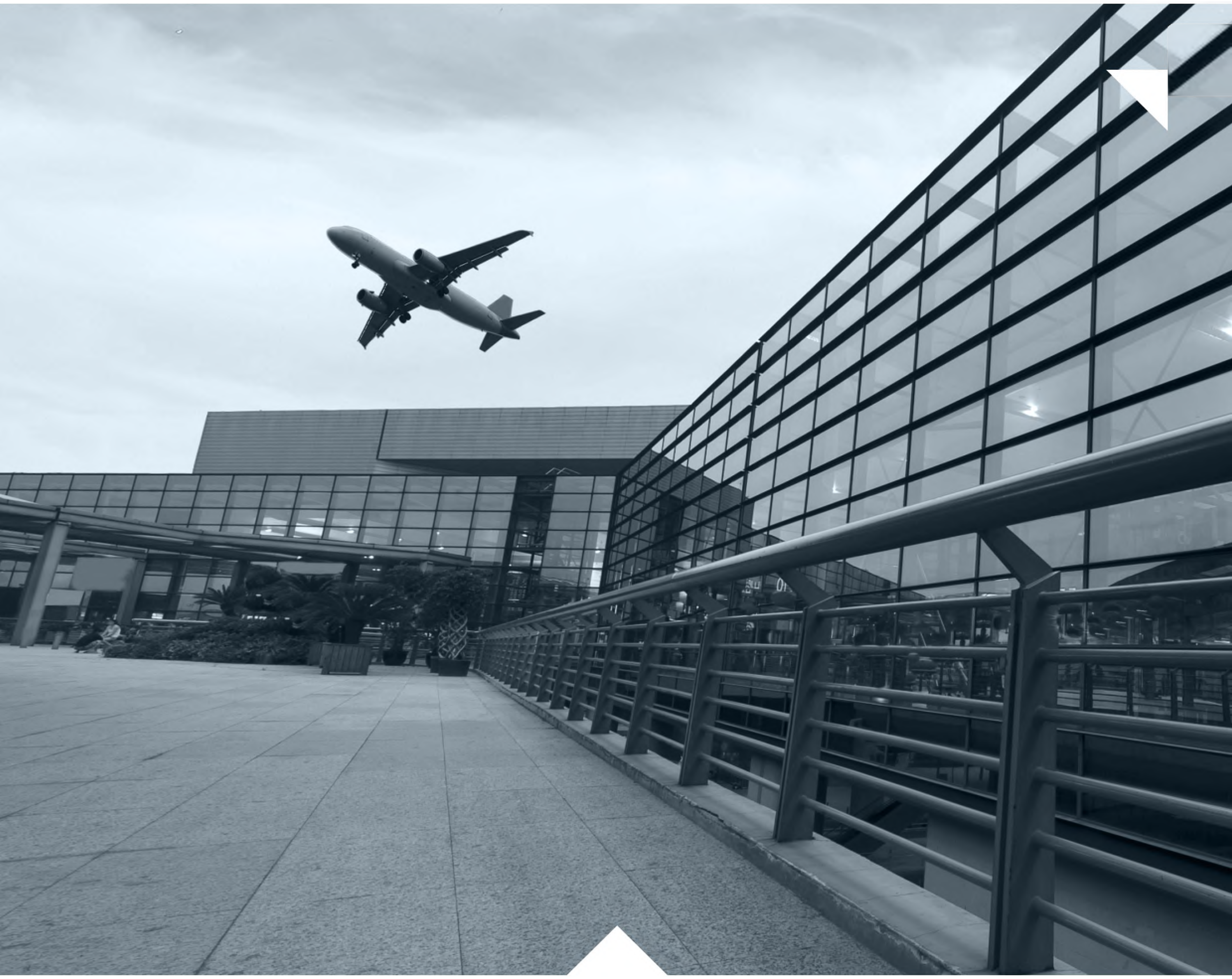
CONTEMPORARY CHALLENGES IN SUPPLY CHAINS VOL. 2

Piotr Cyplik, Grzegorz Bartoszewicz,
Wojciech Machowiak, Łukasz Brzeziński (Eds.)



Spatium

Piotr Cyplik

Grzegorz Bartoszewicz

Wojciech Machowiak

Łukasz Brzeziński

CONTEMPORARY CHALLENGES IN SUPPLY CHAINS

Radom

Recenzenci:
prof. dr hab. Henryk Sobolewski – Wyższa Szkoła Logistyki Poznań
dr inż. Michał Adamczak - Wyższa Szkoła Logistyki Poznań

Afiliacja naukowa: Wyższa Szkoła Logistyki z siedzibą w Poznaniu

Projekt okładki: JUST Agencja Reklamowa
Opracowanie redakcyjne: Piotr Cyplik
Redakcja techniczna: Kamila Janiszewska

e-ISBN 978-83-66017-89-4

Wydano nakładem:
Instytutu Naukowo-Wydawniczego „Spatium"
26-600 Radom, ul. 25 Czerwca 68
tel. 48 369 80 74, fax 48 369 80 75
e-mail: wydawnictwo@inw-spatium.pl
http://www.inw-spatium.pl

CONTENT

Preface

The general subject of this monograph is the contemporary challenges in supply chains. Dynamic and incessant changes in the turbulent business environment make a real, multilateral challenge for supply chain managers. The significant manifestation of this challenge are rapidly progressing processes of digitization, climate changes and legal regulations resulting in significant variations of performance modes and functioning of supply chains. Groundbreaking changes in the development of automation, robotics and web technologies generate the need for new, innovative concepts, strategies and tools in supply chain management.

In the monograph, the authors of particular chapters raise the most important issues in the area supply chains. Investigated challenges include the concepts of sustainable development and Closed Loop Supply Chains, business based on cooperation, crowd economy, Physical Internet, logistics supernets, Gray-power, Cloud Marketplaces, Cloud computing, second-screen revolution, social media, real time access to information and real time decisions, multi-channel, omni-channel as well as changes in the legal and technological environment, and others. The book consists of three complementary parts.

The first part~~s~~ focuses on the global challenges of supply chains. Selected issues start from an analysis of activities and development of airports in selected central and Eastern European countries. Next chapters refer to regulations in the field of air transport are an important element of managing contemporary supply chains, issues related to internet crowdsourcing logistics and problems related to the increased number of road accidents resulting from the growing volumes of transported products and proposition of specialised container for the safe transport of electrically powered passenger cars after an accident. This part is completed by the chapter on logistical measures to combat African swine fever.

