ij} = \frac{x_j - \theta_j}{\max\left|x_j - \theta_j\right|} \quad (6)$$

The last form of normalization is known as ratio transformation where the order form is expressed by the equation:

$$z_{ij} = \frac{x_j}{\theta_j} \quad (7)$$

Furthermore, another form of this transformation, which introduces the multidimensional median vector is based on square values of diagnostic variables and expressed by the following:

$$z_{ij} = \frac{x_j}{\theta_j (x_j)^2} \quad (8)$$

All presented normalization methods are called linear transformations and the synthetic measures constructed on their basis can have different values. Hence, the position of the research objects in the ranking can differ as well.

The basis of synthetic measure construction is a set of diagnostic variables that describe three different areas of transportation, namely, roads, railways, and air. This approach resulted from the terminology accepted in the logistic literature. The data was drawn from the Eurostat database for 2012. The set of twenty-one potential diagnostic variables was treated as a basis of taxonomic analysis with the implementation of different normalization methods for the special assessment of the development level of the transportation system in different areas.

Roads as the first mode of transport is presented by the following variables: X_1 – length of motorways (km/100 km^2), X_2 – length of state roads (km/100 km^2), X_3 – number of motorcycles per 1000 citizens, X_4 – number of passenger cars per 1000 citizens, X_5 – number of lorries and road tractors per 1000 citizens, X_6 – goods transported by roads in 1 million tonne-kilometre per 1000 citizens, X_7 – number of killed in road accidents per 1 million citizens.

Railways as the second mode of transport includes the following features: X_8 – length of railway lines (km/100 km^2), X_9 – number of passengers per one citizen, X_{10} – number of passenger-kilometre per one citizen, X_{11} – goods transported by railways in tonnes per one citizen, X_{12} – railways-goods transported in 1 million tonne-kilometre per 1000 citizens, X_{13} – number of suicides connected with railways per 100 thousand citizens, X_{14} – number of killed per 1 million passengers, X_{15} – number of injured per 1 million passengers, X_{16} – number of railway accidents per 1 million citizens.

Air is the third mode of transport and includes the following variables: X_{17} – number of airports (with over 15000 passenger units per year) per 10 000 km^2, X_{18} – number of airline passengers per one citizen, X_{19} – number of commercial aircraft fleet per 1 million passengers, X_{20} – freight and mail transported by air in tonnes per 1000 citizens, X_{21} – number of killed in commercial air transport per 1 million passengers.

It is worth mentioning that all three branches of transportation include variables that are related to cargo transport changes in the country. Moreover, there are some facts about these modes of transport. On the one hand, road transport plays a key role in the cargo transportation. Nevertheless, the transport absorption is decreasing due to economic growth. On the other hand, the railway transport is not efficiently used, and inland waterways cannot compensate for cargo transportation by railways or roads (Strojny, 2013). It is worth emphasizing the fact that all modes of transport are complex and generate external effects (Chruzik & Sitarz, 2014).

Furthermore, the inland waterways transport is not greatly significant that is why it was omitted from the research. On the other hand, the pipeline transport is considered to be specific and significant for the economy. Nevertheless, it is very difficult to access interdependence with other branches of the transportation system.

Tab. 1. Chosen statistical measures of particular variables and values of the main diagonal of inverted Pearson correlation matrixes

Variable	Means of transport	Mean	M_B	M_W	A_S	S_X	Mad (W)	R	V_S	V_W	MDIM
X_1	Roads	1.37	1.12	1.38	0.85	1.17	0.90	3.79	85.18	65.20	2.11
X_2		15.22	9.51	12.51	0.65	12.05	7.73	34.87	79.17	61.80	1.93
X_3		33.11	21.03	34.89	1.46	29.91	19.94	104.72	90.36	57.16	1.87
X_4		453.28	464.77	447.34	-0.57	108.22	82.31	400.99	23.87	18.40	2.13
X_5		57.06	54.62	66.04	0.82	22.27	20.66	75.36	39.03	31.28	2.02
X_6		4.20	4.04	4.62	0.58	1.84	1.31	6.33	43.90	28.47	1.82
X_7		634.00	62.50	64.24	0.27	21.27	17.50	72.00	33.24	27.24	2.16
X_8	Railways	5.51	5.06	5.26	0.94	3.03	2.26	10.38	54.90	43.01	4.78
X_9		12.61	10.89	10.38	0.97	9.05	5.27	30.51	71.72	50.83	9.29
X_{10}		612.47	471.94	502.80	0.73	396.56	261.99	1304.65	64.75	52.11	6.83
X_{11}		8.16	5.39	6.97	1.88	9.57	5.07	33.63	117.22	72.69	5.16
X_{12}		1.88	1.32	1.62	2.82	2.53	1.04	10.67	134.50	64.02	4.51
X_{13}		0.63	0.44	0.54	1.81	0.51	0.24	2.02	81.17	44.73	2.98
X_{14}		0.78	0.24	0.71	2.34	1.13	0.64	4.47	145.22	90.08	4.80
X_{15}		0.60	0.39	0.54	1.27	0.70	0.50	2.28	116.43	91.67	6.62
X_{16}		7.57	7.73	7.59	0.28	5.44	4.31	17.76	71.91	56.84	3.41
X_{17}	Air	0.70	0.62	0.64	1.03	0.44	0.30	1.70	63.23	47.00	1.67
X_{18}		1.90	1.82	1.87	0.85	1.31	1.10	4.87	69.18	59.04	2.20
X_{19}		9.91	6.74	9.35	2.07	7.11	3.61	29.63	71.75	38.59	3.05
X_{20}		16.65	12.97	11.91	1.11	15.32	8.72	53.94	92.01	73.21	2.01
X_{21}		0.29	0.00	0.30	4.24	1.21	0.30	5.14	421.38	100.00	3.17

Notation: M_B – border median, M_W – Weber median, A_S – skewness, S_X – standard deviation, mad (W) – median absolute deviation (Weber Median), R – range, V_S – classical variation coefficient, V_W – order variation coefficient based on Weber median, MDIM – main diagonal of inverted Pearson correlation matrixes.

It is worth mentioning that the objective causes of railway disasters and railway accidents were the basis for treating this variable as a separate one. However, suicides are considered as a specific form of death, which results from personal decisions, and that is why this variable should not be combined with the number of killed.

All potential diagnostic variables were put under statistical investigation due to variation as well as correlation analysis. The chosen statistical measures of particular features are presented in Table 1.

The investigation of classical and order form of variation coefficients proved that all diagnostic variables have a strong differentiation, which results in their inclusion into the process of the synthetic measure construction.

In the scope of dealing with correlation analysis, three inverted matrixes of Pearson correlation coefficients have been constructed (Malina & Zeliaś, 1997). The values located on the main diagonal of particular inverted matrixes in three areas of the transportation system are presented in Table 1. The analysis of correlation measures proved that all potential variables could be taken for the further analysis.

To sum up, it should be mentioned that all three investigated areas are described by the features connected with infrastructure, equipment, people, and freight transport as well as safety. Moreover, there are mutual interactions among these three areas as well as in the whole set of diagnostic variables. Furthermore, some of the diagnostic features have strong skewness, which encourages to use order statistic measures instead of the classical ones. Hence, the process of synthetic measure construction of transport development should be based on normalization methods, which implement the multidimensional Weber median.

3. Research results

To bring the variables to comparability, seven presented normalization methods were introduced into the analysis in the form of standardization, unitarization, and ratio transformation. Additionally, these forms of transformation implemented the Weber median to take into account the sophisticated

Tab. 2. Positions of countries in the ranking according to different normalization methods

Country	Roads							Railways						
	S(1)	S(2)	U(3)	U(4)	U(5)	RT(6)	RT(7)	S(1)	S(2)	U(3)	U(4)	U(5)	RT(6)	RT(7)
Bulgaria	14	15	15	15	16	12	12	15	14	15	15	14	15	12
Czech Republic	12	13	13	13	13	15	17	8	16	14	13	13	13	18
Germany	5	3	4	4	4	2	2	3	6	6	5	5	5	11
Estonia	11	14	14	14	14	16	14	17	10	12	12	12	11	13
Ireland	13	9	9	8	9	9	9	13	9	9	9	9	9	2
Spain	9	2	1	1	1	3	3	9	8	8	8	8	8	4
France	7	5	5	5	5	6	6	1	4	3	1	2	4	6
Italy	1	12	10	10	10	11	16	5	5	5	4	4	6	3
Latvia	17	17	17	17	17	17	15	12	1	4	6	6	1	1
Lithuania	3	11	12	12	12	13	11	18	17	17	17	17	17	17
Hungary	16	16	16	16	15	14	13	6	13	13	14	15	14	16
Austria	4	6	6	6	6	4	5	2	2	1	3	3	2	9
Poland	8	7	8	9	8	8	8	10	12	11	11	11	12	8
Romania	18	18	18	18	18	18	18	16	18	18	18	18	18	15
Slovenia	6	1	2	2	2	1	1	14	11	10	10	10	10	10
Slovakia	15	10	11	11	11	10	10	11	15	16	16	16	16	14
Finland	2	4	3	3	3	5	4	7	7	7	7	7	7	7
United Kingdom	10	8	7	7	7	7	7	4	3	2	2	1	3	5
	Air							Total Measure						
Bulgaria	16	14	14	15	15	14	14	17	15	16	16	17	13	11
Czech Republic	15	12	13	13	12	13	13	13	14	14	13	13	14	18
Germany	1	3	3	3	4	2	1	1	1	2	2	2	3	3
Estonia	7	7	9	9	9	9	10	8	10	11	11	14	16	17
Ireland	4	1	1	1	1	1	2	6	4	4	4	9	15	7
Spain	11	9	5	5	5	7	7	10	5	6	6	1	2	2
France	6	5	6	6	6	6	5	5	6	5	5	4	4	10
Italy	10	13	12	12	13	12	12	7	9	8	8	8	8	6
Latvia	8	6	8	8	8	8	8	12	8	9	10	11	10	8
Lithuania	12	10	10	10	10	10	11	11	12	15	15	15	17	16
Hungary	14	15	15	16	16	15	15	16	17	17	17	16	12	13
Austria	5	2	2	2	2	3	4	4	2	1	1	5	6	12
Poland	17	17	18	18	18	17	17	14	13	12	12	10	5	4
Romania	18	16	17	17	17	16	16	18	18	18	18	18	18	15
Slovenia	9	18	16	14	14	18	18	9	16	10	9	7	1	1
Slovakia	13	11	11	11	11	11	9	15	11	13	14	12	11	14
Finland	3	4	4	4	3	4	3	2	3	3	3	3	9	5
United Kingdom	2	8	7	7	7	5	6	3	7	7	7	6	7	9

Notation: S(1) – standardization I, S(2) – standardization II, U(3) – unitarization I, U(4) – unitraization II, U(5) – unitarization III, RT(6) – ratio transformation I, RT(7) – ratio transformation II.

character of particular branches of the transportation system. Furthermore, the multidimensional median allowed making the taxonomic analysis immune to the skewness of particular features. The values of synthetic measures for railway transport development, which were put together with different normalization methods, are presented in Figure 1.

limitation of the Pearson's coefficient, which can incorrectly indicate the character of interdependence (Luszniewicz & Słaby, 2008). To assure adequate results of carried out research, box and whisker plots were put together and presented in Figure 2.

