

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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ESTIMATION OF AIRPORT INFRASTRUCTURE EXPLOITATION EFFICIENCY BY UPGRADED DATA ENVELOPMENT ANALYSIS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
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Ilona JARŽEMSKIENĖ

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Introduction

The research problem

Competition in air transport as a result of the abolition of state regulation of the market in 1970 is becoming more acute. Airports are forced to increase their exploitation efficiency of the existing infrastructure in order to remain competitive. With the increasing number of flights, the airports are forced to develop their infrastructure to meet the growing needs of the market, but the financial resources are limited so not all airports will be developed. The total comparative airport exploitation efficiency (TCAEE) is an important factor in attracting investors, whether it is an investment bank or the government, or a company, or a private investor. Efficiency is not a unified concept. To determine how operationally-efficient the airport is the evaluation model of technical, operational indicators is required which allows us to identify how the change (improvement) of one technical parameter partially affecting the exploitation efficiency leads to a change in the total exploitation efficiency. Currently such a complex model of total exploitation efficiency does not exist, while the decisions on the improvement of technical parameters are made without evaluating a complex effect on the airport exploitation efficiency, instead, assessing only the future benefits of improved specific technical parameter, such as prolonged runway or expanded passenger waiting rooms.

The relevance of the work

The issue examined in the dissertation is acute in the context of the European Union and the global air transport organizations. The Advisory Council of Aviation Research and Innovation in Europe, *ACARE* has developed air transport vision for 2020 and identified the most important research directions. One of the main directions is the increase of airport exploitation efficiency while reducing the negative environmental impact, reducing the prices for airport services and shortening the passenger, cargo and aircraft service time.

The International Civil Aviation Organization *ICAO* considers the problems of infrastructure efficiency to be among the most important directions of their activities because the airport exploitation efficiency becomes significant with the increase of airport load. The International Air Transport Association *IATA* among its working groups has established a working group “Airports and Navigation”, one of the most important tasks of which is the measurability and increase of airport exploitation efficiency. Airports exploitation efficiency is an object relevant to the transport themes of the European Commission’s Seventh Framework Programme for Research.

The dissertation is relevant in terms of practical applicability of developed theoretical models. The airports with inefficient performance will no longer be dependent on the state and eventually collapse. Exploitation efficiency (EE) is measured as the ratio between the input and output. The comparison of the airport exploitation efficiency with other major airports is significant for the airport management in planning and management of airport operations and monitoring of performance. With the same investments, the airports with different efficiency can accommodate different traffic flows of passengers, cargo and aircraft. The identification of operational efficiency indicators enables to compare airports and forecast their development trends.

The object of the research

The object of this research is airport infrastructure exploitation efficiency indicators.

The aim of the work

This work aims to create and experimentally test an assessment model of the total comparative airport exploitation efficiency (TCAEE) according to partial indicators, which would be applicable in practice to any range of airports, and which can be used to determine how a change in one of the technical parameters affect the exploitation efficiency of a range of airports under the investigation.

The tasks of the work

To achieve the aim the following tasks were formulated:

1. To conduct the analysis of theories on airport exploitation efficiency created by various authors.
2. To design an evaluation model of general comparative airport exploitation efficiency in order to compare the exploitation efficiency of one airport in respect to exploitation efficiency of other airports.
3. To test the developed model in order to solve a real task. Experimentally evaluate the infrastructure covering 15 airports.

The methodology of the research

The scientific research methodology is based on literature study, data envelopment analysis method, expert survey, weighted evaluation, multi-purpose assessments, statistical data processing.

Works of the authors from the US, EU, China and Japan were investigated. This investigation included articles published in journals recognized by the global transport research community, books of various

authors, doctoral dissertations, publications of presentations at international scientific and practical conferences in the field of transport, the EU strategic planning documents, the EU legal acts, EUROSTAT data, statistical databases of air transport associated structures.

The scientific novelty

New results relevant for transportation engineering science obtained by the author of the dissertation are as follows:

1. A model was developed and experimentally tested that can be applied for ranking, combining and comparing exploitation efficiency indicators of one airport with combined exploitation efficiency indicators of other airports.
2. The model is based on data envelopment analysis according to partial indicators. The analysis was enhanced by introduction of weighting parameters to partial indicators.
3. The developed model allows us to evaluate TCAEE according to partial indicators of positive and negative output.