The second area described in the monograph are challenges in external supply chain processes. The authors of chapters in this part consider problems related to methods of evaluating process maturity level in complex supply chains, an impact of Omni-channel on B2B sales process, an impact of the common market on the structure of transport companies in new members states and an efficiency of the maritime container supply chain at the maritime container terminal with reference to identified risks. This type of challenges should be treated as a challenge on which company (as a single link in the supply chain) has only indirect influence.

The last part of the monograph contains selected aspects of internal supply chain processes. We may find here such issues as engineering changes implementation process map for automotive industry, optimization of the warehouse elements of the enterprise's logistics system, challenges and constraints for purchasing in small and medium-sized family enterprises, services in the digital age - review of selected service areas and multiple-dimensional analysis and evaluation of infrastructure boards in the Polish armed forces.

We encourage you to read and contact the authors of individual chapters. One of the goals of the monograph is to present the results of the authors' works, which will enable or improve ~~establishing~~ cooperation, building new scientific teams and conducting research relevant to the development of the logistics field.

Piotr Cyplik, Grzegorz Bartoszewicz, Wojciech Machowiak, Łukasz Brzeziński
Editors

I. GENERAL CHALLENGES IN SUPPLY CHAINS

Tomasz Pisula
Politechnika Rzeszowska im. Ignacego Łukasiewicza
e-mail: tpisula@prz.edu.pl
Katarzyna Chudy-Laskowska
Politechnika Rzeszowska im. Ignacego Łukasiewicza
e-mail: kacha877@prz.edu.pl

ANALYSIS OF THE OPERATIONS AND DEVELOPMENT OF AIRPORTS IN SELECTED COUNTRIES OF EAST-CENTRAL EUROPE

ABSTRACT

Background: Recent years have seen a substantial growth in passenger traffic in airports globally. Consequently, airports should constantly endeavour to meet customers' needs. For these reasons, analysis of the activities and development of airports appears to be of great significance, since it may help us determine whether airports are able to meet travellers' expectations and customise their offer to passengers' requirements.

Methods: This study uses statistical and taxonomic methods (cluster analysis, ranking) as well as selected non-parametric tests to evaluate the clusters created on the basis of designed diagnostic variables describing the operational efficiency and development of airports.

Results: The airports subjected to analysis were characterised in terms of selected financial and economic ratios describing airport management efficiency, as well as aviation infrastructure ratios, the number of passengers served and the availability and types of services provided to passengers. Airports were grouped with regard to similarity of selected ratios by means of cluster analysis. The analysis was performed on latest available statistical data for the year 2018. The groups of airports obtained were subjected to statistical analysis with the use of non-parametric tests for selected ratios. An airport ranking (a synthetic measure) was created through linear ordering in order to determine most efficiently managed and fastest-developing airports.

Conclusions: Taxonomic analysis and ranking enable identification of airports with the greatest development potential and those which fall behind. The tools can also be successfully applied to compare the level of development of Polish airports in relation to other countries of East-Central Europe.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Keywords: airports, taxonomic analysis, ranking, level of development

INTRODUCTION

Air transport is currently one of the fastest-growing types of transport. Although at the end of the 20th century flying was still considered an 'elite' way of travelling, and today it is a key component of the global economy. The dynamic growth of the sector allowed airports to become an essential part of transport infrastructure and one of the symbols of modern economy. Multiple factors triggered the growth of the popularity of air travel, most importantly technological advances and the application of new solutions in aviation, legal and organisational changes [Pijet-Migoń 2012], and also a shift in potential passengers' attitudes. The growth of air transport is of radical importance to the economic development of a given country and to the progress of the integration process. Air travel serves two basic purposes: business and leisure. Passengers expect quite different things from airports depending on the purpose of travel. Time and comfort are priority for business passengers. They expect quick check-ins and flexible network of connections with many transfer possibilities; they also take advantage of various types of retail and service facilities, VIP check-ins and other luxury amenities at the airport. They leave for a short period of time and are less sensitive to price changes. In contrast, passengers travelling privately for leisure or visiting someone are characterised by greater price flexibility; they travel for longer periods, usually in larger groups (friends, family). They have lower expectations concerning the availability of shops and services at the airport and the level of their demand for flights varies considerably in time, with peak periods occurring on public holidays and periods in which people commonly take days off work [Graham et al. 2010]. Geographic distribution of passengers between airports is very uneven. The main aim of this publication to present the operational efficiency and level of development of selected airports in Poland and several countries of East-Central Europe. Clusters of airports similar in terms of development were determined by taxonomic methods on the basis of 18 ratios describing management efficiency and the level of development of airports subjected to analysis. Linear ordering ranking methods (TOPSIS) were applied to create an airport ranking, highlighting best – and worst – developed airports. The analysis also revealed the condition of Polish airports in comparison to other airports in selected countries.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

ANALYSIS OF LITERATURE

Analysis of the operational efficiency of airports by means of various approaches (research methods) and different analytical and calculation techniques has been discussed in publications. The majority of studies deal with the subject of development level as well as performance and efficiency of airport operations using DEA (Data Envelopment Analysis) methods. A study by [Kadziński et al. 2017] presents comprehensive characteristics of different variants of DEA methods used in research, i.e. in comparative analysis and the assessment of airport performance, and proposes the authors' own concept of the application of DEA with regard to comparison of the efficiency of Polish airport operations. Many works discuss the problem of using DEA methods to evaluate and analyse the operational efficiency of airports by means of classical models and the efficiency analysis in a single period of time (in a given year). Such research was done e.g. by [Pels et al. 2001, Sarkis and Talluri 2004]. Some studies also compared operational efficiency of airports and analysed their changes over multiple time periods with the application of various productivity indexes. This subject was discussed e.g. by [Gillen and Lall 2001, Barros and Weber 2009, Fung et al. 2008]. Publications on this subject concern the analysis of operational efficiency of airports using different types and variants of input and output variables in DEA models applied. Studies use variables characterising handling capacity (in terms of travellers, cargo) at and by airport terminals as input and output variables [Gillen and Lall 2001, Pells et al. 2001, Sarkis and Taluri 2004, Yoshida and Fujimoto 2004, Barros and Dieke 2008]. Some studies are dedicated to the application of characteristics describing movement capabilities for airports (movement models) such as: airport area, aircraft parking positions, number of connections to other airports (number of runways), runway length, aircraft movements, number of air carrier operations as input or output variables in DEA models [Gillen and Lall 2001, Pells et al. 2001, Fun et al. 2008, Yu et al. 2013]. In addition, the DEA models for operational efficiency of airports use financial aspects of airport operations as input variables in their models, e.g. operating costs, cost of labour, invested capital, airport charges [Sarkis and Talluri 2004, Yoshida and Fujimoto 2004, Baros and Dieke 2008], as well as output variables in such models, e.g. total revenue on operations, revenue from sales to the number of passengers, etc. [Sarkis and Talluri 2004, Baros and Dieke 2008]. Certain publications on the application of DEA methods in comparative analyses and the assessment of operational efficiency of airports refer to studies carried out for selected airports from across the continent (e.g. Europe, Asia) [Pels et al. 2001, Yang 2010, Tsui et al. 2014] as well as for individual countries, e.g. Poland, Turkey, Spain, Italy, US, Japan, China [Martin and Roman 2001, Sarkis and Talluri 2004, Yoshida

