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LOCATION OF AIRPORTS - SELECTED QUANTITATIVE METHODS

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ABSTRACT. **Background:** The role of air transport in the economic development of a country and its regions cannot be overestimated. The decision concerning an airport's location must be in line with the expectations of all the stakeholders involved. This article deals with the issues related to the choice of sites where airports should be located.
Methods: Two main quantitative approaches related to the issue of airport location are presented in this article, i.e. the question of optimizing such a choice and the issue of selecting the location from a predefined set. The former involves mathematical programming and formulating the problem as an optimization task, the latter, however, involves ranking the possible variations. Due to various methodological backgrounds, the authors present the advantages and disadvantages of both approaches and point to the one which currently has its own practical application.
Results: Based on real-life examples, the authors present a multi-stage procedure, which renders it possible to solve the problem of airport location.
Conclusions: Based on the overview of literature of the subject, the authors point to three types of approach to the issue of airport location which could enable further development of currently applied methods.

Key words: airport location, optimization, ranking variations.

INTRODUCTION

Within the last twenty years there has been a rapid development in air transport not only in Poland but in other European countries. After a drop in the number of passengers in 2009, since 2010 there has been an increase in the number of passengers interested in this type of transport in Poland, as well as in all 28 European Union member states (see Fig.1a). Within four years (2009-2013), the annual number of passengers increased by over 6.2 million in Poland and by almost 90 million in the EU, reaching the level of 23.2 million in Poland and 842.2 million in the EU (28 countries). Interestingly, this increase in passenger transport was notably higher in Poland than in other European Union countries and in the peak year (2011), the increase exceeded 12%. Slightly higher dynamics of change occurred in freight transport. In the years 2009 - 2013, the weight of goods transported by road in Poland dropped on two occasions (in 2009 and 2012), while in the European Union the same problem occurred three times (in 2009, 2012 and 2013) - see Fig. 1b. Regarding air transport, in 2013 the total weight of goods transported in the 28 countries of the European Union increased by almost 2 million tons compared to 2009 (up to 13.5 million tons). In the same period in Poland, this amount increased by 25,400 tons (up to 78,700 tons). In 2013 the share of Polish air transport in total air transport within the EU (28) amounted to 1.3% as regards freight transport and 2.8% for passenger transport.

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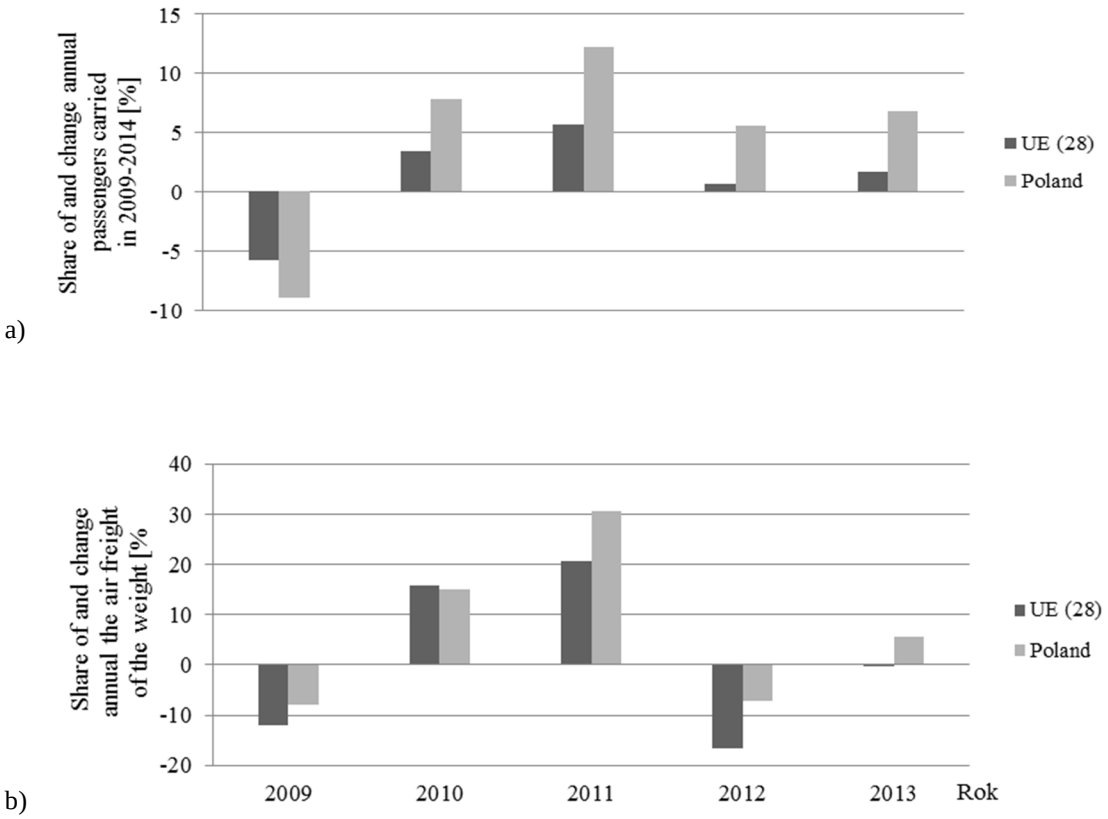