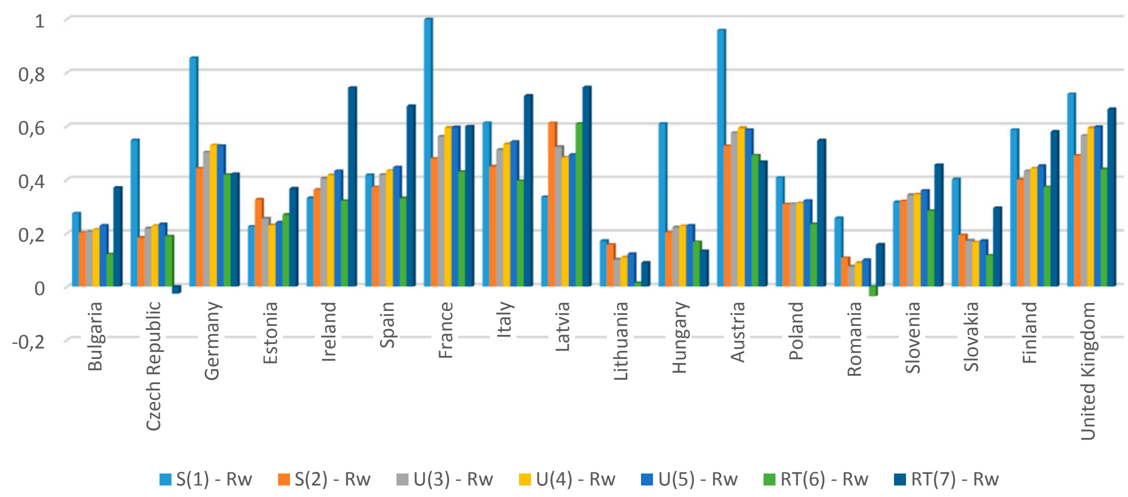

Fig. 1. Values of order synthetic measures constructed with different normalization methods in the area of railway transport

Notation: S(1) – standardization I, S(2) – standardization II, U(3) – unitarization I, U(4) – unitraization II, U(5) – unitarization III, RT(6) – ratio transformation I, RT(7) – ratio transformation II.

The analysis of graphical presentation proved that in most cases of normalization methods, the values of railway transport synthetic measures achieve similar values for particular member states.

Further, the values of synthetic measures in three different areas of transportation system were treated as the basis for the construction of the total European Union transport development measure. The maximum values of synthetic measures for modes of transport were treated as stimulants in the further analysis. This approach has already been introduced into poverty research because of the sophistic character of analysed phenomenon as well as a very wide range of diagnostic variables (Młodak et al., 2016). The location of European Union member states in the scope of transport mode development as well as the total approach are presented in Table 2.

The analysis of presented rankings of the European Union transport development according to different normalization methods proved that some of the constructed measures resulted in similar positions of particular member states. On the other hand, in few cases, constructed measures give quite different orders. It is to be noticed that rankings constructed with two forms of ratio transformations locate Austria the sixth or twelfth in the case of total development of transportation system. This proves that this kind of normalization is not applicable in linear ordering, however, Austria is considered as one of the most developed countries in Europe in the area of transportation.

Hence, to compare distributions of synthetic measures Pearson correlation coefficients were calculated and presented in Table 3.

The analysis of presented data indicates that the total synthetic measure of transportation development constructed with two forms of ratio transformation is very weakly correlated with other taxonomic measures. Furthermore, a similar phenomenon is noticed in the area of roads as well as air transport. Almost all synthetic measures are highly correlated, which proves the previous analysis in the transport development of chosen European Union member states. Evidence suggests that the suspicion regarding ratio transformation can bring results in the process of synthetic measure construction, which do not reflect the real state of transport development. Nevertheless, it is very important to be aware of the linear

Tab. 3. Matrixes of Pearson's correlation coefficients of synthetic measures constructed according to different normalization methods

	S(1)	S(2)	U(3)	U(4)	U(5)	RT(6)	RT(7)	S(1)	S(2)	U(3)	U(4)	U(5)	RT(6)	RT(7)
	Roads							**Railways**						
S(1)	1.00	0.78	0.77	0.78	0.78	0.64	0.55	1.00	0.55	0.71	0.75	0.73	0.57	0.22
S(2)	0.78	1.00	1.00	0.99	0.99	0.95	0.91	0.55	1.00	0.96	0.93	0.93	0.98	0.80
U(3)	0.77	1.00	1.00	1.00	1.00	0.95	0.90	0.71	0.96	1.00	1.00	1.00	0.95	0.79
U(4)	0.78	0.99	1.00	1.00	1.00	0.94	0.89	0.75	0.93	1.00	1.00	1.00	0.92	0.76
U(5)	0.78	0.99	1.00	1.00	1.00	0.93	0.88	0.73	0.93	1.00	1.00	1.00	0.92	0.78
RT(6)	0.64	0.95	0.95	0.94	0.93	1.00	0.96	0.57	0.98	0.95	0.92	0.92	1.00	0.76
RT(7)	0.55	0.91	0.90	0.89	0.88	0.96	1.00	0.22	0.80	0.79	0.76	0.78	0.76	1.00
	Air							**Total**						
S(1)	1.00	0.81	0.60	0.82	0.80	0.43	0.24	1.00	0.86	0.89	0.90	0.83	0.28	-0.01
S(2)	0.81	1.00	0.86	1.00	1.00	0.66	0.46	0.86	1.00	0.95	0.94	0.84	0.12	-0.25
U(3)	0.60	0.86	1.00	0.82	0.82	0.94	0.84	0.89	0.95	1.00	1.00	0.94	0.37	0.00
U(4)	0.82	1.00	0.82	1.00	1.00	0.60	0.39	0.90	0.94	1.00	1.00	0.95	0.39	0.02
U(5)	0.80	1.00	0.82	1.00	1.00	0.60	0.39	0.83	0.84	0.94	0.95	1.00	0.58	0.19
RT(6)	0.43	0.66	0.94	0.60	0.60	1.00	0.97	0.28	0.12	0.37	0.39	0.58	1.00	0.87
RT(7)	0.24	0.46	0.84	0.39	0.39	0.97	1.00	-0.01	-0.25	0.00	0.02	0.19	0.87	1.00

Notation: S(1) – standardization I, S(2) – standardization II, U(3) – unitarization I, U(4) – unitraization II, U(5) – unitarization III, RT(6) – ratio transformation I, RT(7) – ratio transformation II.

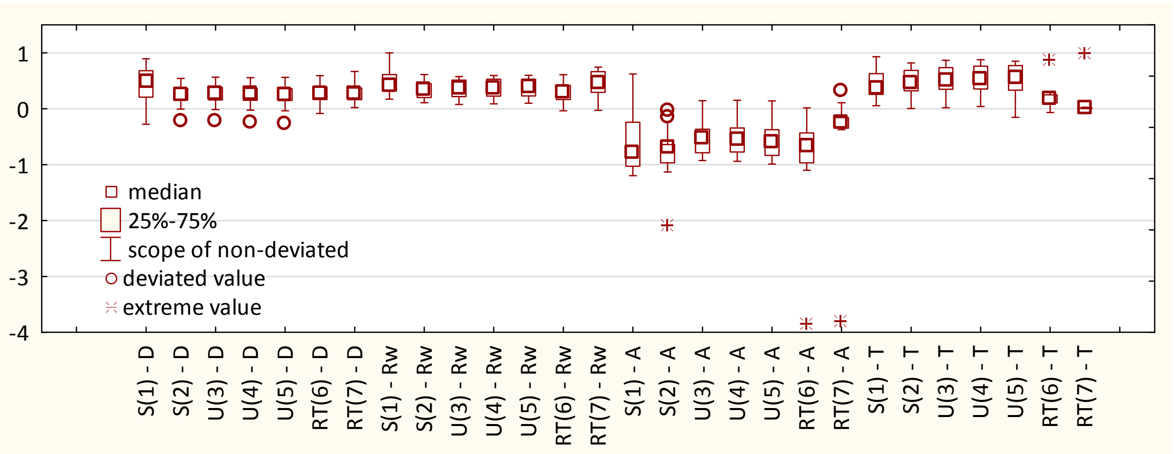

Fig 2. Distributions of order synthetic measures constructed according to different normalization methods

Notation: S(1) – standardization I, S(2) – standardization II, U(3) – unitarization I, U(4) – unitraization II, U(5) – unitarization III, RT(6) – ratio transformation I, RT(7) – ratio transformation II, D – roads, Rw – railways, A – air, T – total.

The analysis of presented graphical distributions of particular synthetic measures in three transport branches as well as the total one indicates the skewness in their distributions. Furthermore, the existence of non-typical (deviated and extreme) values of synthetic measures as well as the asymmetrical location of the median and a different length of whiskers in plots indicate that the implementation of the Pearson's correlation coefficients may not be proper. Hence, the Spearman correlation coefficient was introduced to compare the results of the taxonomic research. The exchange of values of synthetic measures on ranks eliminates the negative impact of non-typical observations (Stanisz, 2006). The results of carried out correlation analysis confirmed the results obtained with the Pearson's coefficient about synthetic measure construction with ratio transformation for the whole transportation system.

4. Discussion of the results

The task of the synthetic measure construction with different normalization methods was to confirm the previous research of the European Union transport development. The paper presents the results obtained in the process of taxonomic research with the Weber median to take into account interactions in a sophisticated transportation system.

The analysis of the data presented in Table 2 allows indicating some trends connected with the ranking of the selected European Union countries in the scope of the road, railway, and air transport development. There are large spans of the development of certain branches of the transportation system in European Union member states. In addition, there is a noticeable correlation between the socio-economic development of particular European Union member states and technical infrastructure, including the logistics one.

The largest European economies, such as Germany, the United Kingdom or France, are considered leading countries in the development of road and railway networks. The carried out analysis proved that the situation connected with the condition of road network and railway transport is more favourable to smaller countries, such as Latvia and Ireland, compared to large ones, such as Finland.

Hence, the observed situation arose due to the influence of the socio-economic policy of European Union member states. It should be noted that the sustainable development policy is considered a priority in some member states. Unfortunately, this kind of policy conflicts with the needs of transport infrastructure development, which creates conditions for the balanced development of regions in those countries. The constant saturation level of roads and railway tracks is observed in Germany, Italy, and the United Kingdom. However, the new investments in those fields are occasionally introduced. The burden of investment concerns modernization and upgrading the existing railway tracks and roads in Germany and France. In addition, the most dynamic growth is observed in air transport of those countries. The carried out analysis proved that both member states took leading positions. Furthermore, the leader of the ranking in the area of air transport is Germany. Apart from Germany, high positions are occupied by Ireland and Finland, which take the second and third place.

The research analysis, which took into account indirectly observed relationships, brought some unforeseen results. On the one hand, the ranking connected with the development level of traditional modes of transport that is roads and railways indicate the leading position of Germany, Slovenia, Spain, and France. Furthermore, Germany, Ireland, Finland, and the United Kingdom are placed highly in the area of air transport. On the other hand, the distant location in that ranking is taken by Romania, Poland, and Slovenia, which occupy positions sixteen to eighteen among the eighteen countries included in the analysis.

The research of the total synthetic measure of transport development led to several conclusions. The high positions of Slovenia, Poland or Latvia, can be considered unexpected. However, the leading positions according to the total ranking are occupied by the most developed and so-called old member states, such as Spain, Germany, Finland, and Italy. Nevertheless, the ninth, tenth and twelfth positions of Great Brittan, France, and Austria according to the synthetic measure constructed with the ratio transformation is unexpected. In addition, the choice of the improper normalization method can deliver the ranking, which does not reflect the socio-economic reality.

Conclusions

The conducted research according to some normalization methods allowed stating that in most cases, different normalization methods lead to similar results.

On the one hand, most of the so-called old member states have a well-developed logistics infrastructure, which is highly correlated with the whole socio-economic space. Going further, the well-developed railways, roads, motorways, and airports are the elements of this infrastructure. It is strictly connected with such countries as Germany, Spain or Finland.

On the other hand, the group of countries that take a distant place in the rankings of all three examined modes of transport was named. In general, the conclusion relates to the following countries: Romania, Czech Republic, and Lithuania. The underdevelopment of technical infrastructure of these countries is caused by historical conditions and the pace of construction of the so-called new market reality. This proposal is adjusted to most states and regions that have been under the influence of the Soviet Union.

In addition, there is a group of states with one better-developed branch of transport in comparison to two others. Slovenia is a member state that takes the first place in the summary ranking. Nevertheless, this country has the eighteen position in the scope of air transport development. Hence, the mountainous terrain and relatively small surface of this country have a significant impact on its state.

To sum up, the synthetic measure construction with most of the normalization methods relates to selected European Union countries and confirms the previous scientific research of the European Union transport development. The researcher feels that the study findings will facilitate such analysis and create more efficient transportation policy for the whole European Union. Moreover, the presented statistical research methods can be used by economic practices; however, the strict cooperation between science and business is a crucial factor.