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

and Fujimoto 2004, Baros and Dieke 2008, Fung et al. 2008, Kocak 2011, Kadziński et al. 2017]. Some studies use surveys to evaluate the quality of airport operations from passenger's point of view. [Suarez-Aleman and Jimenez 2016] estimated a regression model evaluating quality of operations based on passenger feedback for 111 airports worldwide. The regression model depended on multiple factors: nature of airports' properties, level of their technical infrastructure, characteristics of the country in which they are located, as well as macroeconomic determinants linked to the development of the country of location. It has been found that airports managed by private entities are rated better in terms of quality by their customers (travellers). Several studies also discussed the analysis of the significance of the effect of airport privatization on their operational efficiency by means of multi-criteria decision analysis (MCDA) methods: AHP, TOPSIS, VIKOR and other methods, e.g. a study by [Keskin and Ulas 2017]. MCDA methods also provide analytical tools for comparing the operational efficiency of airports in studies by [Kuo Liang 2011, Kazemi et al. 2016].

A novelty in the research is the use of taxonomic methods to analyze the efficiency of ports and their level of development. Also new is the fact that for multivariate comparative analysis, both data on the financial activities of airports and their infrastructure and technical potential were taken.

PRESENTATION OF AIRPORTS CONCERNED

In the early days of aviation, i.e. the first half of the 20th century, airports were seen primarily as fundamental components of the national defence system. The First World War had a significant impact on the increase in the number of airports, albeit passenger airports usually developed at a later stage and their rate of their progress was varied. The beginnings of the vast majority of airports were similar; they usually started as grass- or dirt-surfaced military airfields. Their infrastructure deviated from the present image of an airport [Pijet-Migoń 2012]. Airports were initially situated in the centre of cities. This study analyses airports in six countries of East-Central Europe belonging to international economic and political Tree Seas Initiative. The primary objective of the initiative is cooperation in the area of power industry, logistics and transport, and IT/telecom within Central Europe. The selection of airports was dictated mainly by data availability and similar development level of analysed countries. A total of 17 airports in six countries were analysed. Brief characteristics of selected airports are provided in Table 1.

Table 1. Characteristics of airports concerned

City/Country	Characteristics

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Brno CZ	Located 7.5 km south-east of the centre of Brno at an altitude of 237 m a.s.l, the airport dates back to 1923. The first landing took place three years later. It has seen two extensive modernisations: one in 1994 and another in 2002, carried out by the Czech Aviation Authority; the cost of the project was CZK 160 million. It is the second largest Czech airport with a capacity of **3 million passengers** a year.
Ostrava (2016) CZ	Located approx. 20 km from Ostrava, altitude 257 m a.s.l., the airport was opened in 1959. In 2006, it was modernised and a new terminal was handed over for use. NATO Days have been regularly held at the airport since September 2001. The airport can handle **1.5 million passengers** annually.
Prague CZ	The Vaclav Havel Airport lies 10 km north-west of the centre of Prague. Established in 1933, it is a modern and spacious ports with many amenities. It features two runways, four helipads and two passenger terminals. Unfortunately, connections from the airport to the city are poor. The airport is capable of handling **17 million passengers** a year.
Sofia BG	Also known as Wrazhdebna, the Sofia airport is situated at an altitude of 520 m a.s.l. about 10 km from Sofia. It is the largest airport in Bulgaria. The construction of the airport started in 1937 with first passengers served in the year 1939. In 2006, a new passenger terminal was commissioned. The old one is still used by budget airlines. The airport is capable of handling **4.6 million passengers** a year.
Dubrovnik CHR	The airport lies 15.5 km away from Dubrovnik at an altitude of 161 m a.s.l. Its history starts in 1936; initially, it was used only in summer months. The airport as it is today was opened in 1962. Currently it is the country's most modern airport; a new terminal replaced the old one, which was built in 1962. The airport can handle **3.5 million passengers** a year.
Zagreb CHR	Located 17 km south-east of Zagreb. The largest one in Croatia; altitude 108 m a.s.l. The first airport was built in 1909. In 1928 a new airport, situated in a different location near Lucko started handling passenger traffic. In 1962, it was moved to its present location. A modern passenger terminal was commissioned in 2017. The airport can handle **5 million passengers** annually.
Split CHR	Located 24 km away from Split at an altitude of 24 m a.s.l., it is the second largest Croatian airport, offering good connections to Split and Torgir. First commercial flights started in 1931. Thanks to the recent extension completed in 2019, the airport may handle up to **5 million passengers** a year.
Košice SK	The airport of the second largest Slovak city is situated 6 km from the centre of the city at an altitude of 230 m a.s.l. The first airport was built in this location in 1954, and first flights to Prague commenced in 1955. The present terminal was built in in the years 2001-2004, and it has an annual capacity of **800,000 passengers.**
Bratislava SK	Located 9 km north-east of Bratislava at the height of 133 m a. s. l., it is the country's most important airport. First regular flights to Prague took place as early as 1923. The construction of the present airport started in 1948, and it was opened three years later. Currently it can handle **5 million passengers** per year.
Debrecen HGR	The airport in Debrecen is located 5 km from the city centre at an altitude of 110 m a.s.l. It is one of Hungary's five international airports. Dating back to 1930, it was initially used for sports and military purposes. Since 2001 it has enjoyed the status of an international airport. It is capable of handling **600,000 passengers** a year.
Budapest HGR	The airport in Budapest is located 16 km from the city centre at an altitude of 151 m a.s.l. It is Hungary's biggest airport. Its construction lasted from 1939 to 1944. The airport was modernised at 20-year intervals, with the most recent works completed in 2012. The airport can handle 7 **million passengers** a year.
Krakow Balice PL	The airport is located 11 km from the centre of Krakow at an altitude of 241 m a.s.l. Currently it is the second largest airport in Poland. It took its present form in 1964, when a part of the then military airfield was allocated to civil aviation. The airport is constantly modified; the most recent project, an air traffic control tower, was commissioned in 2018. The airport is capable of handling **8 million passengers** a year, and there are plans to increase its annual capacity to 12 million passengers.
Gdańsk PL	The airport in Gdańsk is located 10 km from the city centre at an altitude of 149 m a.s.l. It is the third largest airport in Poland. The airport in its current form was opened in 1974. The latest modernisation was completed in 2012, although further works are under way with a view to increase annual capacity to 9 million passengers. Today, the airport can handle 7 **million passengers** per year.
Poznań/Lawica PL	The airport is located 5 km from the centre of Poznań at an altitude of 94 m a.s.l. The Poznań Aircraft Station was established in 1913. In 2012, a new passenger terminal was commissioned at the airport and decision was made on its further modernization. Current capacity: **3 million passengers** a year.
Rzeszów/Jasionka PL	The Rzeszów-Jasionka airport is located 14 km from the city centre at the altitude of 211 m a.s.l.; it is the Polish airport which lies farthest to the south-east. Its origins date back to the years of Nazi occupation, when an airstrip was built in 1940. In 1974 it was granted international status; a modern passenger terminal was commissioned in 2012. The airport is capable of handling **1.8 million passengers** a year.
PPL Warsaw Okęcie PL	The airport was opened in 1934 at a military airfield. Currently it is the largest Polish airport and the headquarters of the PLL LOT aviation company. The airport is located 8 km from the centre of Warsaw at an altitude of 110 m a.s.l. New investments have been repeatedly added to the airport since 2014. The latest one involved an upgrade to terminal A with a glazed and roofed observation deck in 2015. The airport's annual capacity is **23 million passengers**.
Katowice/Pyrzowice PL	The airport is located 30 km from the centre of Katowice at an altitude of 303 m a.s.l. It has one of the longest runways in Poland. It is the highest-lying and fourth largest airport in Poland. The airport was built in place of an old airfield established by the Third Reich during World War II. It has been constantly upgraded since 2010. The current capacity of all terminals is **5.5 million passengers** a year.