a)

b)

Source: the authors' based on EUROSTAT

Fig. 1. Dynamics of change in the volume of air freight transported in Poland and in the 28 countries of the European Union in the years 2009-2013: a) air transport of passengers, b) freight and mail transport.
Rys. 1. Dynamika zmian wielkości przewozów transportem lotniczym w Polsce oraz 28 krajach Unii Europejskiej w latach 2009-2013: a) transport pasażerski, b) transport towarowy.

It must be stressed that this increase was caused by continuous improvements in economic conditions, new technologies and in the case of passenger air transport, a substantial development in tourism. For those who travel long distances, the key criterion is travelling time. Due to its central location in Europe and relatively poor road and rail network, especially for high-speed trains which could compete with air transport as far as travelling time is concerned, Poland is a natural area for the development of air transport. Regarding passenger transport, amongst the most frequently mentioned motives are work, study, tourism and socializing (family and friends). Globalization has also an impact in this respect [Chakuu et al. 2012], and consequently, the tendency for migration. This means that the demand for travelling longer and longer distances is growing continuously.

Due to its speed, air transport satisfies the needs of the more demanding clients. In this particular respect, the authors analysed passenger air transport. As has been stressed, the demand for air transport services is growing, therefore developed countries transform their largest airports into hubs which are the points where passengers change planes when travelling from their regional airports [Adler et al. 2003, Neves Juncioni and Oliveira 2015, Postorino and Pratico 2012]. This approach is very efficient as it rationalizes the use of the means of air transport and decreases the costs of operation of minor regional airports. However, opening regional airports, might pose several threats including:

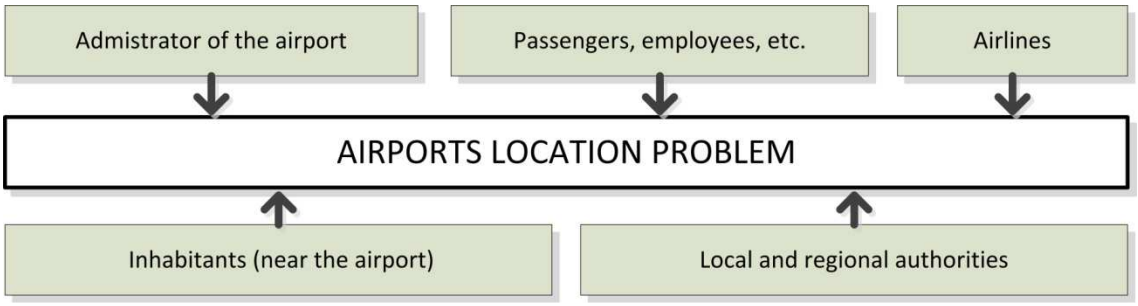
– Increased exposure to noise due to the higher number of take-offs and landings [Kupfel et al. 2016, Gaetano et al. 2014]

– Spreading various diseases, e.g. pandemics [A. Warren et al. 2012].

In Poland, the feasibility of and need to build a central airport has been discussed on numerous occasions, yet it is extremely difficult to justify such a need nowadays.