The practical value

1. The model is tested in an experimental set of airports and can be applied in practice of airport infrastructure development decision makers.
2. The developed TCAEE model is suitable for simulation steps. Having developed virtual technical airport different parameters, the applied model will determine its future (virtual) TCAEE in respect to other comparable airports in the same sample.

Defended propositions

1. The original model designed by the author to measure and evaluate the total comparative airport exploitation efficiency is introduced. Applying the model in the experimental set of airports, TCAEE of any airport can be compared to TCAEE of any other airport in the same set.
2. DEA enhancement method applying Delphi method for the selection of indicators and the introduction of weighting parameters for partial EE provides the opportunity to compare total exploitation efficiency even of different sized airports with each other.

The scope of the work

The work consists of the general characteristics of the dissertation, three chapters, a list of literature sources, a list of publications and annexes. The total scope of the work is 98 pages, 22 figures, 22 tables and 1 annex.

1. The research on theories of exploitation efficiency of airport

The chapter examines: types of exploitation efficiency indicators and their classification according to various authors, value creation theory application to airports when the interests and goals of the airport's interested parties are different and exploitation efficiency indicators can be understood in different ways, as well as data envelopment analysis application to determine the exploitation efficiency of an airport.

Exploitation efficiency is often defined as the ratio between the amount of invested resources and benefits received. In such complex systems as airports and their interaction, the evaluation of efficiency becomes problematic. It is pointed out by many authors in their works. There are a great many interrelated internal and external indicators. Not all of them are measurable. The indicators of invested resources are usually derived and are described as invested labour and capital. The invested resources generate the output which results in derivative indicators, commonly such as the number of served aircraft, passenger and cargo throughput. The input and output consist of a complex of partial indicators.

The literature reflects the division of airport exploitation efficiency by partial factors and by joint factors. Exploitation efficiency estimates are substantially related to the airport output by one factor, for example, the number of passengers per unit area of the terminal. This evaluation by one indicator is partial. Efficiency by partial factors is measured in several dimensions: the global, partial, specific activities and services for passengers.

Quite a number of assessment criteria according to partial factors are mentioned in literature but combined assessment factors are rather scarce. Key scientific issues in assessing airport exploitation efficiency by combined indicators focus on attributing weights to each of the indicators and determining the functional dependence between the parameters describing input and output.

To evaluate the efficiency the scientists also distinguish parametric and nonparametric approaches. The parametric approach may be described as an attempt to determine the functional relationship between the input and output of certain selected indicators, whereas the nonparametric approach does not require the evaluation of parameters, so there is no need to establish the parameters and their estimates, which is difficult due to a lack of statistical data. The most important procedure in a nonparametric approach is data envelopment analysis (DEA).

The passenger will assess the exploitation efficiency in one way, otherwise the consignor – in the other way, airport staff still in a different way, airport owners or investors will have a different exploitation efficiency concept. As a solution to this problem foreign scientists use value creation theory. This theory is

based on the fact that each parameter, in contrast to the interested party that will assess the productivity, may have a different value.

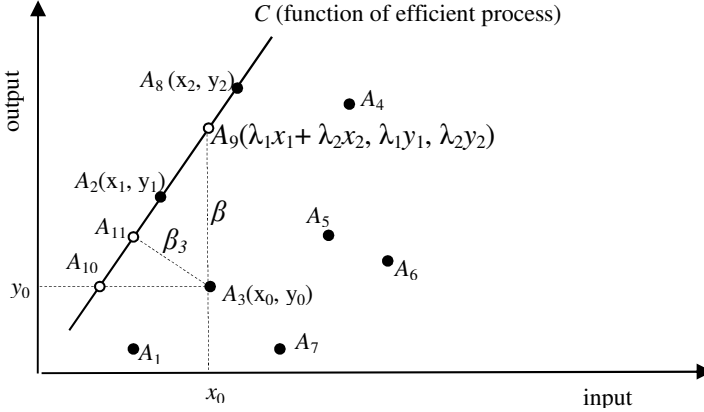


Fig. 1. The application of data envelopment analysis

Data envelopment analysis is a methodology to assess threshold values, rather than mean trends. Suppose we have a set of M airports $A_1, A_2, \dots, A_m$ (Fig. 1), each of which is evaluated through a separate input, for example, such as a number of runways and a separate output, such as the number of aircraft handled. The input and output of every airport are indicated in the coordinate system. For airports A_1, A_7 and A_6 negative residues were received while for airports A_2, A_4 and A_8 positive residues were received. Every airport that has a positive residue is effective at certain inputs. Function C of effective exploitation process merely points to the exploitation efficiency at the specific values of the input. Data envelopment analysis method enables to determine the efficiency threshold in assessing its distances for each airport.