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Ranking of office lease options by multi-criteria methods

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ABSTRACT

Due to the growing scales of business and internationalisation, the issue of the office lease is becoming more and more relevant for companies. They are becoming an inherent part of business, on which the results of the commercial activity depend. Currently existing methodologies for the assessment of the office lease options are imperfect as they lack complexity; they are not associated with the objective of the lease – the improvement of the business results; the methods of the quantitative assessment of lease options are far from perfect. The paper aims at formulating the hierarchical indicator system of commercial real estate facilities (offices) adjusted for the multi-criteria assessment and at calculating the lease options based on this indicator system. To achieve this goal, the following methods have been used: scientific literature analysis and multi-criteria assessment methods.

KEY WORDS

lease of commercial facilities (offices), forming the indicator system, multi-criteria assessment methods

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Introduction

The business trend analysis shows that the gradually increasing demand for offices derives from both internal and external needs. The former appear where the companies establish their affiliates and subsidiaries, expand their business in new areas, want to improve the office environment and focus their activities on one space. The external demand is the need for offices among foreign companies that invest in the country. The global investors currently optimising their business are increasingly interested in the Middle Europe and the Baltic States, and they are gradually turning away from India and Asian countries. Consequently, the demand for offices will continue to grow.

Recently, an office has been considered an important factor affecting the business results. Therefore, the premises for rent are subject to more stringent requirements regarding technical characteristics, quality and variety of offered services, working environment, etc. (French & Wisemann, 2003; Nase et al., 2013; Pagourtzi et al., 2003; Ginevičius et al., 2004; Zhang, 2015). Consequently, the potential tenant, when selecting the premises, considers the aggregate of criteria covering various aspects. It depends on a place (Alonso, 1964; Muth, 1969; Mills, 1972; DiPasaquale & Wheaton, 1992; Dunse & Jones, 1998; French & Wiseman, 2003; Pagourtzi et al., 2003; Čeh et al., 2012; Nase et al., 2013), year of built and architectural solutions (Wagner et al., 2014; French & Wiseman, 2003; Pagourtzi et al., 2003; Nase et al., 2013), engineering infrastructure (Dunse & Jones, 1998; Ncube & Riffat, 2012), car parking facilities (Nase et al., 2013; Wagner et al., 2014), additional services provided (Peng et al., 2014; Wagner et al., 2014), level of fit out at the premises (Nase et al., 2013; Khamkanya et al., 2012; French & Wiseman, 2003, Pagourtzi et al., 2003), external environment (Nase et al., 2013; Čeh et al., 2012).

In this case, the office lease options are defined by multiple various indicators. Phenomena manifesting through various aspects of reality are attributed to complicated and complex ones. Such phenomena may only be recognised when assessing all criteria reflecting such a phenomenon as a whole. This is where the criteria-based approach of the office lease comes from as a phenomenon. The multi-criteria methods are most eligible for the assessment.

1. Formation of the Indicator System of Office Lease Options

The essential stage of the multi-criteria assessment is the formation of the indicator system of the phenomenon in question. This is because the adequacy of reflecting the phenomenon in question largely depends on its completeness and structure. When forming such a system, the following statements are usually referred to (Ginevičius et al., 2004; Ginevičius & Podvezko, 2005): first, the more indicators are included in the system, the more thoroughly the phenomenon in question is reflected, and vice versa, the fewer indicators are included in the system, the greater is a threat that the significant indicators will not be assessed and the assessment of the status of the phenomenon in question will seem inadequate; second, the more indicators are included in the system, the more indicators will be difficult to formalise; moreover, the system will become complicated, and it will be hard to accurately determine weights of the indicators, which will result in higher calculation costs and lower accuracy.

The formation of the indicator system starts with the list compilation. The objective of formation of the system itself is an adequate reflection of the phenomenon in question and its adjustment for the multi-criteria assessment. The content and result of this process depend on how many indicators are included in the system. Where there are a few indicators, the single-level indicator system is formed (Fig. 1).

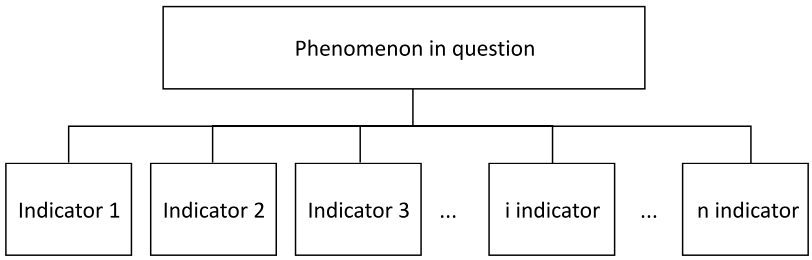

Fig. 1. Single-level indicator system

The use of such an indicator system for the multi-criteria assessment of complicated complex phenomena is rather limited as in this case, it is subject to an intractable issue related to the indicator significance determination. This means that the experts may somewhat accurately assess the weights of a limited number of indicators only. The proposed complicated approaches to determine the significance of indicators do not fully resolve this problem as well (Saaty, 1980). According to the references, without greater evidence, however, this number equals 10–12 (Ginevičius, 2009). When looking for a solution, it is necessary to find a method enabling to reduce the number of simultaneously assessed indicators. This problem may be resolved by means of hierarchical structuring of the indicator system, which enables the reduction in the number of simultaneously assessed indicators to the preferred number (Ginevičius, 2007a, 2007b, 2009).

Based on this methodology, the following hierarchically structured system of indicators of the office lease options was formed (Fig. 1). It consists of 51 indicators; all of them are divided into three blocks by affinity, i.e. economic, environmental, and premises. The number of indicators in some of the main blocks (environmental and buildings) appeared to be too high in terms of the weight assessment; therefore, based on the principles of affinity again, they were divided into several parts: the block of environmental indicators – into infrastructure and location, and buildings – into the level of technical layout, atmosphere and options (Fig. 2).

2. Multi-Criteria Assessment of the Office Lease Indicator System

First of all, the method of carrying out the multi-criteria assessment of the hierarchically structured indicator system needs to be discussed. To carry out such an assessment, the weights and values of all indicators of the hierarchical level must be known.

The determination of the indicator weights starts from the lowest level of the hierarchical structure. This is done in two stages. Firstly, the experts set the indicator ranks for each group of the indicators of this level (in our case, there are six groups). This helps the experts to express a more uniform opinion when it comes to the assessment of the indicator weights. As the number of indicators in each group does not exceed 12, their weights may be determined directly, i.e. by distributing 1 among the indicators subject to assessment.

It is presumed that $\sum_{i=1}^{n} w_i = 1$

where:

- w_i – i-th indicator weight, n – a number of indicators, $i = \overline{1,n}$).

When the weights of the indicators of the lowest level of the hierarchical indicator system are determined, the weights of the higher-level indicators must be determined. As shown in Fig. 1, this level contains two environmental blocks and three premise indicator blocks. Their weights are determined in the same way as in the previous case.

Similarly, the weights of three main indicator blocks (economic, environmental, and premises) are determined. In all cases, the indicator weights were determined directly, i.e. the experts had to distribute parts of 1 among the indicators subject to assessment, where weights were equal to one.

When the weights of the hierarchical structure indicators are determined, their values must be set. A further complication is that a part of them is expressed in measurable dimensions, i.e. per cent, units, euro, metres, etc., and others belong to the hardly formalised ones, i.e. the ones that cannot be measured, for instance, prestige of the location, view through the office windows, the administration procedure, etc. In such cases, the only way to attribute values to such indicators is per expert assessment.

Lease options differ not only in economic (price, contract terms and conditions, etc.), environmental (prestige of the location, geographical location, communications, etc.) and premise (technical layout, arrangement, lighting, etc.) indicators, but also in their nature as some of them are maximising (the situation improves with the increasing indicator value) and other indicators are minimising (the increasing value leads to the worsening of the situation). The multi-criteria assessment method SAW, which was applied when determining the priorities of the lease options, requires the uniformity of changes in the indicators, i.e. all of them must be either maximising or minimising. The maximisation of minimising indicators is carried out as follows (Hwang & Yoon, 1981):

$$q_{ij\ \max} = \frac{q_{j\ \min}}{q_j} \tag{1}$$

where:

- $q_{ij\ \max}$ – the maximised value of the i-th indicator of the j-th variant,
- q_{ij} – the value of the i-th indicator of the j-th variant,
- $q_{ij\ \min}$ – the lowest possible value of the i-th indicator of the j-th variant.

The minimisation of indicator values is carried out as follows (Hwang & Yoon, 1981):

$$q_{ij\ \min} = \frac{q_j}{q_{j\ \max}} \tag{2}$$

where:

- $q_{ij\ \min}$ – the minimised value of the i-th indicator of the j-th variant,
- $q_{ij\ \max}$ – the highest possible value of the i-th indicator of the j-th variant.

The lease options are expressed in different dimensions; therefore, they cannot be combined in one generalised unit. They are converted into non-dimensional ones through the value standardisation (Podvezko 2008):

Office lease indicators — K = 0.378

Economic — W = 0.43, K = 0.4107

No.	Indicator weight	Standardised indicator value
1.	0.20	0.42
2.	0.15	0.56
3.	0.09	0.51
4.	0.03	0.13
5.	0.06	0.35
6.	0.08	0.47
7.	0.03	0.42
8.	0.05	0.47
9.	0.07	0.30
10.	0.12	0.44
11.	0.04	0.25
12.	0.08	0.18
K = 0.4107		

Environmental — W = 0.22, K = 0.3680

Infrastructure — W = 0.64, K = 0.4033

No.	Indicator weight	Standardised indicator value
1.	0.10	0.24
2.	0.07	0.38
3.	0.25	0.63
4.	0.17	0.21
5.	0.13	0.27
6.	0.03	0.25
7.	0.10	0.38
8.	0.12	0.50
9.	0.03	0.63
K = 0.4033		

Location — W = 0.36, K = 0.3054

No.	Indicator weight	Standardised indicator value
1.	0.05	0.50
2.	0.06	0.56
3.	0.21	0.06
4.	0.07	0.27
5.	0.15	0.43
6.	0.20	0.39
7.	0.26	0.28
K = 0.3054		

Premise — W = 0.35, K = 0.346

Technical layout — W = 0.24, K = 0.408

No.	Indicator weight	Standardised indicator value
1.	0.05	0.59
2.	0.04	1.00
3.	0.14	0.33
4.	0.03	0.42
5.	0.06	0.24
6.	0.15	0.29
7.	0.07	0.38
8.	0.20	0.45
9.	0.14	0.42
10.	0.08	0.39
11.	0.04	0.38
K = 0.408		

Atmosphere — W = 0.33, K = 0.3107

No.	Indicator weight	Standardised indicator value
1.	0.15	0.26
2.	0.24	0.32
3.	0.25	0.33
4.	0.16	0.29
5.	0.20	0.33
K = 0.3107		

Options — W = 0.43, K = 0.347

No.	Indicator weight	Standardised indicator value
1.	0.08	0.41
2.	0.12	0.33
3.	0.09	0.35
4.	0.27	0.38
5.	0.05	0.50
6.	0.15	0.33
7.	0.20	0.33
8.	0.04	0.27
K = 0.3470		

Fig. 2. Hierarchical indicator system of commercial real estate facilities (offices) lease