Importantly, the development of this sector of transport is triggered by the fact that its operations are regulated by legal acts which pertain to all those who participate in the process including the airports themselves [Silva et al. 2015]. There are numerous organizations and associations which supervise this branch of transport, e.g. Airports Council International, International Civil Aviation Organization, International Air Transport Association [Beary 2011] [Chakuu et al. 2012].

The location of an airport is a key factor in making it possible for the above organizations to achieve their statutory goals. Due to the fact that planning is time-consuming and the financial support required is substantial, the location decision is definitely a strategic issue. Difficulties start at the stage of analysing the question of choosing an airport location which must account for all organizational, financial and social issues. The location should consider the interests of five main groups of stakeholders (see Fig.2). Thus, regarding the users of such airport (including passengers), convenient roads to the facilities must be ensured [Stevens et al. 2010], as well as the quality of services offered by the airport [Pabedinskaité and Akstinaité 2014, Pantouvakis and Renzi 2016]. This pertains to regional transport (at the level of województwo (provinces) in Poland), but also to connecting the airport with the city (urban area and suburbs). Depending on the category of users, public transport must be ensured (e.g. buses, trams, underground, municipal railway, local air transport) as well as individual transport such as taxis. Moreover, one needs to take into account such factors as parking facilities, which should be adjustable to changing needs [Budd et al. 2014] and potential companies providing cargo services [Kupfer et al. 2016].



Source: authors' research

Fig. 2. Stakeholders interested in the issue of location of airports
Rys. 2. Interesariusze w problemie lokalizacji portów lotniczych

Based on real-life observations, the authors stress the complex and problematic nature of passenger airport location in Poland. In fact, a complete and all-embracing analysis which would aim to indicate optimal airport locations has not yet been carried out. The Ministry of Transport points to the need to make use of existing airport facilities as potential location of airports [Ministry of Transport, 2007]. In this situation it is advisable to carry out an analysis of available methodological solutions, which will allow an original solution to be developed, which would serve as a tool in the process of selecting airport locations.

PROBLEMS CONCERNING THE LOCATION OF INFRASTRUCTURAL FACILITES

The location of infrastructural facilities is one of key elements in strategic planning of any organization's operation. Generally, this

issue involves selecting the best location for an infrastructural facility (e.g. premises, site or building) for a specific entity (private or public) in a defined area, with certain references of the interested parties as well as numerous limitations which might occur. The location of objects always involves long-term investments, since the process of obtaining funding is complex, the time of implementation is enormous and the facility is to operate for a very long time. The decision maker must indicate the best location, accounting for the changing conditions to which the facility might have to adjust in the future. These include market trends, the development of trade and industry, demographic changes as well as environmental changes. The following elements must be considered in the process of determining the best location of airports:

- the number of analysed facilities,
- geographical location,
- size (area),
- assumed demand,
- their importance at the local/regional/ national/international level.

There might be several approaches to solving this problem, which might be found in the literature on the subject, for instance, solutions related to:

- centres of distribution [Nozick and Turnquist 2001],
- cranes on construction sites [Abdelmegid 2015],
- heat and power plant [Barda et al. 1990],
- airports [Landa-Silva 2009, Yang et al. 2014],
- warehouses [Wan et al. 1998] logistic centres [Chen et al. 2014, Turskis and Zavadskas 2010],
- shopping malls [Chen et al. 2007, Alnahhal and Noche 2015],
- sites of vehicle recycling [Merkisz-Guranowska 2011, 2012, 2013],
- cargo ports [Lirn et al. 2012],
- car parks [Bieńczak et al. 2009],
- fire stations [Badri et al. 1998],
- hospitals [Daskin 1995],
- cargo terminals [Bagoius et al. 2014],
- tram terminals [Kupka and Sawicki 2015],
- manufacturing plants [Badri et al. 1995].

One solution involves the issue of coverage, where the distance constitutes the decisive parameter; the shortest distance between the demand generating point and the one that offers supply, the better. It is usually assumed that the distance cannot exceed a certain value. This definition might be expanded with the aim of serving all the clients at the smallest possible number of service points.