Source: own work.

CHARACTERISTICS OF RESEARCH METHODS APPLIED

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

The level of development of airports was determined by cluster analysis – a multivariate comparative analysis method. The term was coined by [Tryon 1939], and subsequently elaborated by [Cattell 1944]. The method allows us to clearly and precisely divide units (i.e. airports) characterised by multiple features (18 ratios were used in this study) into clusters (groups) of objects similar to one another in terms of analysed characteristics. Cluster analysis is widely applied in various scientific fields. The method enables us to verify the extent to which the airports have developed and their financial circumstances in respective groups. Features were characterised by means of basic descriptive statistics. This study uses Ward's method, an agglomerative hierarchical clustering procedure, which is based on the analysis of variance approach [Grabiński 1992]. The method seeks to minimize the sum of squared deviations of any two clusters which may be formed at each stage. It is one of the most effective clustering methods. The order of steps in Ward's method is similar as in other agglomerative methods. Significant differences are present in the parameters used in the formula. The course of action is as follows: first, taxonomic distance matrix *n x n* is determined, containing distance between objects in each pair. The matrix is symmetrical in relation to the main diagonal, which consists exclusively of zeros. Subsequently, pairs of objects (and later on, clusters) for which mutual distance is the shortest are found. The objects are labelled "p" and "q", with p < q. "p" and "q" are subsequently merged in a single new cluster, which takes position numbered "p". At the same time, the object (cluster) marked with "q" is deleted, and cluster numbers higher than the number of the deleted object are decreased by one. In this way, the size of the matrix is decreased by 1. Next, distance to a new cluster from each of the remaining ones is determined according to formula:

$$D_{pr} = a_1 \cdot d_{pr} + a_2 \cdot d_{qr} + b \cdot d_{pq} \tag{1}$$

where:

D_{pr} – distance from the new cluster to cluster „r"

d_{pr} – distance of the original cluster "p" to cluster "r"

d_{qr} – distance of the original cluster "q" to cluster "r"

d_{pq} – distance between original clusters "p" and "q"

a_1, a_2, b – parameters, which in Ward's method are given by formulas:

$$a_1 = \frac{n_p+n_r}{n_p+n_q+n_r}, a_2 = \frac{n_q+n_r}{n_p+n_q+n_r}, b = \frac{-n_r}{n_p+n_q+n_r} \tag{2}$$

In formulas, "n" stands for the number of single objects in individual groups.

The group mean method was used to describe the resulting clusters. For resulting clusters, a group mean analysis was performed, designed to indicate which ratios (diagnostic features) were dominant in a given group. Arithmetic means of the ratios, given by $\overline{W}_i$, were calculated for the numerical data

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

matrix. Next, arithmetic means of the ratios in resulting clusters were calculated and labelled $\overline{w}_i$. The structural ratio of each cluster is given by quotient ${\overline{w}_i}/{\overline{W}_i}$. The maximum value of the structural ratio corresponds to the dominance of the feature in the resulting group. The average level of the phenomenon assumes the value of 1. Any value in excess of 1 indicates ratios higher than the mean, and below 1 ratios the level of which in each group is lower than the average.

Statistical decision methods of linear ordering of multivariate objects were used in ranking analyses. The study used the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method by [Hwang and Yoon 1981]. Given is an input matrix of decision (diagnostic) variables $X_{ij}, i = 1, \dots, m; j = 1, \dots, n$, where n – number of diagnostic variables, m – number of ranked (ordered) statistical objects (airports) and a set weight vector for diagnostic variables $w_j \in [0,1], \sum_{j=1}^{n} w_j = 1$. The following steps were taken during the decision-making process of airport ranking:

1. It is assumed that all diagnostic variables X_j will be treated as stimulants or destimulants. The values of those features which function as nominants were converted into corresponding stimulant values by means of the following transformation:

$$X_{ij} = \frac{min\{nom_j; X_{ij}^N\}}{max\{nom_j; X_{ij}^N\}} \quad (3)$$

   where: X_{ij}^N – value of the j-th nominant observed for the j-th object, nom_j – nominal value of the j-th variable.