The Data envelopment analysis tested each airport to identify which is at a maximum exploitation efficiency threshold. Letter β marks scalar coefficient of the specific airport A_3 output Y_2 to achieve maximum exploitation efficiency level according to maximum exploitation efficiency threshold function. Let's create a virtual airport A_9 , which can be expressed as linear function of airports A_2 and A_8 ($\lambda_1 x_1 + \lambda_2 x_2, \lambda_1 y_1, \lambda_2 y_2$). A_2 and A_8 are the most efficient airports, so the growth rate does not apply or applies, but is calculated equal to one. All other inefficient airports will have a coefficient uneven to one. In reality the efficiency of such airports is determined not by a single input and output but by

lots of them, but in this case, to reflect the efficiency in a two-dimensional picture plane becomes impossible.

2. Formulation of total comparable exploitation efficiency methodology

Further developing the theory of an effective process threshold determination, the vector distance A_3A_{11} can be marked β_k (Fig. 1) which by radian geometric equations is calculated for any airport in the set A (A_1, A_8), A , where scalar expression for each A input and output is available. For each A_k will be $e \beta_k$ accordingly. β_{kn} vector value of the distance from marginal exploitation efficiency function C of each airport (A_k) of the investigated range determines the airport exploitation inefficiency degree according to n -th index. Provided that two or more airports which are positioned on the marginal exploitation efficiency line C , have the exploitation efficiency that is maximum in the given range of airports (A_1, A_k), according to the given partial n -th exploitation efficiency indicator β_{kn} (when the number of partial exploitation efficiency indicators is N), then those two or more airports will show the highest exploitation efficiency, which we will assess by the 100-point system.

In this case (Fig. 1) the estimation of airports A_2 and A_8 will be 100. A 100-point system was basically introduced to unify different scalar values β_{kn} and perform mathematical operations with different scalar values. The airport A_k with the highest β_k for the n -th partial exploitation efficiency indicator will have the lowest exploitation efficiency and assessed as 0. The remaining airports A_k , which are not on the threshold of exploitation efficiency (not on a straight line C) and with the β_k for the n -th partial exploitation efficiency indicator not the lowest, will take various exploitation efficiency percentages on the straight line C scale drawn between the airports with the maximum exploitation efficiency and the airport with the lowest exploitation efficiency. In this way, for each k -th airport we can attribute each n -th partial exploitation efficiency comparative (relative) index $\beta_{100kn} \cdot \beta_{100kn}$ introduction is a significant improvement in DEA because of the possibility to mathematically use exploitation efficiency values according to different indicators. There is an opportunity to compare the exploitation efficiency of the airport not according to one indicator, but according to set of indicators. This basically provides an opportunity to determine the total exploitation efficiency of k -th airport, in a range of K airports, according to N partial exploitation efficiency indicators. Other authors attempting to use DEA method of partial exploitation operational indicators to calculate the general comparative exploitation efficiency, did not see the possibility to introduce this relative value so the calculation and justification of the total (combining a number of indicators) exploitation efficiency was