If the definition of the problem is to be further expanded to include cost optimization, a group of P-median problems appears, where the minimization of distance, costs and the number of objects plays an important role [Daskin 1995, Owen and Daskin 1998]. The methods prepared for solving the issue of location are based on mathematical programming techniques, classification or variation ranking [Sikora 2008]. The mathematical programming model of facility location involves formulating several functions of the aim with several, frequently contradictory, criteria. Most of these are to be done by computer software. On the other hand, formulating the problem of location as one of variation ranking or classification calls for constructing models characteristic for facilitating multicriteria decisions. In this case, two approaches to creating variations are possible:

- heuristic (expert) construction of variations, or
- designing a procedure (method) for generating sets of solutions to the problem.

It needs to be clearly stated that both mathematical modelling and applyin a ranking method merely support the decision makers and analysts in the process of decision making and do not exempt them from assuming full responsibility for their choices and actions.

OVERVIEW OF SOLUTIONS TO THE ISSUE OF AIRPORT LOCATION, INCLUDING A CLASSIFICATION OF CASES OF DETERMINING SUCH LOCATIONS

The issue of airport location constitutes a special case of the location problems discussed below. The first work on the subject

of location is a monograph written by Alfred Weber in 1909, although some researchers believe that this issue's roots reach back as far as the 17th century [Farahani et al. 2010]. In the literature, one might encounter two different approaches to the issue of airport location. In the first, known as airport site selection, the best of all known options is chosen. This constitutes a special instance of the problem of choice in which the possible options or variations are ranked so that the best one can be chosen. In the other approach. The best location on a particular territory must be found and initially no particular options are specified. This is a special instance of the optimization problem. The differences between these approaches, based on the AHP method – – Analytic Hierarchy Process [Saaty 1980] and the multicriteria programming were described in detail by Min and Melachrinoudis [1997] and are presented in Table 1. Both these approaches to the problem of location are elaborated upon in this article.

Table 1. Comparison of ranking and optimization methods for solving the problem of location
Tabela 1. Porównanie metod rankingowych oraz optymalizacyjnych dla problemu lokalizacji

Feature	Ranking methods	Optimization methods
Type of problem	Selecting the location	The choice of location which may be combined with allocating the nearby objects (cities) to be served by the airport under discussion
Methodology	Evaluation based on the decision maker's preferences	Optimization within the set of allowed solutions
Solutions	Hierarchical	Non-hierarchical
Limitations	Not required	Required
Limitation regarding airport capacity	No	Yes
Subjective evaluation of the decision maker	Applied	Not applied
Deciding on dynamic (time related) aspects	Difficult	Relatively easy

The problem of selecting an airport location

The issue of selecting the location of an airport is widely discussed in the literature. Before making the choice of location, the usefulness of such an airport for the air transport system must analysed. As Kazda and Cavese [2007] claim, this is due to the fact that in almost every case it is easier to modernize existing airports than to build a new one on a site previously designated for other purposes. Moreover, the choice of a new location should not influence current traffic negatively [Stevens et al. 2010] (which is especially important in view of the demand for airlines in the vicinity of airports) [Wells 2000]. Whilst doing this type of analysis, the key is to forecast the growth of passenger traffic accurately (including that regarding tourist traffic [Fragoudaki and Giokas 2016]) and cargo [Kazda and Caves 2007, Kupfer et al. 2016, Walls 2000]. Once this issue is analysed, can one move on to solving the problem of airport location.

The complete procedure of selecting a new airport location, used in designing, involves ten basic steps:

1. Estimate the area needed to construct the airport.
2. Evaluate the factors determining the location.
3. Conduct a preliminary selection of possible locations.
4. Analyse and evaluate each of the preliminary choices of location.
5. Evaluate the environmental impact of these airport locations.
6. Conduct another evaluation of each of the possible locations.
7. Prepare drawings of potential airports for each of the locations being considered.

8. Evaluate the potential costs as well as the potential income; airport profitability analysis.
9. Make the final selection of airport location.
10. Prepare the final report with recommendations for the airport location selected.