2. Determine a normalized data matrix in a standardization procedure according to formula:

$$Z_{ij} = \frac{X_{ij} - \overline{X_j}}{S_j} \quad (4)$$

   where: $\overline{X_j}$ – mean value of the j-th original variable, whereas S_j – standard deviation of the j-th variable.

3. Determine coordinates for pattern vector a^+ (ideal solution) for optimum values of diagnostic variables and coordinates of anti-pattern vector a^- (anti-ideal solution) for the worst values of diagnostic variables according to formula:

$$a^+ = (a_1^+, a_2^+, \dots, a_n^+) := \left\{\left(\max_{i=1,\dots,m} Z_{ij} | j \in J_S\right), \left(\min_{i=1,\dots,m} Z_{ij} | j \in J_D\right)\right\} \quad (5)$$

$$a^- = (a_1^-, a_2^-, \dots, a_n^-) := \left\{\left(\min_{i=1,\dots,m} Z_{ij} | j \in J_S\right), \left(\max_{i=1,\dots,m} Z_{ij} | j \in J_D\right)\right\} \quad (6)$$

   where: J_S – set of stimulants, while J_D – set of destimulants.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

4. Calculate distance of the i-th analysed object to pattern GDM_i^+ and anti-pattern GDM_i^-. A Generalized Distance Measure (GDM) [Walesiak 2016] was applied in calculations:

$$GDM_i^+ = \frac{1}{2} - \frac{\sum_{j=1}^{n} w_j\left(z_{ij}-a_j^+\right)\left(a_j^+-z_{ij}\right)+\sum_{j=1}^{n}\sum_{l=1,l\neq i,l\neq i_+}^{m} w_j\left(z_{ij}-z_{lj}\right)\left(a_j^+-z_{lj}\right)}{2\left[\sum_{j=1}^{n}\sum_{l=1}^{m} w_j\left(z_{ij}-z_{lj}\right)^2\cdot\sum_{j=1}^{n}\sum_{l=1}^{m} w_j\left(a_j^+-z_{lj}\right)^2\right]^{\frac{1}{2}}} \quad (7)$$

$$GDM_i^- = \frac{1}{2} - \frac{\sum_{j=1}^{n} w_j\left(z_{ij}-a_j^-\right)\left(a_j^--z_{ij}\right)+\sum_{j=1}^{n}\sum_{l=1,l\neq i,l\neq i_-}^{m} w_j\left(z_{ij}-z_{lj}\right)\left(a_j^--z_{lj}\right)}{2\left[\sum_{j=1}^{n}\sum_{l=1}^{m} w_j\left(z_{ij}-z_{lj}\right)^2\cdot\sum_{j=1}^{n}\sum_{l=1}^{m} w_j\left(a_j^--z_{lj}\right)^2\right]^{\frac{1}{2}}} \quad (8)$$

where: i_+ – index (number) of the pattern object, and i_- – index (number) of the anti-pattern object.

5. Determine aggregate measure (ranking ratio) describing the degree of similarity of the objects to the ideal solution according to formula:

$$TOPSIS\ (GDM)R_i = \frac{GDM_i^-}{GDM_i^- + GDM_i^+} \quad (9)$$

for i=1,…,m; where: $0 \leq R_i \leq 1$.

6. Finally, rank the analysed objects (airports) by value of measure R_i. The higher the values of the synthetic ratio, the higher the object's position in the ranking.

CHARACTERISTICS OF SELECTED DIAGNOSTIC VARIABLES USED IN THE STUDY

Comparative analyses concerning operational efficiency and development level of selected airports in East-Central Europe used 18 diagnostic variables. Table 1 presents a list of all 18 diagnostic variables together with computed values of the basic descriptive statistics: mean value, minimum value, maximum value and the coefficient of variation, which indicates what percentage of variation (expressed by standard deviation s) is associated with the mean value of the variable: $V_s = \frac{s}{\bar{x}} \cdot 100\%$. Values of the coefficient of variation for all selected diagnostic variables were higher than 10%, so the selected variables adequately differentiate the analysed airports. Pearson's linear correlation coefficients were also calculated. It was found that their absolute value is below 0.8 for all selected variables, which indicates the absence of strong, significant linear relationships between selected variables which could be potentially duplicate instances of the same statistical information. Values of all diagnostic variables were determined on the basis of latest available statistical data for the year 2018 (in certain cases 2017). Statistical data were retrieved from the following databases: Eurostat (https://ec.europa.eu/eurostat/data/database), EMIS system's database of financial indexes for businesses (http://www.emis.com) as well as airport websites.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Table 1. Basic descriptive statistics for diagnostic variables applied.

Diagnostic variable	Description of the variable used in the study	Mean value $\bar{X}$	Minimum value X_{min}	Maximum value X_{max}	Variation (coefficient of variation) V_s [%]
Characteristics of airports' transport potential					
X_1	Number of passengers (persons)	4685534	318342	15757010	110
X_2	Number of employees (persons)	724	76	2380	102
X_3	Number of destinations (airports) – regular departures/arrivals	69	10	211	79
X_4	Number of airlines (carriers) handling connections	23	3	63	84
Characteristics of airport infrastructure condition and availability of services for passengers at the airport					
X_5	Number of terminals (departures/arrivals)	2	1	3	37
X_6	Number of conventional check-in desks	32	3	125	98
X_7	Length of the longest runway [m]	3118	2498	3715	14
X_8	Rating of the number and type of services for passengers at the airport (point rating from 0 to 15, 0 – lowest level, 15 – highest level of services offered)	12	7	15	19
Ratios characterising the financial and economic condition and management efficiency for the airports					
X_9	Current ratio indicating the company's ability to pay short-term obligations, calculated as: Current assets / Current liabilities	3	0.4	13	119
X_{10}	Debt ratio (leverage ratio) – indicating how many assets the company has in proportion to its equity, and to what extent the company uses its equity to finance its assets, calculated as: Total assets / Equity * 100 [%]	209	-458	931	127
X_{11}	Profitability ratio – return on assets (ROA), calculated as: Net profit / Total assets * 100 [%]	2	-34	32	547
X_{12}	Return on Equity (ROE) – describing the relationship between net profit generated by the company and the invested equity, calculated as: Net profit / Total equity * 100 [%]	17	-15.3	156	237
X_{13}	Net profitability ratio – measuring how efficiently the company generates its profit through its invested capital by comparing operating result with invested capital, calculated as: Operating result (EBIT) / (Total assets - Short-term liabilities) * 100 [%]	8	-44.3	98	428
X_{14}	EBIT margin – a measure of operational efficiency, calculated as: Operating result (EBIT) / Net sales * 100 [%]	11	-44.5	57	227
X_{15}	Current assets turnover ratio – indicates how effectively the company uses its own current assets to generate revenue, calculated as: Net sales / Current assets	2	0.5	3	44
X_{16}	Fixed assets turnover ratio–- indicates how effectively the company uses its own fixed assets to generate revenue, calculated as: Net sales / Fixed assets	1	0.1	6	192
X_{17}	Total assets turnover ratio – a measure of sales generated for the company's assets, calculated as: Net sales / Assets	0	0.1	1	94
X_{18}	Net profit dynamics ratio [%] - a percentage change in the company's net profit, and therefore a rise or fall in its net profit in a given year in comparison to the previous year, calculated as: (Net profit$_{(t)}$ – Net profit$_{(t-1)}$) / Net profit$_{(t-1)}$ * 100 [%]	-51	-563.8	135	314