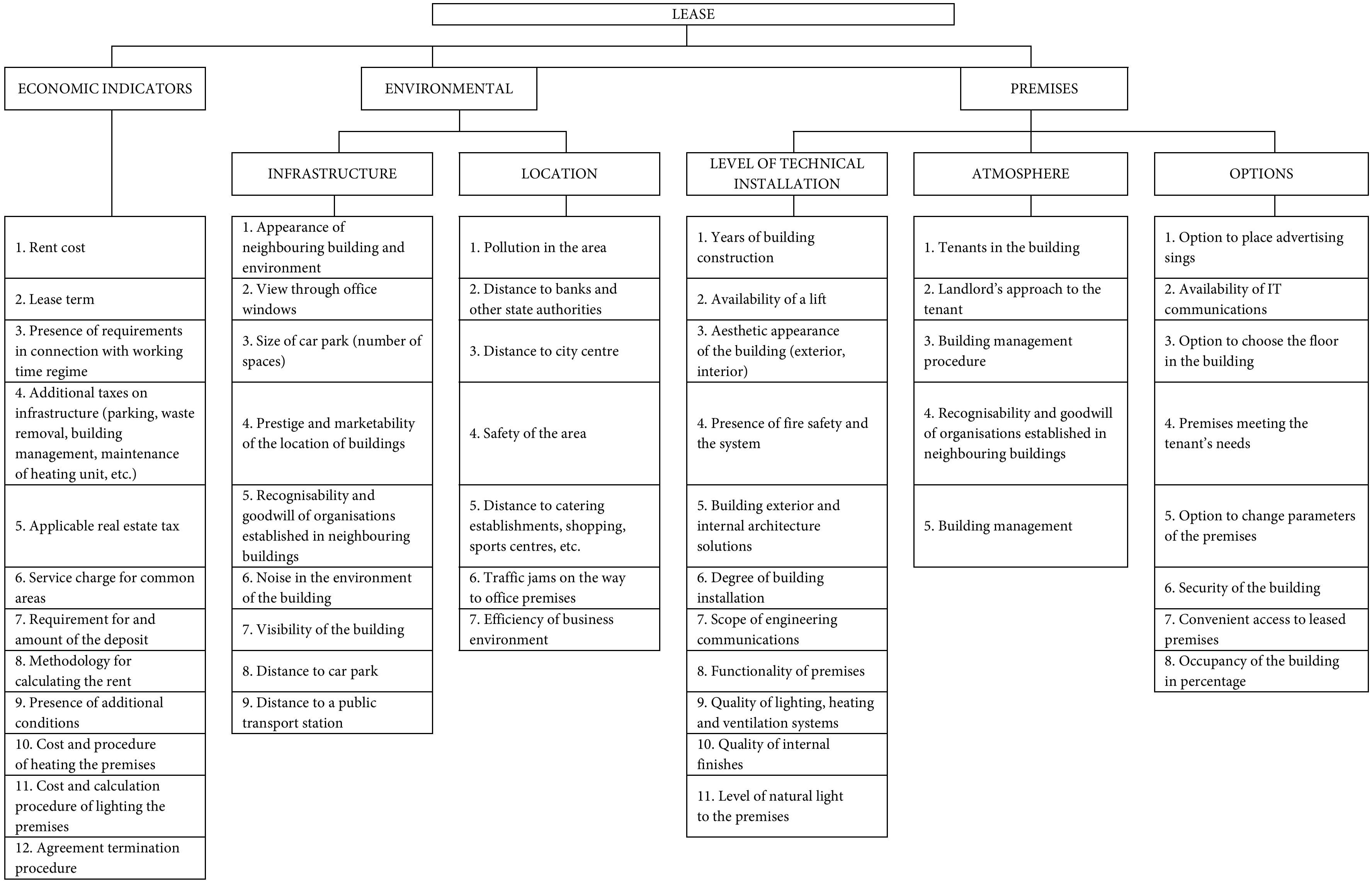

Fig. 3. Hierarchically structured system of commercial real estate (office) lease indicator

$$\tilde{q}_{ij} = \frac{q_j}{\sum_{i=1}^{n} q_j} \quad (3)$$

where:

- $\tilde{q}_{ij}$ – the standardised value of the i-th indicator of the j-th lease option,
- n – a number of indicators ($i = \overline{1, n}$).

The multi-criteria assessment of the hierarchical indicator system of the lease options was carried out by means of the method SAW (Hwang & Yoon, 1981):

$$K_{jk} = \sum_{i=1}^{n} w_{jik} \tilde{q}_{jik} \quad (4)$$

where:

- K_j – the value of indicator system of multi-criteria assessment through SAW of the k-th indicator group of the j-th hierarchical level,
- w_{jik} – the weight of the i-th indicator of the k-th indicator group of the j-th hierarchical level,
- $\tilde{q}_{jik}$ – the standardised value of the i-th indicator of the k-th indicator group of the j-th hierarchical level.

3. Ranking of Office Lease Options Based on the Hierarchical System of Indicators

The multicriteria assessment of hierarchically structured system of indicators is bottom-up, i.e. it starts at the bottom level in the hierarchy. Following formulas (1–3), the weights and normalised values of all six groups of related indicators are determined (Fig. 3).

Based on Table 1, the following values of the third-level multicriteria assessment of the lease of a commercial real estate object (office) have been obtained.

These values immediately become the same of the units combining the above groups of indicators and positioned on a higher level of the hierarchical structure (infrastructure, location, level of technical installations, ambience, and options).

To perform a second-level multicriteria assessment of the hierarchical structure, one needs to know the weights of the environmental and premises groups of indicators. Following the expert survey, it has been obtained that the weights of groups of environmental indicators (infrastructure and location) equal 0.64 and 0.36, respectively; whereas the same of groups of premises indicators (level of technical installations, ambience, and options) are 0.24; 0.33 and 0.43, accordingly. Based on Table 1 and the weights determined, the following results of the multicriteria assessment for the second-level indicators have been obtained for the lease of a commercial real estate object (office), (Table 2).

The values of the multicriteria assessment of the first-level economic indicators (Table 1) and the second-level environmental and premises indicators (Table 2) of the hierarchical system of indicators are the values of the key units (economic, environmental, and premises) of the system of indicators. To carry out the final multicriteria assessment of lease options, one needs to know the weights of the above units. Following an expert evaluation performed, it has been obtained that the above weights equal 0.43, 0.22, and 0.35, respectively.

Following the multicriteria assessment, the following results have been obtained (Table 3).

It is evident in the multicriteria assessment of three lease options carried out based on the hierarchically structured system of indicators that such assessment calls for many calculations. The scope will significantly increase if there are many options to be

Tab. 1. Results of multicriteria assessment of the third-level indicators of the lease of a commercial real estate object (office) using the SAW method

Name of indicator group	Economic			Environmental						Premises								
				Infrastructure			Location			Level of technical installations			Ambience			Options		
	Alternatives			Alternatives			Alternatives			Alternatives			Alternatives			Alternatives		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SAW value	0.4107	0.3136	0.4183	0.4033	0.3172	0.2778	0.3054	0.263	0.4316	0.408	0.3281	0.2829	0.3107	0.3206	0.3687	0.347	0.3567	0.2855

Tab. 2. Results of multicriteria assessment of the second-level indicators of commercial real estate object (office) lease using the SAW method

Name of indicator units	Environment			Premises		
	alternatives			alternatives		
	1	2	3	1	2	3
SAW value	0.3680	0.2977	0.3332	0.3496	0.3379	0.3124

Tab. 3. Results of the multicriteria assessment for the first-level indicators of the lease of a commercial real estate object (office) using the SAW method

Options	First	Second	Third
SAW value	0.3780	0.3186	0.261
Rank	first	second	third

assessed (there can be dozens of them). Hence, the assessment of lease options provided will only be worthwhile if the calculations are automated. They can be performed by a computerised decision-support system.

Conclusions

Today, the company offices are becoming an inherent part of the business that significantly affects the results of the commercial activity. The increasing demand for offices derives from both the internal and external needs. The former arise where the companies establish their affiliates and subsidiaries, expand their business in new areas, improve the office environment, focus their activities on one space, and improve their image; the latter mean the foreign capital. The global investors optimising their business are increasingly interested in the Middle Europe and the Baltic States, and they are gradually turning away from India and Asian countries.

Today, when selecting the premises, a potential tenant considers the aggregate of criteria covering various aspects rather than several basic criteria. In this case, the office lease options are defined by multiple various indicators. To rank such options, the indicators need to be combined in one generalised unit. The multi-criteria methods may be used to resolve such tasks.

The adequacy of the lease option assessment largely depends on the system reflecting their indicators. In the case of a small number of indicators, a single-level system may be used. And in the case of many indicators, the experts cannot accurately assess their weights. The formation of the hierarchical system is a proven method to reduce the number of simultaneously assessed indicators. The hierarchical structure of the lease option indicators was formed on their basis. It consists of three main blocks, i.e. economic, environmental, and premise indicators. The first was assigned 11 indicators, environmental – 16 indicators, and premises – 24 indicators. The number of indicators in environmental and premise blocks appeared to be too high in terms of the weight assessment; therefore, they were divided into several parts: the block of environmental indicators – infrastructure and location, and buildings – the technical layout, atmosphere, and options.

The multi-criteria assessment of one of the lease options, based on the hierarchical indicator system, was carried out as follows: first, the multi-criteria assessment values of all six allied indicator groups were determined through the method SAW. They became the values of the blocks combining such groups (infrastructure, location, technical layout, atmosphere, and options). On this basis and the weights of such blocks, the values of the blocks of the previous level (environmental and premises) were determined. During the last stage, based on the weights and values of three main blocks, the generalised multi-criteria assessment of the determined lease option was carried out.

The multicriteria assessment of lease options for commercial real estate objects (offices) requires large-scale calculations. They significantly increase if we take dozens of options for consideration. Hence, to make use of the proposed methodology efficiently, a computerised decision-support system needs to be developed.

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Memetic pool as a new approach in service quality analysis

Krzysztof Stepaniuk

ABSTRACT

This paper attempts to decompose, as well as perform a quantitative and qualitative analysis of the way to externalize the perception of the accommodation service. The research material consisted of the opinions of users of accommodation facilities, located in the vicinity of the twelve selected national parks in Poland. It was assumed that the reflection of the perception of the quality of the service process is the transfer of intangible content related to the service itself, which can be externalized, among other things, through entries in social networks.

The study was conducted based on the theory of memes as cultural information carriers. According to this theory, in such a transmission, it is possible to distinguish certain components, which can be defined as memes. Therefore, it is possible to analyse and track their presence, transfer, as well as incidence. A memetic pool was constructed using the assumptions of the perceptual-cognitive model of the formation of the tourism image. It was a direct expression of the mental changes of the recipient, resulting from the use of the service.

Studies of this type are intended to optimize the design of services in terms of building positive relationships on the line service provider-customer. At the same time, they allow for a slightly different, evolutionary approach to analyses, concerning the formation of the image of the service provider, as well as forming the expectations of service recipients.

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accommodation service, service quality perception, meme theory, meme transfer, User Generated Content, memetic pool formation

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Introduction

The systemic approach to service quality refers to three basic components, i.e. the quality of input (the competence of employees providing a service, the circumstances of the service), process quality (interactions between the staff providing a service and the recipient), and the quality of output (changes in the physical and mental state of a recipient, resulting from the consumption of a service), (Urban, 2007; Juran, 1992 based on: Johnson et al. (1995) as well as Lehtinen & Lehtinen (1991).

The customer perception of the quality of service summarizes his/her expectations with the actual effects of the consumption of the service. From this perspective, the decomposition of the perception of the quality of service, in terms of the quality process, provides a chance to extract quantitative and qualitative parameters (attributes) that make up the image of the service. These parameters are reflected in the mental image (and its externalization) of the quality of the service by the customer. This externalization, on a wider scale, can accumulate in the form of a set of defined and structured attributes. The thus obtained package of quantitative and qualitative characteristics can be used in a variety of ways. Firstly, during the design or modification of the service, it is possible to emphasize the elements most frequently perceived by the recipients, and also introduce new elements. Secondly, by emphasizing the service and its promotion during the planning stage, it is possible to build and manage certain expectations for the service. Extensive possibilities of conducting research from this perspective are provided by the application of the theory of memes (Dawkins, 1976, 1982).

The main scientific objective of the study was to demonstrate the possibility of building a memetic pool relating to the method of decoding the perception of service quality, using the example of the quality of the accommodation service.

1. Literature review

1.1. Meme theory

Memes are the carriers of cultural information (Dawkins, 1976). They are the cultural analogue of genes. They shape attitudes, styles, behaviour, ways of dressing, and the manner of self-expression. Memes spread in the community through imitation or copying (Blackmoore, 2000). Because of this feature, it is possible to refer to them as replicators (Ball, 1984). Replicators exist and reproduce themselves through social interactions, passing from person to person, from brain to brain (Gabora, 2013). A slightly different viewpoint, associated with the viral approach to the transfer of replicators has been presented by Wang & Wood (2011). The subsequent properties of replicators are (Dawkins, 1982; Gabora, 2013):

- Longevity – it survives long enough to replicate, or make copies of itself;
- Fecundity – at least one version of it can replicate;
- Fidelity – even after several generations of replication, it is still almost identical to the original.