All stakeholders must participate in this procedure, i.e. the investor, local authorities andthe inhabitants of the regions which are to be served by the airport [Kazda and Caves 2007, Silva et al. 2015, Stevens et al. 2010, Walls 2000]. This results from the fact that this sort of decisions are usually of a political nature. Moreover, as Stevens et al. [2010] sees it, one must consider both public and private interests, as well as spatial planning at various levels.

In the procedure of selecting the airport location, the choice of criteria used for evaluating particular locations is key. Kazda and Caves [2007] and also Silva et al. [2015] point to a set of factors which should be decisive whilst selecting airport locations. These include:

1. The maximum capacity of the airport which can be achieved in each location. At the same time, the airport needs to fulfil certain minimum requirements, such as the ability to serve certain streams of passengers [Bezić et al. 2010, Ha et al., 2010].
2. The impact on the surroundings, i.e. people and the natural environment [Daley 2010, Gaetano et al. 2014, Silva et al. 2015] (the environmental criterion)
3. The aspects related to the security of aviation operations at a specific location. The relevant factors include meteorological conditions (the strength and directions of the wind, visibility, etc.) [Kassomenos et al. 2005, Kazda and Caves 2007], threats of collisions with birds which have their habitats in particular potential locations or which migrate over this particular location [Blackwell et al. 2009, Kazda and Caves 2007].
4. The cost of construction (including the cost of land to be purchased from its current owners) [Walls 2000], levelling the land and removing obstacles, as well as building the necessary infrastructure [Kazda and Caves 2007, Silva et al. 2015]), operating and maintaining the airports in a given location.

Generally, when selecting airport locations, one should consider the options incurring the lowest possible costs and the least negative impact on people and natural environment [Kazda and Caves 2007, Silva et al. 2015]. Based on the above, it may be said that the issue under discussion encompasses multiple criteria, which shall be further discussed in this article.

Both Kazda and Caves [2007] and Wells [2000] claim that the procedure of selecting a location is an intuitive process (expert) and is carried out without any need to use multicriteria decision aids. Martel and Aouni [1992], however, suggest using a method similar to PROMETHEE [Brans and Mareschal 2005]. Ballis [2003] and Togatlian et al [2007] suggest using the AHP method [Saaty 1980]. Van der Kleij et al [2003] combine AHP [Saaty 1980] with the Monte Carlo method in order to model uncertainty while evaluating each of the variations.

Min and Melachrinoudis [1997] present a slightly different approach as they suggest a dynamic model of solving the problem of airport location based on multicriteria integer programming (MIP). The evaluation criteria in this approach include cost, noise, impact on the economic development of the region, and also accessibility (measured as road congestion between the airport and residential areas). The values of these criteria were assessed in an assumed time span. The problem was solved using solvera hyper-lindo, which helped to generate a set of non-dominated solutions (pareto optimal). When solving a real problem for the region of Massachusetts, seven preliminary selected locations were evaluated. Therefore, the problem formulated in this manner positions itself between the typical location selection problems using multicriteria analysis (predefining the possible location) and the typical problems of optimization, which are of continual nature (the optimization methods used) and which are discussed below.

The problem of airport location

The issue of airport location can be perceived as a special instance of the location problem in general. The task at hand is to find the best site for a given facility (an airport and its infrastructure) on a given area using e.g. the methods of optimization. All of the potential locations are evaluated by defining a calculable criterion (a single-criterion task) or a set of criteria (a bi-criterion or a multiple criterion task) of evaluation and limitations. Thus this issue is continual (no predefined potential locations – the new airport may be located at any site of the area under consideration). To solve the issue, optimization methods (algorithms) are used. Notably, in the literature, airports are considered to be partially semi-obnoxious and semi-desirable objects [Farahani et al. 2010, Brimberg and Juel 1998, Fernández et al. 2000, Skriver and Andersen 2003]. In the case of such facilities, the decision maker intends to locate them as close to the air transport demand/supply generating sites as possible (in order to bring down the costs/time of travelling to and from the airport). On the other hand, airports generate unwanted phenomena such as noise, which is perceived as a serious problem for nearby communities. Thus such objects should be located as far from residential areas as possible. The above factors are at the root of the conflict to which decision makers are exposed.