Source: own work.

RESULTS

The first stage of the study involved an analysis of clusters of similar airports in East-Central Europe based on 18 selected ratios; a ranking of the airports was subsequently generated.

- results of airport clustering using Ward's method

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Four clusters of airports were obtained on the basis of the analyses. The first one contains four airports located in capital cities: Sofia, Warsaw, Budapest and Prague. This group was labelled A for further analyses. The second group includes the airport in Debrecen in Hungary – labelled B. The third cluster, labelled C, includes airports in: Poznań, Zagreb, Gdańsk, Katowice, Bratislava, Rzeszów and Ostrava. The last cluster, marked as D, included five airports: Košice, Split, Krakow, Dubrovnik and Brno. Results of cluster analysis are presented in Figure 1.

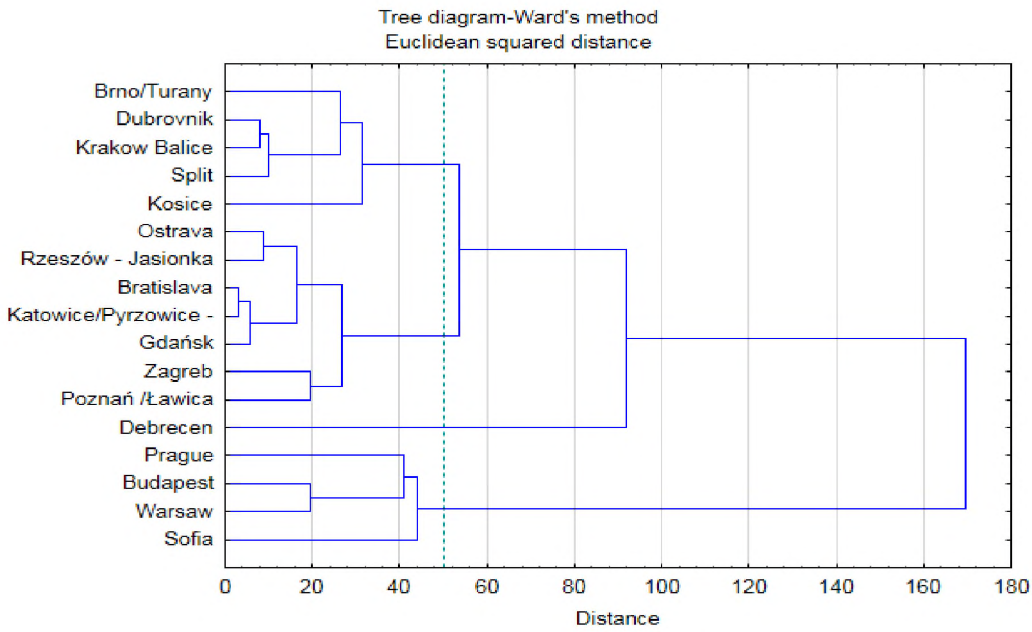


Fig. 1. Cluster analysis results for airports.
Source: own work.

Cluster analysis groups objects similar to one another in terms of analysed features, but does not provide any explanation as to why the airports are clustered in such a way. In order to establish which features are dominant in a cluster and which are responsible for its formation we need to use group mean analysis, the results of which are presented in Figure 2. Group A comprises largest airports located in four capital cities of six countries concerned: these are airports in Sofia, Warsaw, Budapest and Prague. Bratislava and Zagreb were placed in a different group. The cluster contains the most modern airports, which handle the biggest numbers of passengers, offer the highest number of connections to various locations globally and are used by the largest number of carriers. Economic performance of the airports in this group is very good. Liquidity and profitability ratios are on top level. Return on assets (ROA) and fixed assets turnover reach the highest values. Group B is a single-item cluster, which includes the Debrecen airport. It has the lowest throughput of all the analysed airports and has enjoyed its international status only since 2001. It is characterised by the worst infrastructure, and its financial ratios are on the lowest levels, too. The lowest ratio in the group is ROA, which

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

occupies the lowest position, with a negative value. On the other hand, return on equity is high, and it has the highest value among all four resulting clusters. Profitability and EBIT margin are very low, and they also reach negative values. The following airports were allocated to Group C: Poznań, Zagreb, Gdańsk, Katowice, Bratislava, Rzeszów and Ostrava. This group may be placed at the penultimate position. It is made up mostly of airports located in Poland (57%), but capital cities of other countries are (Zagreb and Bratislava) also found in the group. Passenger traffic and airport infrastructure levels are low in this cluster. Some financial ratios have negative values, e.g. net profit dynamics, ROA, ROE and operating profit margin.