Knobel & Lankshear (2007) divide memes into less and more "expansive". The incidence of the effects of more expansive memes will be significantly higher in the analysed group than that of the less expansive ones. Memes compete for the "existence" in the population. The most popular ones, i.e. the ones most commonly used by an individual or social group are visible in the form of specific behaviours or styles decidedly more often than the less popular ones. Depending on the nature of the social environment, a specific set of adapted (assimilated) memes can contribute to an increase or decrease in the level adjustment of an individual. Thus, the "success" of a single meme or a set of memes is determined not only by the content but also by the environment, in which this content is externalized. The increase in the level of adaptation would then be synonymous with the increase in the level of acceptance of certain behaviours and their frequent imitation by the other members of the community. This is a situation analogous to biological evolution, where one phenotype can be beneficial in a variety of environmental conditions, while not in others.

1.2. Memes and service quality

Parasuraman et al. (1988) define the concept of service quality as the difference between customer expectations and the experience resulting from the consumption of such a service. The potentially memetic nature of the quality of services is evidenced by its features, identical to the properties of memes (Shifman, 2013):

- object/content of services – understood as a comprehensive set of goods, obtained by the recipient of the service;
- a form of communication, which may be identical to the method of service realization;
- relationship/correlation between the provider and the recipient, i.e. the source and the recipient of the message (i.e. stance).

The subject, form, and relationship are the basic features of memes. At the same time, these elements, combined with the characteristic of the quality of services, which causes changes in the mental and the physical state of clients (Johnson, 1995), justify the memetic approach. Difficulties may also be caused by isolating a single meme, which, being a carrier of a particular meaning, affects the mental state change of the consumer. For further consideration, it is assumed that the quality of the service process is a conglomeration of memes, i.e. a memetic pool, by analogy with the genetic pool, as a set of genes in the population. Constructing a memetic pool can facilitate the analysis of the manner of the perception of service quality, the image of the reception area, etc.

The memetic content, emphasized with a varying intensity during the consumption of a service, can be reflected in the manner of perception of the quality of service. This feature is conditioned by the possibility of the transfer of memes between the members of the community. The transfer of the memetic content is carried out, among other ways, through the method of building a subjective perception of reality, and manifests itself in the method of conveying this content to the environment (Lisch, 2014). The content shared on the social networks is, in this case, the direct expression of the perception of reality by network users, and, therefore, also reflects their perception of the quality of a service.

1.3. Social media and their connections with the meme theory

The possibility of a direct and individual expression of the perception of reality is provided by the social media. Kaplan & Haenlein (2010) define social media as online platforms enabling the creation of individual accounts, building a network of friends, as well as the creation and sharing of a variety of pieces of content (graphics, text, and multimedia). The content elements, to a large extent, consist of the so-called User Generated Content (UGC), i.e. the content created and shared by the users with other people. This content is used to obtain information on tourist attractions, services, the experiences of others, etc. (Sparks et al., 2013). Each of these elements contains some semantic meaning, which is read and absorbed by the recipient. Sometimes, certain content seems to exist in a veiled, hidden form. Kim & Stepchenkova (2015) showed a significant influence of the so-called latent content, the elements not constituting the main plan of a photograph on the affective and cognitive activity of customers. Moreover, based on the obtained results, the authors confirm that the photos represent a set of attributes captured by the author, sent in the form of a photograph, and interpreted by the recipient. The emotional factor is also important with regard to the method of interpretation. Xu et al. (2015) argue that social media provide a platform for the presentation and transfer of emotions, which can have a positive, negative or neutral character (Li & Xu, 2014). Choi & Tom (2014) indicate the importance of the emotional component in the transfer of content via social networks. A similar approach is demonstrated by Highhouse et al. (2009), suggesting that through the proper formulation of the communication content, it is possible to control the impressions of the recipients of specific content. Using the desired pool of traits, this enables the formation of a particular perception of places, events, etc. At the same time, Kim & Stepchenkova (2015) show that the recipients of the content "decode" their meaning in a way very similar to the organic image of a destination (Gartner, 1994), i.e. the one formed on the basis of the non-commercial sources of information. These sources are most likely related to the activities of local DMOs (Destination Management Organisations). They build a positive impression of a particular area, and at the same time create a mental, so-called "iconic" impression of the destination in the head of the customer.

2. Research questions and the development of a hypothesis

Su et al. (2015) suggest that customer-company identification, created by building mutual relationships, is one of the variables mediating between the perception of the quality of the product/service and the loyalty to a product/service as well as own well-being. Therefore, building high-quality services is one of the elements of relationship marketing, on the way to building customer confidence (Kim & Cha, 2002). Relationship marketing deals with the establishment of partner relationships between the provider and the recipient to achieve individual goals through the exchange of certain values and the meeting of commitments (Grönroos, 1984). Replacing certain values, meanings, ideas, combined with the property of the quality of services, changing the physical and mental state of the recipients (Johnson et al., 1995) are the factors driving the use of the memetic approach in the analysis of perception and externalization of the quality of services. It is problematic, however, to transform the memetic content into measurable variables. With this in mind, the main research questions have been formulated:

- RQ1: Is it possible to construct a hypothetical memetic pool concerning the perception of the quality of certain services by a group of consumers?
- RQ2: Is it possible to divide the thus created memetic pool into the groups of attributes

(memes) allowing for the examination of their incidence?

The aim of the study was to use the netnographic method (Jemielniak, 2013) to demonstrate the practical possibilities of using the model for the creation of the tourism image (Baloglu & McCleary, 1999) to form, describe, and decompose the memetic pool related to the perception of the quality of certain services. Such a pool, as an effect of mental changes created due to the accommodation service consumption, has been developed based on the semantic analysis of the comments left on business cards of agrotourism farms located in the vicinity of the selected national parks in Poland, and the ones listed on the sites that compare offers for tourists.

The contents of the comments were referred to the cognitive-perceptual attributes of the model of the tourism image, grouped into three main factors (Baloglu & McCleary, 1999):

- Factor I Experience: Cleanliness and hygiene of accommodation and catering; Quality of the available infrastructure; High quality of entertainment; Tasty cuisine; Good conditions for practicing recreation; Cosy accommodation; Interesting, Friendly People; Personal safety;
- Factor II Attractions: Historical monuments; Local handcraft; Cultural attractions; Mass events;
- Factor III: Environment: Clean, unpolluted environment; Beautiful, natural landscape; Attractive wild fauna and flora; Health-friendly climate

These are the indicators enabling the decomposition of the hotel service and its perception from the perspective of the quality of the process (Grönroos, 1984). From this perspective, the quality of the service is simultaneously reflected, among other things, in the mental state of the service recipient (Johnson et al., 1995), which can be externalized and transmitted, for example in the form of short entries on the sites comparing tourist offers. This latter feature allows for the examination of the quality of services from the perspective of the memetic approach (Dawkins, 1976).

The problematic issue, however, is the task of defining a meme itself. In the case of this study, it was assumed that a meme is a semantic reflection of the mental state of the recipient of the specific content. This condition, in turn, is externalized, among other ways, through the manner of expression of the opinion about a specific subject, product or service. The direct expression of the transfer and decomposition of fragments the memetic pool were the authorial entries of social network users, defined as UGC.

Another problem was to generate a point of reference and a tool, through the use of which it would be possible to decode and read the specific memetic content. In this paper, it is assumed that the use of the perceptual-cognitive component of the model of creating the tourist image (Baloglu & McCleary, 1999) provides a basis for the creation of a memetic pool, as a set of memes relating to a particular service. At the same time, a collection created in that manner, can be easily decomposed. This distribution, in turn, allows for the analysis of the incidence of specific memes.

To gather as many comments as possible, the contents of five randomly selected comparison sites for tourist offers were analysed i.e. e-holiday.pl, nocowanie.pl, spanie.pl, emeteor.pl, and e-turysta.net. Due to the pilot nature of the research, the work included 12 of the 23 Polish national parks. In each of the comparison sites, with the use of the search engine integrated into the site, business cards have been identified relating to the agrotourism farms associated with each of the analysed national parks. The comments were archived with the use of Google spreadsheets. The contents of each comment were referred to the attributes grouped according to the three main factors mentioned above: experience, attractions, environment (based on Baloglu & McCleary, 1999). A single comment can contain one or more semantic references to the attributes mentioned above. At the same time, each of them was seen by the author as a single meme. The study was conducted between January and March 2016.

3. Research results

During the conducted pilot research, 497 comments were identified. Out of these, 104 were related to the tourist lodging, located in the vicinity of Białowieski National Park (104), Biebrzanski National Park (45), Bieszczadzki National Park (31), Kampinoski National Park (21), Karkonoski National Park (19), Narwiański National Park (84), Ojcowski National Park (24), Roztoczański National Park (66), Słowiński National Park (19), Tatrzański National Park (8), Wigierski National Park (21), and Woliński National Park (55).

Using the three classification factors presented above, it was found that among the analysed comments, 1341 semantic and direct references were made to the attributes identified with the quality of service. This pool (Fig. 1) was dominated by the indications associated with Factor I, i.e. concerning the overall experience (1127, i.e. 83.9%). The second most frequently noted group of indications (193, i.e. 14.54%) was related to the third factor, referring to the perception of the natural attributes in the immediate vicinity of the accommodation services (environment). The least numerous (21, i.e. 1.56%) were the indications relating to Factor II, describing the attributes associated with the local cultural heritage (attractions).

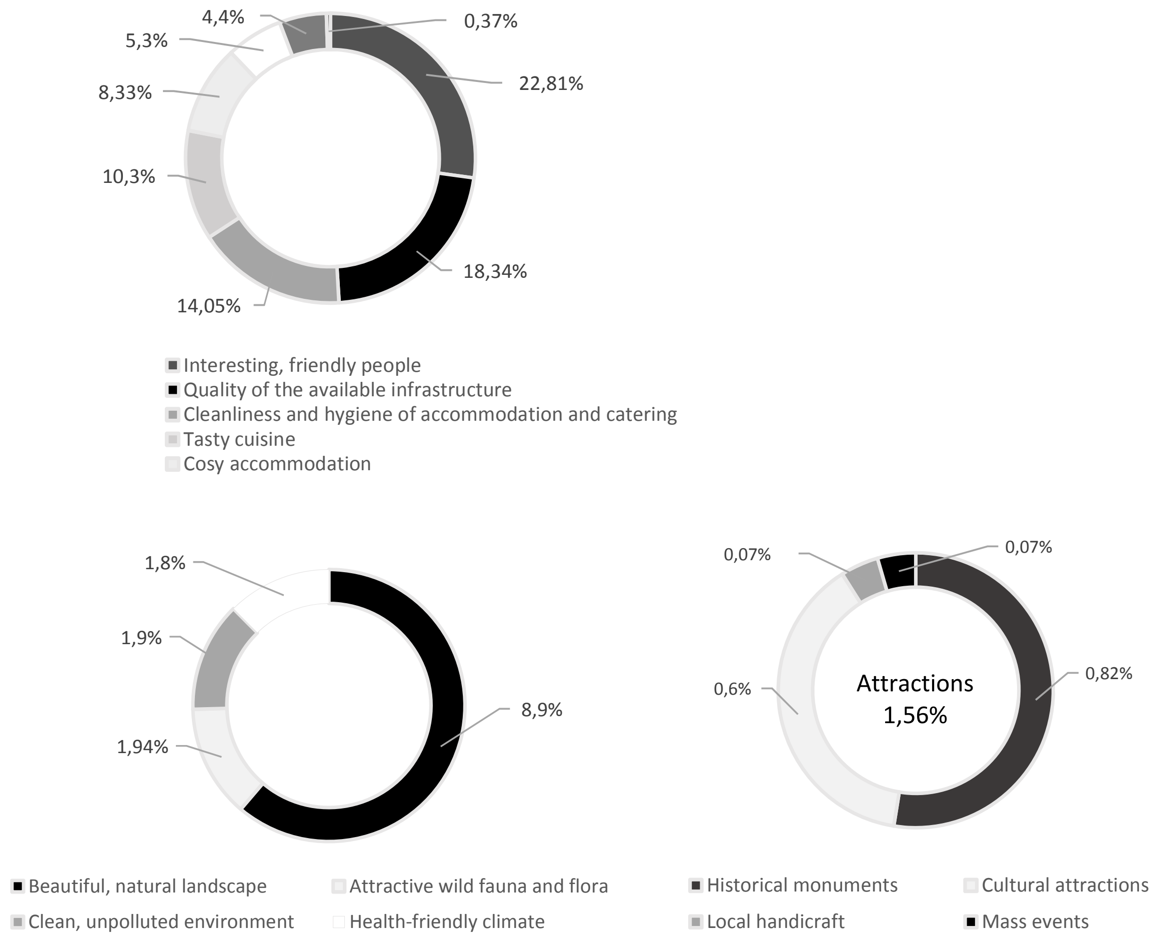

Fig. 1. Content of the memetic pool, reflecting the manner of perception of the quality of the accommodation service by its recipients from the perspective of the quality of the process

From the perspective of the first factor (experience), the dominant roles belong to the memes relating meaningfully to the friendly and welcoming service (22.81%) and the quality of the available infrastructure (18.34%). The least frequently represented factor is personal safety (0.37%). The third factor (environment) was represented mainly by the references to the landscape (8.9%). The semantic references to the second factor (attractions), was the least represented category of memes across the analysed memetic pool. Its share, not exceeding 2% of the total, relates mainly to historical monuments (0.82%).