Fernández et al. [2000] suggest a single criterion planar model, i.e. one based on minimizing the aversion of residents in the cities located in the region under discussion. Additionally, the above authors assume a limitation preventing them from building an airport in the vicinity of cities. Within this criterion, the size of a given community and its distance from the planned site are important factors. To solve this problem, the method of branch and bound is suggested [Hillier and Lieberman 2012]).

Skriver and Andersen [2003] suggest two bi-criteria models - planar and network - for solving the issue of locating semi-desirable facilities, and present an example of applying this in the case of an airport in Denmark. For the planar model, the first optimization criterion was minimizing the weighted sum (the sum of products) of the distance from nearby communities raised to a negative exponent, where the weight is the size of each community's population. This criterion reflects the negative impact of the airport on the population. In the other criterion, the weighted sum of the distance between the planned location and the existing objects is minimized, which reflects transport costs. In this case, the weight is the population of the city to be served by the airport multiplied by the weight of the region where this city is located. The smaller the weight of the region, the further it is located from the planned airport location (in this case the city of Århus, which the new airport was to serve), which is to reflect a situation where passengers from distant locations prefer another airport, and thus intend to use this particular one less frequently. The authors suggest solving the planar problem by means of the Big Square Small Square (BSSS) algorithm, which is close to the branch and bound method and which allows solutions similar to the optimum one to be obtained. In the case of the network problem, the Edge Dividing (ED) algorithm was suggested, which is close to the idea of the BSSS.

CONCLUSIONS

The above overview of approaches towards solving the problem of airport location reveals the following aspects:

1. Due to the resulting complications of a political nature, the issues under consideration should be viewed as multicriteria problems [Owen and Daskin 1998]. Clearly, there are several groups of decision makers (the investor, the administrative authorities, local communities, economic entities) who have various expectations regarding the location of a given airport.
2. There are two different types of approach towards solving the problem. These are presented as ranking problems to be solved by means of the methods of multicriteria analysis as well as location problems to be solved by means of multicriteria optimization.

3. Due to the substantial computational complexity of the problems, the methods of approximation (e.g. heuristic methods) should be applied for solving location problems.
4. Both approaches to solving the problem of airport location have some drawbacks. In the case of problems related to choosing the location, it is essential to predefine the potential locations which are to be subsequently evaluated, although it is possible to unintentionally overlook some potentially good solutions. On the other hand, in the case of location problems, the set of criteria which are used for solving the problem seems to be too narrow. In the literature, the only factors considered are the size of the population and the distance from the airport.

In view of the above, the authors prepare three types of approach which would make it possible to develop the currently applied methods and alleviate their downsides. These concepts point to the directions of further research related to the issue of airport location.

The first concept assumes expanding the issue of location, so that it could consider additional criteria such as the environmental criterion. In this approach, the suggestion is to use metaheuristic methods, which constitute an extension of the method presented in this article. Additionally, developing the genetic algorithm is also suggested, so that it is possible to make use of the possibilities of multi-core processes which are currently standard even in PCs. In line with the concept presented by Luque et al. [2008], simultaneous computations might result in an almost linear reduction of computation time.

The second concept constitutes a development of methods for solving the location problem. The authors suggest using more modern methods based on fuzzy set theory, e.g. the fuzzy-AHP method or the theory of approximated set, such as jRank [Szeląg et al. 2010, 2014]. This concept assumes a preselection of sites to be considered using multicriteria classification problems.

The third concept is a development of the method suggested by Min and Melachrinoudis [1997]. It assumes preliminary generation of non-dominated solutions using generators of efficient solutions such as Megros. This set is to be subsequently evaluated by the decision maker using some interactive methods such as BIPOLAR [Konarzewska-Gubała 1989], INSDECEM – INteractive Stochastic DECision Making Procedure [Nowak 2006], LBS – Light Beam Search method [Jaszkiewicz and Słowiński 1999], STEM-DPR – STEp Method for Discrete Decision Making Problems under Risk [Nowak 2008]. Moreover, the authors point to the fact that it is possible to implement many other methods of multicriteria decision analysis [Trzaskalik 2014], for instance, those based on reference points, e.g. DEMATEL – – DEcision Making Trial and Evaluation Laboratory [Gabus and Fontela 1973], VIKOR (Serb. VIsekrzterijumska Optimizacija i Kompromisno Resenje) or to combine the DEMATEL+ANP+VIKOR methods [Tzeng and Huang 2011].