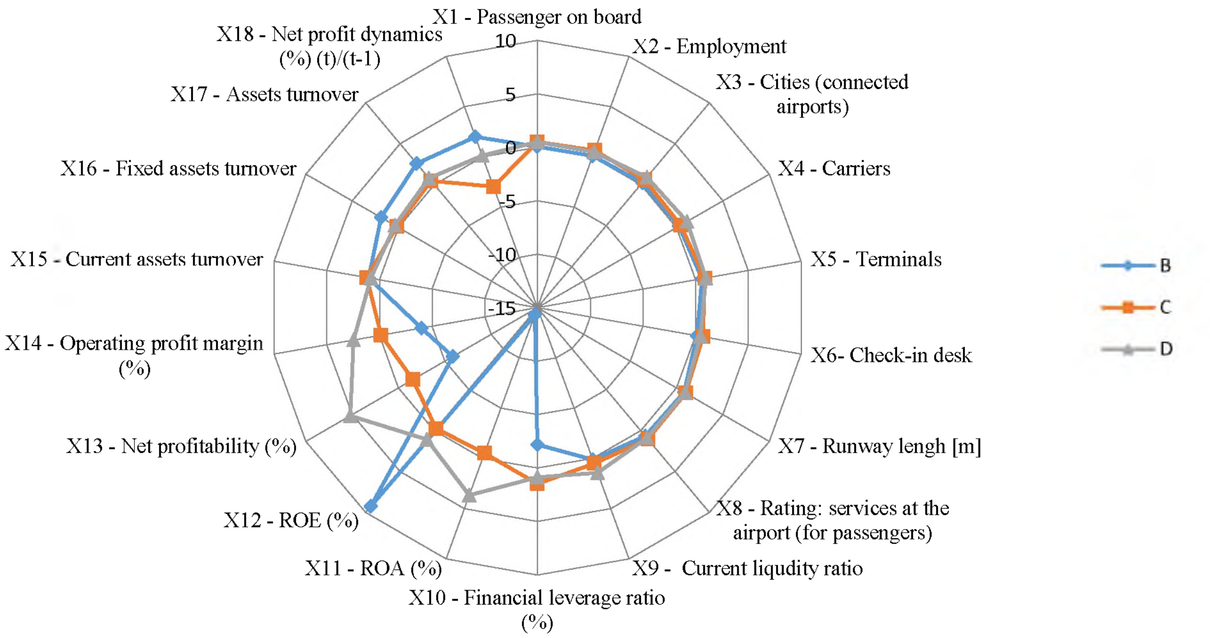


Fig. 2. Group means in clusters – radar chart.
Source: own work.

Group D is second best in terms of services and development. It comprises five airports: Košice, Split, Krakow, Dubrovnik and Brno. They are all large cities which attract tourists. The airports located in those areas are profitable, all financial ratios are high, albeit slightly lower than in group A; however, there is no ratio with a value below zero. These airports have been upgraded in the recent years and feature modern design. We may conclude that the level of development of these airports is high.

- airports ranked by means of linear ordering methods

An operational efficiency and development level ranking of analysed airports in selected countries of East-Central Europe was created using linear ordering method TOPSIS with a synthetic measure of the degree of similarity to the pattern (9). Almost all diagnostic variables in the study are stimulants, except for variables X_9 and X_{10}, which were treated as nominants. Optimum nominal values of these variables were established on the level of nom_9=1.5, and nom_{10}=100. The ranking assumed an identical

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

system of weights of all diagnostic variables using a standardization procedure (4). Figure 3 shows results for measurements of distance of all objects (airports) to the pattern and anti-pattern, as well as values of TOPSIS R_i synthetic measurements and the ranking. The Prague airport is in the top position. It is followed by airports in Budapest, Warsaw and Sofia. Airports in Poznań, Ostrava and Debrecen are located at the bottom of the ranking

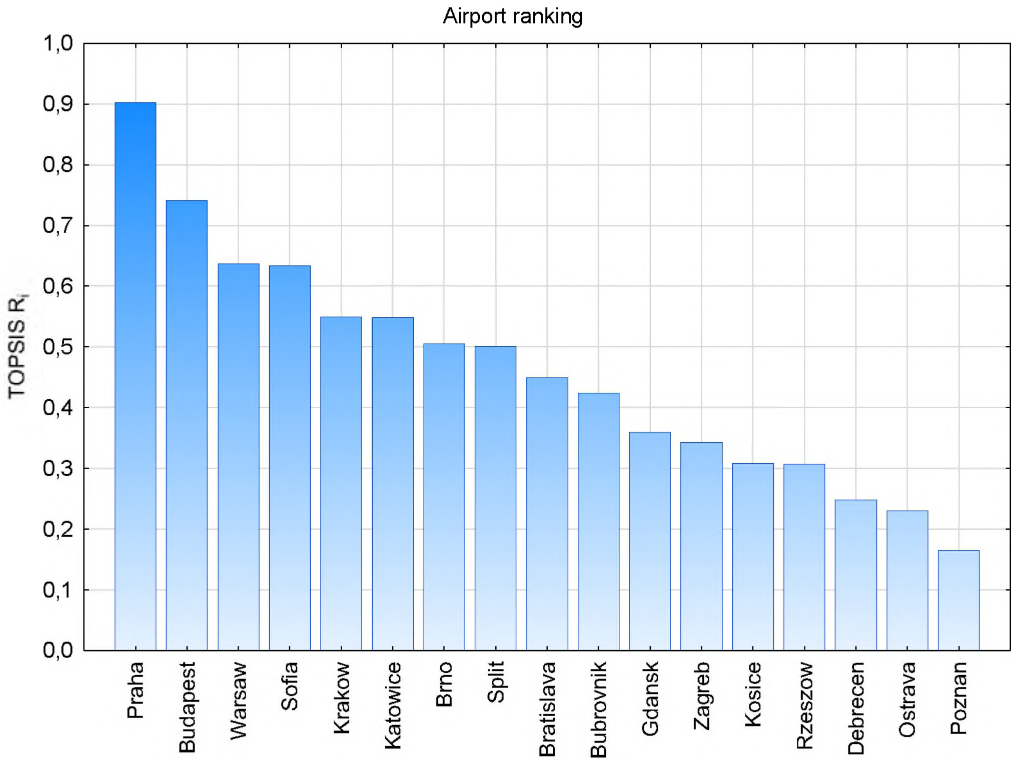


Fig. 3. Airports ranked by the TOPSIS synthetic measure.
Source: own work.