4. Discussion of the results

The conducted studies have shown the ability to identify and analyse the memetic bank, relating to a particular phenomenon (quality of accommodation service). Therefore, it is possible to create a set of memes being the result of changes in the mental and emotional state of the consumer. In this case, the factor attributes of the formation model of tourist image by Baloglu & McCleary (1999) were the tools of decomposition. A similar approach but without any indication of the memetic context was showed by Tiago et al. (2015). The authors analysed the contents of commentaries regarding the semantic links to the senses of sight, hearing, taste, and touch, demonstrating that the meaning of the comments refers not so much to taste and smell, but also to a number of other attributes e.g. visual effect, freshness of the ingredients, and healthiness of the meal. At the same time, these are the factors based on the direct experience of consumers, and, thus, positively affecting the scope of the spread of the content within the social network. Undoubtedly, the factor deciding about the increased coverage in this case is a positive emotional tone. The potential and positive impact of the transfer of experience through UGC in building the trust and making consumer decisions is also indicated by Bahtar & Muda (2016).

The need to systematise and organise the data available within the social network is shown, among others, by Injadat et al. (2016). The authors particularly emphasize the unstructured nature of social media data, connected with different data types, such as text, images, and videos. Application of the theory of memes and the memetic bank as a collection of memes, allows for a simple systematisation of photographs, films and text elements, using common criteria. Assigning particular content to a single or several memes may be problematic, however, because of the subjective approach to categorizing.

Zhang et al. (2016) had an interesting debate, related in meaning to the theory of memes, although not referring directly to it, on the example of the financial markets. The authors argue that "… market can be partially predicted since people tend to accept messages which are confirmed by social environment and then invest according to what they have learned".

In this case, one may try to explain the transfer of the memetic content using the IPI (influence of Presumed Influence) theory. In the situation when a recipient of chosen content assumes that certain attitudes and behaviours presented in the transmission constitute a norm in a social (peer) group, there is a greater probability that they will be implemented by him/her (Gunther et al., 2006). From this perspective, building a high quality service is the transfer of information related to the "exceptional" nature of the specific service. The acquisition of such content by the recipient results in its further sharing. At the same time, the so-called "iconic" image of the provider is being built, setting out the way the provider is perceived by potential consumers. And, in turn, this implies a certain organic image of the provider, whose expression can be transferred. At the same time, certain expectations of the recipient in relation to the offered service are created. However, the analysis of the relationship between the perception of service quality and its impact on the formation of expectations regarding the quality of the service among future consumers requires a further detailed study.

D'Agostino et al. (2015) show that social networks are collections of hidden knowledge, relating to many fields of human activity. These authors distinguish general networks (Facebook), where the content on various aspects is collected, and specific networks (e.g. LinkedIn), associated with profiled areas of user activity. Therefore, it can be assumed that these networks are holistic or specific memetic banks, where takeover and replacement of certain memes take place. To some extent, this approach enforces the way of defining the memetic bank as a set of memes (present in the content elements) and transmitted across the network or beyond it. In turn, the nature of the network depends on the number of users, motives of their activities, interests, primary and secondary social bonds (Podgórecki & Łoś, 1979). Also, the phenomenon of homophile, i.e., the integration of people with similar interests, is not without significance (Lazarsfeld, 1954). On the other hand, the occurrence of certain memes depends on the type of network and subject area, for which it exists.

At the same time, D'Agostino et al. (2015) compare the transfer of content within the SN to the physical process of diffusion. The memetic approach, in turn, transfers the level of the considerations similar to biological sciences and evolutionary phenomena. Such studies enable attempts to build scenarios for the development of the perception of the quality of services in the future, and the prediction of the potential distribution of the incidence of memes in a memetic pool concerning e.g. the quality of products or services.

Lymperopoulos & Ioannou (2015) indicate that the impact (positive or negative) on the determination of the affective and behavioural activities of social network users is mainly exerted by self-generated bias, the online interactions, and the external environment. This approach is identical to the processes of exchange of genetic information in bacteria. Similar to these organisms, the users in the process of transformation, download information (memes) from the environment (other users, groups, associations of users, communities). This acquired piece of information is in the next type of information/meme flow process, i.e. conjugation is transmitted between the individuals and entities creating a social network.

Assuming that the quality of the process can be regarded as the so-called memetic pool (i.e. the total set of quantitative and qualitative attributes for describing the whole service process), it is possible to distinguish more expansive and less expansive memes (attributes) within it. The first category will dominate in the transmission to the recipient, while the other will constitute a subordinate element. The dominant memes will be identical to customer expectations, completed in the course of the consumption of the service. They will be transferred and/or processed (in the form of UGC). This transformation, from the perspective of a single recipient, may vary substantially in terms of quantity and quality. However, in the case analysis of a sample from the population (i.e. the analysis of the content of UGC and the memes externalized within them), it will create a ranking of the elements of the cultural transmission, which dominate the manner of perception of a service by the recipients. This, in turn, will provide a theoretical basis for the creation of strategies for building the quality of services while simultaneously building certain tourist expectations (Smoleński, 2011), as well as the tourist image (Tosun et al., 2015; Smoleński, 2010).

In summary, it has been shown that based on the semantic analysis of User Generated Content, is possible to construct a memetic bank, illustrating the manner of perceiving the accommodation service quality. To understand this phenomenon more thoroughly, we should carry out further research regarding the manner of creating the service quality by the service provider. Confronting the base bank, created by the service provider, with a bank, which was assimilated and externalized by recipients, would provide interesting results in the analysis of the effectiveness of the memetic content transfer.

Conclusions

The aim of the study was to demonstrate the potentially memetic nature of the quality of accommodation services. The quality of service, as perceived from the perspective of the quality of the process, was adopted as the theoretical basis. In this perspective, the manifestation of memetic transmission is the way of describing the quality of services by the recipients.

In this approach, the quality attributes of services form the memetic transmission, constituting a kind of a memetic pool. During service realization, but also indirectly during the image building of service providers in social networks, this transmission is transmitted in the direction of the recipients (current and potential). The result of the transmission is the perception of services and their quality through confrontation with the expectations of a service recipient (after using the service) or building the expectations themselves (before using the service). Subsequently, thanks to the properties of memes, an individual way of communication regarding the services and their quality is formed and expressed. This stage may be identified with the adoption of a specific subset – part of the meme pool, and the process of their transformation, i.e. individual transformations done by a single customer. The final stage will be the further transfer, i.e. to subsequent users through sharing, of a packet of memes in the UGC form.

The presented considerations, although supported by the results of partial studies, are theoretical in nature. They direct the research on the phenomenon of the quality of services to the population-evolutionary approach. The meme pools, described by the frequency of occurrence of individual memes, are dynamic, i.e. changing over time, depending on the external factors influencing the demand for certain products and services. At the same time, the chances for evolutionary success, defined as the stable presence on the market, pertain only to those services and related service providers, in the case of which the marketing activities and the process of service realization itself, are building the proper relationship with service recipients.

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Identification of production bottlenecks with the use of Plant Simulation software

Mateusz Kikolski

ABSTRACT
The problem of bottlenecks is a key issue in optimising and increasing the efficiency of manufacturing processes. Detecting and analysing bottlenecks is one of the basic constraints to the contemporary production enterprises. The enterprises should not ignore problems that significantly influence the efficiency of the processes. People responsible for the proper course of production try to devise methods to eliminate bottlenecks and the waiting time at the production line. The possibilities of production lines are limited by the throughput of bottlenecks that disturb the smoothness of the processes. The presented results of the experimental research show the possibilities of a computer simulation as a method for analysing problems connected with limiting the production capacity. A computer-assisted simulation allows for studying issues of various complexities that could be too work-consuming or impossible while using classic analytical methods. The article presents the results of the computer model analysis that involved the functioning of machinery within a chosen technological line of an enterprise from a sanitary sector. The major objective of the paper is to identify the possibility of applying selected simulation tool while analysing production bottlenecks. An additional purpose is to illustrate the subjects of production bottlenecks and creating simulation models. The problem analysis involved the application of the software Tecnomatix Plant Simulation by Siemens. The basic methods of research used in the study were literature studies and computer simulation.

KEY WORDS
computer simulation, production process, bottleneck, simulation model, Tecnomatix Plant Simulation

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Introduction

Contemporary production is characterised by a wide selection of products, reduction of the product's life cycle, production costs and the time span between designing and launching products (Weiss, 1998). A constantly shortened cycle of the product's life caused by strong competition and changing requirements of customers, force producers to identify weak points of production processes and implement changes aimed at improving their operation. It can be stated with high probability that every production process allows for some limitations to the manufacturing capacity of the enterprise since the existence of a bottleneck is the main factor affecting the efficiency of the production line and management (Liu & Lin, 1994; Chiang et al., 2001). Every enterprise can face constraints limiting the obtained revenue. The Theory of Constraints (TOC) assumes that every system has one basic limitation that influences the efficiency of the system in a given period (Chlebus, 2000; Goldratt et al., 2004). Localising bottlenecks is a key issue of production systems. Studying production bottlenecks is also a regular subject matter of scientific research. Production bottlenecks lead to various consequences. They can cause two major problems in a production process. Firstly, if the capacity of the assembly line does not suffice to meet the demand, an enterprise may lose its customers. Secondly, if the surplus of stocks is accumulated before the workstations of the bottleneck, this breeds additional costs connected with storing.

The development of computer science and the enormous computing power boost the increasing popularity of simulations that use appropriate software to project changes on real objects and situations before making any changes. The advancing computer simulation technology is gaining importance and becoming one of the most significant elements of production management. The reason behind this development is the necessity for companies to solve increasingly complex production problems as soon as possible. The development of programs for the simulation of processes makes it possible to use them in any enterprise, regardless of the profile. This software is used e.g. in the cells of the design, management and storage (Zdanowicz, 2007). The construction of a simulation model is a difficult task and requires a lot of information about the real process.

Simulation models allow evaluating different variants of production and their effectiveness. In addition, the simulation allows to use new strategies and procedures, verification of the production in the revised system, locate bottlenecks in the flow of materials, increase productivity while reducing inventory and reduce the cost of the implemented changes (Hromada & Plinta, 2000).

1. Literature review

Literature provides many definitions of bottlenecks, though most of them cannot be applied in general (Wang et al., 2005). According to one of the definitions referring to production, a bottleneck is an element of a production process, where every resource that must be used to maximise production, is used in 100% (Durlik, 1995). A one-hundred-percent use of the production capacity of a given workstation breeds a considerable threat to the effectiveness of production processes. A workstation, being a bottleneck, is characterised by the highest level of exploitation, which also means a high risk of failure. At the same time, it is also the main factor affecting the completion date concerning the entire production process (Koliński, 2010).