In all of the above concepts it is assumed that geographic information systems (GIS) will be used in order to facilitate data input and to improve the presentation of results.

To sum up, it must be stressed that the approaches suggested are but a part of the wide range of methods which might be applied in selecting the best airport locations.

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LOKALIZACJA PORTÓW LOTNICZYCH - WYBRANE METODY ILOŚCIOWE

STRESZCZENIE. **Wstęp:** Transport lotniczy obecnie odgrywa ważną rolę, jeśli chodzi o rozwój gospodarczy zarówno kraju, jak i danego regionu. Ewentualna decyzja o jego lokalizacji powinna w maksymalnym stopniu spełniać oczekiwania interesariuszy. Niniejszy artykuł podejmuje tematykę związaną z wyborem lokalizacji portów lotniczych.
Metody: W artykule przedstawiono dwa główne ilościowe nurty (podejścia) związane z problematyką lokalizacyjną portów lotniczych (PL), tj. problem optymalizacji wyboru lokalizacji PL oraz problem wyboru lokalizacji spośród z góry zdefiniowanego zbioru. Pierwszy z nich związany jest z programowaniem matematycznym i sformułowaniem problemu jako zadania optymalizacyjnego drugi natomiast zszeregowaniem wariantów Z uwagi na różne podłoże metodyczne autorzy przedstawili wady i zalety obu podejść oraz wskazali tą, która ma obecnie swoje praktyczne zastosowanie.
Rezultaty: W artykule, opierając się na rzeczywistych przykładach, zaprezentowano procedurę wieloetapową pozwalającą na rozwiązywanie problemu lokalizacji portów lotniczych.
Wnioski: W artykule, wskazano na bazie przeglądu literaturowego trzy koncepcje podejścia do problematyki lokalizacji PL, dzięki którym możliwe byłoby rozwinięcie obecnie stosowanych metod.

Słowa kluczowe: lokalizacja portów lotniczych, optymalizacja, szeregowanie wariantów

DAS PRBLEM DER LOKALISIERUNG VON FLUGHÄFEN - AUSGEWÄHLTE QUANTITATIVE METHODEN

ZUSAMMENFASSUNG. Einleitung: Der Lufttransport spielt derzeit eine wichtige Rolle, wenn es sich um die wirtschaftliche Entwicklung sowohl des Landes als auch der Region handelt. Jede Entscheidung über dessen Beschaffenheit sollte im maximalen Ausmaße den Erwartungen der Interessenten gerecht werden lassen. Dieser Artikel betrifft die Problematik der Auswahl einer optimalen Standort-Platzierung für Flughäfen an.
Methoden: Im Artikel stellte man zwei wichtige quantitative Trends (Ansätze) im Zusammenhang mit der Frage der Lokalisierung von Flughäfen dar, d.h. man projizierte das Problem der optimalen Auswahl eines Flughafen-Standortes sowie das Problem der Auswahl dessen aus einer im Voraus definierten Menge. Das erste ist mit mathematischer Programmierung und der Problemstellung als einer Optimierungsaufgabe verbunden, das andere dagegen mit der Einstufung der einzelnen Varianten. Angesichts der unterschiedlichen methodischen Vorgehensweisen stellen die Autoren die Vor- und Nachteile der beider Ansätze dar und wiesen auf den, der zur Zeit eine praktische Anwendung findet, hin.

Ergebnisse: Basierend auf konkreten Beispielen präsentiert der Artikel ein mehrstufiges Verfahren, das die Problemstellung der Lokalisierung der Flughäfen zu lösen vermag.
Fazit: Gestützt auf die grundlegende Übersicht der Gegenstandsliteratur zeigte man im Artikel drei Vorgehensweisen an die Problematik der Lokalisierung der Flughäfen auf, dank derer die weitere Entwicklung der heutzutage angewendeten Methoden möglich wäre.

Codewörter: Lokalisierung von Flughäfen, Optimierung, Einstufung von Varianten

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