CLOSING REMARKS

The present taxonomic study demonstrated that large airports situated in capital cities of selected countries of East-Central Europe are characterised by the highest level of development, management efficiency and potential in terms of infrastructure and transport. The airport in Prague was reported to be the best one (TOPSIS synthetic measure of its development level was 0.9, a very high value). High development levels and leading places in the ranking were also reported for other airports located in capital cities of countries selected for the study: Budapest (TOPSIS development measure of 0.75), Warsaw and Sofia (TOPSIS 0.65). The other large airports in capital cities such as Bratislava and Zagreb occupied less favourable positions in the ranking and were qualified to other clusters (Bratislava – 9th in the ranking with a TOPSIS of 0.45, whereas Zagreb as low as 12th, with a TOPSIS of 0.34). Smaller airports

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

located in regional cities tended to take lower places in the ranking. In this category, two Polish airports were ranked very high (Krakow and Katowice – 5th and 6th position, TOPSIS ca. 0.6), similarly to airports in Brno, Split and Dubrovnik (7th, 8th and 10th in the ranking). Lowest positions (from 14 to 17) were occupied by local airports in Rzeszów, Debrecen, Ostrava and Poznań. Among all analysed airports, the one in Poznań was in the last position (TOPSIS 0.12). This indicates the weakest relative development potential of those airports. In general, such airports mostly generated loss and had low management efficiency, inferior level of infrastructure, transport potential and services offered.

REFERENCES

Barros C. P., Dieke P., 2008, Measuring the economic efficiency of airports: a Simar-Wilson methodology analysis, Transportation Research Part E, 44, 1039–51, DOI: 10.1016/j.tre.2008.01.001.

Barros C., Weber W., 2009, Productivity growth and biased technological change in UK airports, Transportation Research Part E, 45, 642–53, DOI: 10.1016/j.tre.2009.01.004.

Cattell R. A., 1944, Note on correlation clusters and cluster search methods, Psychonometrica, 9, 169–184.

Fung M., Wan K., Hui Y., Law J., 2008, Productivity changes in Chinese airports 1995–2004. Transportation Research Part E, 44, (2008), 521–42, DOI: 10.1016/j.tre.2007.01.003.

Gillen D., Lall A., 2001, Non-parametric measures of efficiency of US airports, International Journal of Transport Economics, 28, (2001), 283–306.

Grabiński T., 1992, Metody taksonometrii, Wydawnictwo Akademii Ekonomicznej w Krakowie, Krakow.

Graham A., Papatheodorou A., Forsyth P., 2010, Aviation and Tourism: Implications for Leisure Travel, Ashgate Publishing, London.

Hwang C.-L., Yoon K., 1981, Multiple attribute decision making, Lecture notes in economics and mathematical systems, 186, Springer, Berlin Heidelberg New York.

Kadziński M., Labijak A., Napieraj M., 2017, Integrated framework for robustness analysis using ratio-based efficiency model with application to evaluation of Polish airports, Omega, 67, 1–18, DOI: 10.1016/j.omega.2016.03.003.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Kazemi A., Yousefi M., Attari N., Khorasani M., 2016, Evaluating service quality of airports with integrating TOPSIS and VIKOR under fuzzy environment, International Journal of Services Economics and Management, 7, 154-166, DOI: 10.1504/IJSEM.2016.081856.

Keskin B., Ulas E., 2017, Does Privatization Affect Airports Performance? A Comparative Analysis with AHP-TOPSIS and DEA [in:] New Trends in Finance and Accounting, Springer Proceedings in Business and Economics, 335-345, DOI: 10.1007/978-3-319-49559-0_31.

Kocak H., 2011, Efficiency examination of Turkish airports with DEA approach, International Business Research, 4, 204–212, DOI: 10.5539/ibr.v4n2p204.

Kuo M.-S., Liang G.-S., 2011, Combining VIKOR with GRA techniques to evaluate service quality of airports under fuzzy environment, Expert Systems with Applications, 38, 1304–1312, DOI: 10.1016/j.eswa.2010.07.003.

Lotko A., Lotko M., 2015, Cluster analysis of knowledge workers assessment of occupational threats and attitudes of work, Eksploatacja i Niezawodność – Maintenance and Reliability, 17(1), 80–89, DOI: 10.17531/ein.2015.1.11.

Martin J. C., Roman C., 2001, An application of DEA to measure the efficiency of Spanish airports prior to privatization, Journal of Air Transport Management, 7 (3), 149–57, DOI: 10.1016/S0969-6997(00)00044-2.

Pels E., Nijkamp P., Rietveld P., 2001, Relative efficiency of European airports, Transport policy, 8, (2001), 183-192, DOI: 10.1016/S0967-070X(01)00012-9.

Pijet–Migoń E., 2012, Zmiany rynku lotniczych przewozów pasażerskich w Polsce po akcesji do Unii Europejskiej, Prace Naukowe Instytutu Geografii i Rozwoju Regionalnego Uniwersytetu Wrocławskiego 25, Wrocław.

Sarkis J., Talluri S., 2004, Performance based clustering for benchmarking of US airports, Transportation Research Part A, 38, 329–346, DOI: 10.1016/j.tra.2003.11.001.

Suarez-Aleman A., Jimenez J. L., 2016, Quality assessment of airport performance from the passengers perspective, Research in Transportation Business & Management, 20,13–19, DOI: 10.1016/j.rtbm.2016.04.004.

Tryon R., 1939, Cluster Analysis, McGraw-Hill, New York.

Tsui W., Balli H,. Gilbey A., Gow H., 2014, Operational efficiency of Asia-Pacific airports, Journal of Air Transport Management, 40, 16–24, DOI: 10.1016/j.jairtraman.2014.05.003.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1

Walesiak M., 2016, Uogólniona miara odległości GDM w statystycznej analizie wielowymiarowej z wykorzystaniem programu R, Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu, Wrocław.

Yang H.-H., 2010, Measuring the efficiencies of Asia-Pacific international airports - parametric and non-parametric evidence, Computers & Industrial Engineering, 59, 697–702, DOI: 10.1016/j.cie.2010.07.023.

Yoshida Y., Fujimoto H., 2004, Japanese-airport benchmarking with DEA and endogenous-weight TFP methods: testing the criticism of over-investment in Japanese regional airports, Transportation Research Part E, 40, 533–46, DOI: 10.1016/j.tre.2004.08.003.

Yu M.-M., Chern C.-C., Hsiao B., 2013, Human resource rightsizing using centralized data envelopment analysis: evidence from Taiwan's airports, Omega, 41, 1, 119–30, DOI: 10.1016/j.omega.2011.06.009.

P. Cyplik et al. (eds.), *Contemporary challenges in supply chains, Vol. 2*,
https://doi.org/10.17270/B.M.978-83-66017-89-4.1