A bottleneck is defined as a workstation limiting the production efficiency of the entire process (Betterton, 2012; Hsiao et al., 2010). It is the enterprise's workstation or a production cell that is characterised by the lowest level of a specific production parameter among all co-participating parameters in the manufacturing process. This can lead to a situation, in which a workstation before the bottleneck completes processing, but it cannot forward materials, as the workstation that follows it, being the bottleneck of the process, is still engaged in processing earlier orders. Bottlenecks can also extend the time of the standstill in the processes occurring at subsequent stages (Li, 2009), prolonging the waiting time for further orders. Bottlenecks mark the pace of the entire process. All definitions are consistent in one sense – bottlenecks have an adverse effect on the efficiency of production systems, the flow of materials in the process as well as even burdening of workstations (Kuo et al., 1996). Figure 1 presents the idea of bottlenecks.

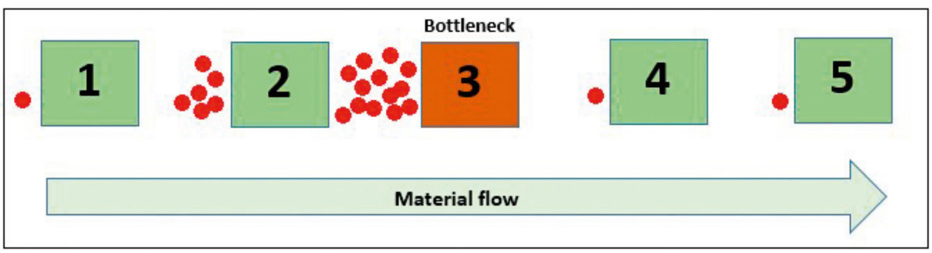

Fig. 1. Idea of bottlenecks

Source: Elaborated by the author based on (Betterton, 2012; Hsiao, Lin, & Huang, 2010).

Improving the functioning of workstations that delay the production is a crucial issue. However, it should be noted that before taking action aimed at improving the operation of workstations defined as bottlenecks, it becomes crucial to identify their precise location.

Identifying a bottleneck in the system is the first stage of managing constraints according to the Theory of Constraints (Goldratt et al., 2004). It involves localising the system's limitations. The following are other stages of managing constraints that can also be used in the analysis of computer-assisted simulation models:

- Making a decision on the manner of using a bottleneck;
- Subordinating all other operations to the decisions made in stage two;
- Eliminating the system's bottleneck;
- Returning to stage one (if it was possible to eliminate the bottleneck) and preventing the limiting effect of inertia.

As every system has its constraints, the identification and elimination of some of them results in the occurrence of the new constraints that replace the old ones. The procedure of a five-stage system management is sequential and continuous.

The literature identifies many methods of detecting production bottlenecks. However, there are still no expanded elaborations and case studies that use digital simulation models in that respect (Kliment et al., 2014; Leporis & Králová, 2010; Pawlewski & Fertsch, 2010; Siderska, 2016). Therefore, the raised issue requires further studies involving diverse software. The developing computer simulation tools with increasing capabilities are an ongoing research challenge.

2. Research methods

Studying phenomena and processes is the aim of many research programmes. This involves the application of various methods, beginning with practical activities in the form of observations, and ending with theoretical analyses. Such procedures require a mathematical apparatus. In the contemporary world dominated by ICT tools, a computer simulation becomes an exceptionally significant and effective research method. It reflects the studied phenomenon or a process in the form of a computer program, also called a computer model, which is created with the use of a mathematical model (Gierulski et al., 2015).

Simulation is an approximate imitation of a studied phenomenon or behaviour of a given system in the virtual space with the use of its so-called simulation model. A simulation model is based on a mathematical model frequently recorded in the form of a computer program. At present, many tools are available for conducting computer simulations that allow creating simulation models (Ciszak, 2007a). Simulation models are used to reduce the risk of failure while implementing significant changes into the existing manufacturing systems. Upon generating the model, a simulation analysis is performed to determine particular elements of the process. The model of a studied system presents its properties, features and limitations as well as the manner in which the process in specific conditions takes place. Simulation, by means of adequate tools, allows for a respectively simple and cheap way of verifying different variants connected with the functioning of the processes (Glinka, 2012).

With a view to the objective of the simulation, it can be divided into three types (Ignasiak, 1997):

- a simulation aimed at understanding the principles of the functioning of the system and its properties that are difficult to distinguish based on a formal analysis;
- a simulation aimed at facilitating decision-making within the functioning of the system;
- a simulation, whose aim is to train decision makers concerning the functioning of the system.

The simulation of production processes is a technique used for solving problems occurring during the manufacturing process. It is based on virtual models (Kłos & Patalas-Maliszewska, 2016). As a method, a computer simulation is a system of research activities, i.e. a structure of stage activities aimed at achieving a research objective. The creation of a simulation model of a process is a multi-stage task (Gordon, 1974; Naylor, 1975; Law, 2008). Figure 2 presents the seven-step approach to conducting a successful simulation study.

Modelling the production process involves the creation of a virtual manufacturing process that allows conducting a simulation and collecting statistics. Statistics facilitate conducting reports and comparing selected settings of the parameters that characterise workstations. Computer models can be freely improved, and further simulations can be applied to various variants and settings anticipated by the user.

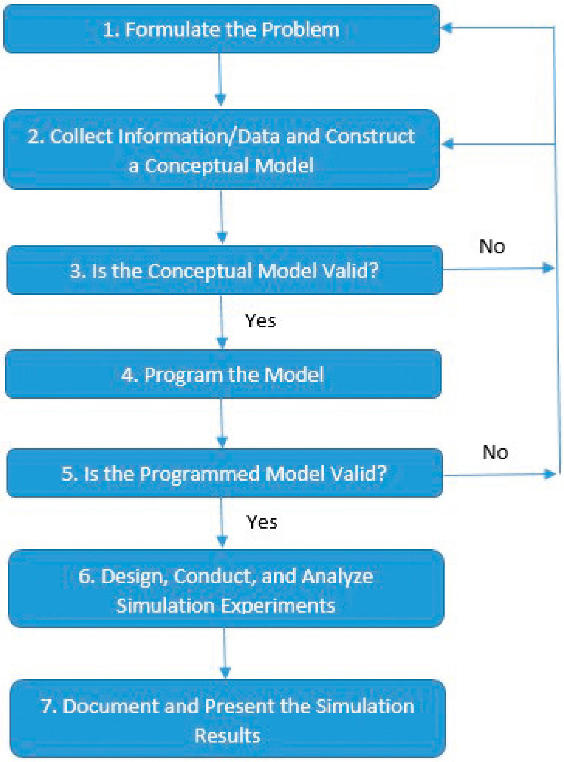

Fig. 2. Seven-step approach to conducting a successful simulation study

Source: (Law, 2008).

Simulation studies are applied to and are used in many scientific fields (Nazarko, 2013; Halicka, 2016). The application of a simulation in production processes constitutes a form of experimenting with a computer model. Its objective is to provide an answer to the question on how the production system will react to various situations, according to arranged scenarios. The application of simulation models allows for a more effective selection of manufacturing strategies by enterprises. Simulation models are typically used when it is impossible or very difficult to devise an analytical solution of a studied problem. This takes place in the case of analysing a dynamic behaviour of production systems and processes. An adequate selection of strategies and skilful management of chosen tools, including methods of computer simulation, allow and facilitate solving of problems that occur in the activity of an enterprise (Karkula, 2012). Digital manufacturing fosters modelling and simulation any product. Thanks to the application of computer assistance, production enterprises can optimise manufacturing processes in terms of time, costs and the quality level. The inclusion of ICT into manufacturing processes is a common phenomenon. The creation of computer models allows analysing manufacturing processes, helps to localise their weak points, and creates possibilities for their improvement (Kikolski, 2016).

Computer simulations are identified as the most popular tools for the analysis of the possibilities that optimise processes in production engineering. Conducting of computer simulations allows assessing whether the undertaking was properly designed and is conducted in an adequate manner. A simulation ensures a total, complex view of the studied process or product, facilitates a multi-criterion analysis and testing various scenarios (Siderska, 2016). Modelling and digital simulations are used when it is too complicated or impossible to obtain a solution with analytical methods and experimenting with the real process within a production hall is too labour- or cost-intensive due to the enforced standstills in operation. Thanks to the application of the Plant Simulation tool, the analysis of chosen production processes is also possible at the stage of production design (Kikolski, 2016). Modelling and simulation are also used in situations where it is impossible to achieve the required level of confidence while applying other methods. The level of confidence means a condition in which the manufacturing process proves assumptions that were ascribed to the virtual model. The simulation of production processes allows familiarising with the functioning of the studied object and its analysis. Among other things, the studied objects are procedures, operations, transportation, stations, distortions, and stocks. A simulation facilitates tracking the system's operation from several minutes to several years. Moreover, it makes it possible to control the established assumptions before their practical application. It also allows for an earlier detection of irregularities that may disturb production in the future (Ćwikała & Gołda, 2005).

3. Case study

To verify theoretical assumptions, the analysis involved a case study, which incorporates modelling and computer simulation into the identification of a production bottleneck. It should be noted that the creation of a simulation model requires adequate knowledge of the modelled object. The success in applying a computer simulation for solving research problems resets in the proper creation of the model and the adequate execution of a simulation experiment. Creating a model of a production system and conducting a proper simulation experiment determine a successful application of a computer-assisted simulation into solving research problems. To create a production system, it is necessary to gather and map out the necessary information as well as input data. They identify the level of the quality, quantity and form. It is an initial stage, thanks to which it is possible to gain knowledge of the problem as well as acquire information on methods that can be used to solve it (Ciszak, 2007b). It is also necessary to properly study the tools of the program that are to be used. and design, through simulation and verification of processes (Danilczuk et al., 2014; Plinta 2013).

The aim is to achieve the simplest possible model; however, the prerogative is to devise a model that describes the activity of the modelled process with the highest precision (Małopolski, 2012). Nevertheless, it should be noted that oversimplifications used in the creation of the model can lead to false results of the simulation, i.e. results that vary from the real state of the system in given conditions. To properly define the parameters of specific operations, it appeared necessary to conduct studies that involved gathering information during the active production hours within the production hall.

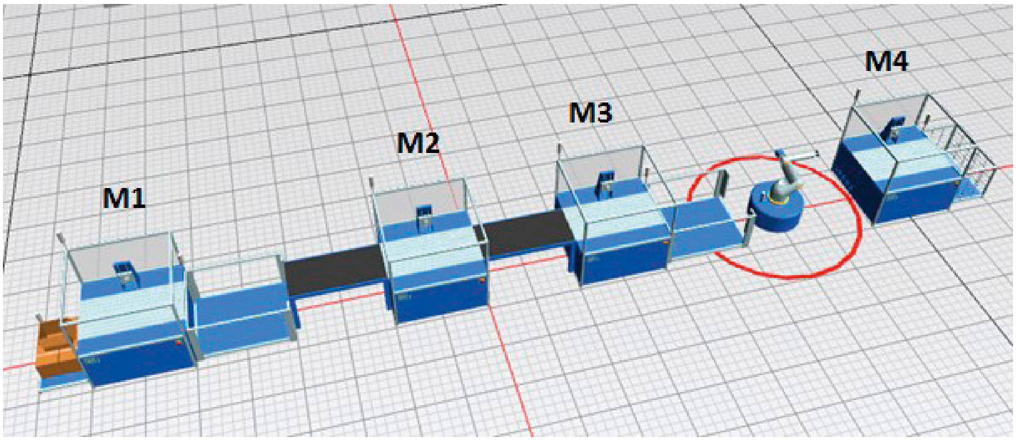

Fig. 3. Virtual 3D model of the analysed process

The research involved the use of the Siemens product Tecnomatix Plant Simulation, one of the tools available on the market for creating simulation models. The choice of the system is not the most important thing. The possibility of applying the system to selected problems should be noted. In addition, studies have used other systems for the simulation of production processes, which include (Ciszak, 2007a; Danilczuk et al., 2014):

- Arena,
- Enterprise Dynamics,
- Flexim,
- Matlab Simulink,
- ShowFlow,
- SIMUL8.

Plant Simulation choice is dictated by the availability of research version. The selected tool enables conducting simulations and product analysis throughout the entire manufacturing process. This ensures planning a sustainable production process prior to its implementation as well as conducting the analysis and optimising already existing processes. It combines the fields of technology, production engineering and logistics. It also includes issues related to planning

The model of a production system (Fig. 3) is based on an example of a real production department, with the use of Tecnomatix Plant Simulation software. The input data are determined based on the known technological data of the process and the data concerning material flow during production. It is particularly essential to reflect activities connected with the processing of individual components.

The project does not use energy and cost data, neither does it consider work performed by the employees. To achieve the objectives of the research paper, it is crucial to incorporate the elements of the production process that directly affect the time of performing tasks within the machine park.

Proper identification of basic properties of the system is crucial for achieving proper results of the analysis. The gathered information was used in creating virtual processes of manufacturing and defining their basic tasks. The creation of simulation models relied on approved assumptions concerning simulation times. Table 1 presents unit timing of processing at specific stations.

Tab. 1. Components time of processing on workplaces (in seconds)

Workplace	Time of processing (in seconds)
M1	24.32
M2	20.16
M3	49.68
M4	32.55

The studied process involves four workstations and auxiliary infrastructure that is used for transporting semi-finished products. The analysis was conducted during one work shift (6:00–14:00), which was broken into two intervals of 30 minutes.

4. Research results

The simulation involved one product; therefore, the model did not require resetting machines at specific stations. All machines have a high (M1 and M3) or medium (M2 and M4) work coefficient. During an eight-hour-long simulation, the virtual model produced 541 units of products prepared for further production and assembly (not covered by the simulation). The Chart in Fig. 4 presents the results gathered during the simulation. It shows the percentage-based burdening of all stations that take part in a process.

An initial analysis of the chart leads to the conclusion that the station M3 is the bottleneck of the analysed process. Table 2 provides detailed results of burdening specific stations.

Tab. 2. Detailed statistics in the basic model

Workplace	Working time [%]	Waiting time [%]	Blocked time [%]	Paused time [%]
M1	88.75	–	5.00	6.25
M2	38.29	0.18	55.28	6.25
M3	93.58	0.17	–	6.25
M4	61.22	32.53	–	6.25

The analysis of detailed data confirms that the bottleneck in the studied example is the station M3, which is used with 93.58% intensity, whereas the remaining time is devoted to breaks in the production that are planned in advance. It can be observed that the station M3 causes considerable standstills at the station M2, reaching 55.28% of the simulation time. Moreover, the identified bottleneck causes increased mid-operation stocks as well as gradual blocking of the station M2. It also enforces the waiting time for semi-finished products at the station M4.

5. Discussion of the results

The analyses required applying adequate software. They involved one of already available systems for designing and optimising virtual models of pro-

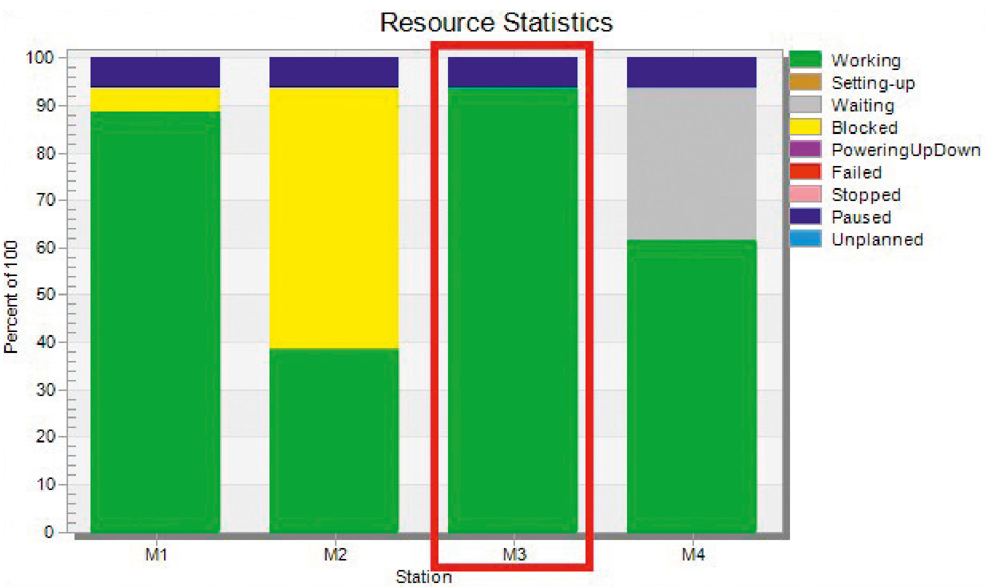

Fig. 4. Chart of efficiency for the basic model

duction processes, identifying possibilities of its use in analysing production processes.

It should be emphasised that the operation of the lowest efficiency limits the efficiency of the entire production process, but also identifies its efficiency. A bottleneck is a resource that prevents from compensating for lagging behind or delayed production orders. It also determines the level of the integration of other workstation in the production process.

Some of the ways to solve problems of a production bottleneck are: introducing shift-based production, increasing the number of overtime, intensifying quality control before the bottleneck to eliminate the production rejected in the bottleneck, expanding the machine park or, ultimately, purchasing from the market the missing semi-finished products manufactured by the bottleneck. All of the above-enumerated solutions can be implemented in a basic model, extending its functionalities in terms of the selected auxiliary assumptions. Tests in the virtual environment facilitate a free configuration of the technological line, without interfering with the real process within the production hall, until the optimum solution that an enterprise can afford is chosen.

As the simulation in the presented case involves the course of one shift, it is not possible to increase the working time of specific stations to compare the basic to the extended model.

One of the solutions that can be implemented in the analysed model is expanding the production line

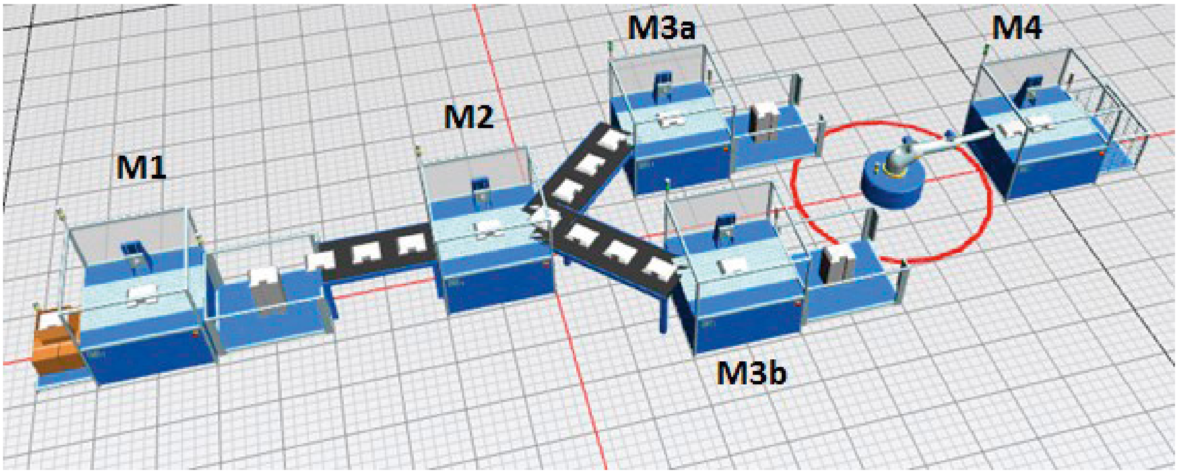

Fig. 5. Extended model of the analysed process

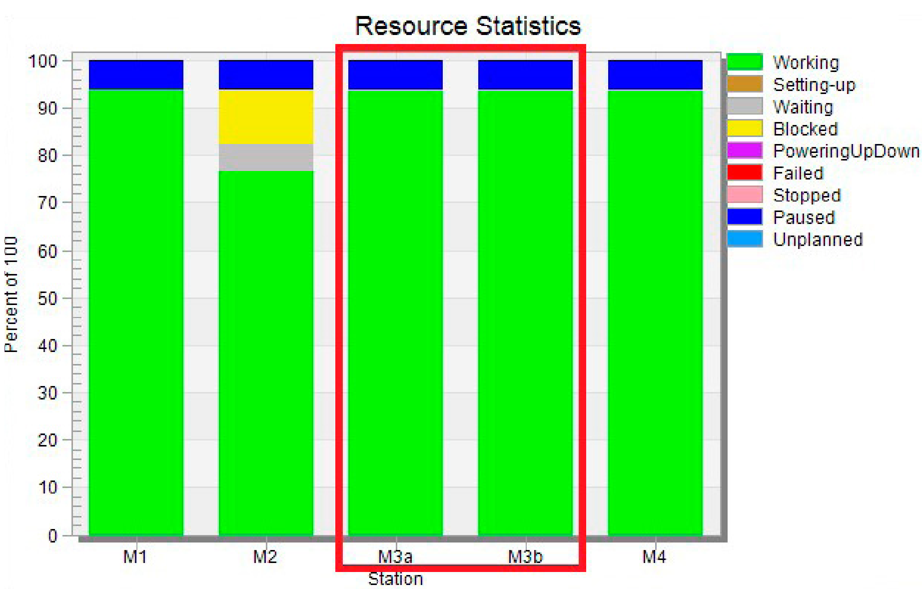

Fig. 6. Chart of efficiency for extended model

by a parallel station of the work node M3, which is the bottleneck of the output process. The extended model is presented in Figure 5. The parameters of workstations remained unchanged. The efficiency of the process, as compared to the basic model, increased from 541 to 826 units of the manufactured semi-finished product during an eight-hour-long shift.

Figure 5 presents the chart that shows the efficiency of the analysed process upon changes made according to the alternative scenario that involves expanding the machine park. Detailed results are presented in Table 3.

Tab. 3. Detailed statistics in extended model

Workplace	Working time (percentage)	Waiting time (percentage)	Blocked time (percentage)	Paused time (percentage)
M1	93.75%	–	–	6.25%
M2	76.58%	5.59%	11.58%	6.25%
M3a	93.58%	0.17%	–	6.25%
M3b	93.49%	0.26%	–	6.25%
M4	61.22%	32.53%	–	6.25%

The introduced changes did not fully solve the problem of the bottleneck at the station M3, but they considerably improved the smooth operation of the entire production line. Firstly, the blocking of the machine M2 was considerably reduced, and the idleness of the machine M4 was eliminated. Machine M4 could prove to be the new production bottleneck in extended studies, though it does not affect the other objects of the process as much as the station M3 in case of the first scenario.

It should be noted that the described scenarios did not consider the costs of expanding and maintaining the machine park. The current model cannot identify if the obtained growth in production efficiency could balance the cost of expanding the production line. This fact necessitates further studies focused not only on the growth in the production efficiency, but also accounting for the costs of implementing changes and their cost-effectiveness.

Conclusions

The problem of a bottleneck is one of the core issues faced by production enterprises while, e.g., planning or optimising their production. The main problem in the case study was to find a production bottleneck with the use of a simulation model.

The article presents the analysis and assessment of the chosen production line in two versions. The studies facilitated an initial evaluation of the efficiency of specific elements in the process and the indication of its bottleneck.

The subject of the reported research was to develop a simulation model of the actual production line and examine the load of individual workstations. Developed simulation model allows the bottleneck location of the production process. The results of simulation studies have shown that one bottleneck exists in the reporting process at the station M3. It interferes with the operation of the entire process, resulting in blocking of the work at the station M2 and forced to idle at the station M4. It has been proposed to improve the process, involving the extension of the parallel position at the point of detection of the bottleneck. The result of the expansion was mainly to increase the production capacity of the process and the vast reduction of the time of locking at the station M2 and expectations for components at the station M4. The analysed production line began to work smoothly.

The performed study confirms the possibility of applying Plant Simulation software in the analysis of simple production processes. The use of computer simulation tool allows to predict the work of the production line and provide some of the behaviour of systems. A wider scope research can provide an answer to the questions concerning the suitability of such solutions in the analysis of complex processes.

Using simulation tools does not exclude a traditional form of design. However, it may become a source of confirming the adequacy of a designed object. The application of a computer simulation for solving research problems relies on the proper creation of the model and adequate execution of a simulation experiment. The choice of the relevant tool for conducting a simulation is extremely essential. It is important that a given program has an adequate functionality in the sense of the simulation's objective.

It should be noted that the conducted analysis is only an example of using simulation models for the identification of bottlenecks and that it was focused on the part of the production process. Expanding research to encompass other elements of the process can affect the statistics of the efficiency of specific stations.

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