essentially the main problem of DEA. Mathematical operations with exploitation efficiency indicators having different dimensions are not possible to perform by means of DEA, so we were seeking to harmonize the dimensions by expressing some indicators over others. The transition to the relative indicators was largely based on the approaches of value of theory. The determining factor of comparative analysis is not the expression or dimension of exploitation efficiency but namely the ratio of exploitation efficiency indicators with other similar indicators of airports. With each of the k -th airport exploitation efficiency indicator β_{100kn} by means of a simple arithmetic mean principle we can calculate the total exploitation efficiency indicator β_{T100k} for each airport. It is significant that these β_{T100k} can be compared with each other only within the range of airports (A_1, A_k) whereas the comparison with other airports from the other ranges does not make sense. Yet, in determining TCAEE β_{T100k} there are still two major problems. First, which namely partial exploitation efficiency indicators β_k must be assessed (i.e. β_{100kn} , where n ranges from 1 to N – range determination), as the range of exploitation efficiency indicators can be very large, so with the increasing quantity of indicators, the problem of statistical information presence and accumulation will increase. The second problem is whether the exploitation efficiency indicators are equally important in respect to value theory, when the TCAEE is determined on their basis. The answers to these two problems are found in airports value theory. The best balance of interests of all interested parties is reflected by the airport representatives. Expert assessment largely solves the first problem, when the experts select a range of partial exploitation efficiency indicators, according to which the total exploitation efficiency rate will be calculated. The second problem is solved by referring to experts by assigning weighted values. With each β_{100kn} weighted values of each n -th index $\beta_{100kn\text{-leverage}}$ and applying $\beta_{100kn\text{-leverage}}$ for each k -th airport by the mathematical aggregation principle, the empirical example with this approach applied is given in chapter 3.

3. Empirical research on airport comparable total exploitation efficiency

The algorithm of empirical research is presented in Fig. 2.

First, a range of airports $K(A_1, \dots, A_k)$ selected for study is determined (Fig. 3). To gain the study's practical relevance to Lithuania, exploitation efficiency of Vilnius, Kaunas and Palanga airports was assessed by comparing them with each other and with 12 other operating airports in the Baltic Sea region.

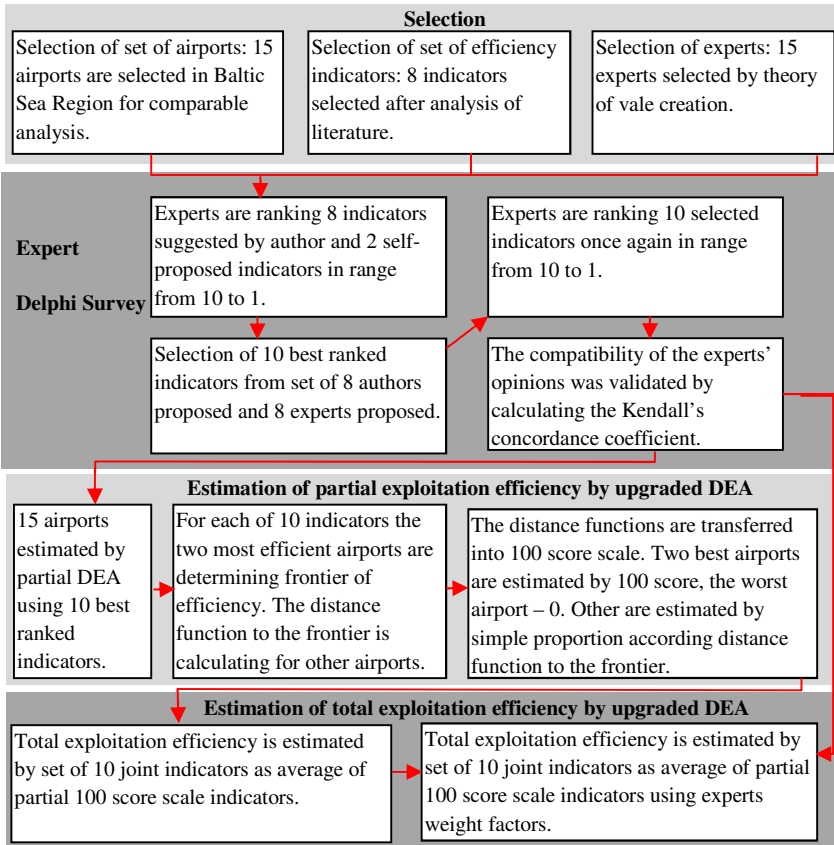


Fig. 2. Algorithm of empirical research

The criteria selection problem has been addressed by the available (secondary) data analysis and expert interviews. Based on the work of other researchers eight partial airport exploitation efficiency indicators were selected. Expert (selected on the basis of the investigated area) survey was used to extend a list of partial exploitation efficiency indicators and to determine the weights of partial exploitation efficiency indicators. 15 experts were selected from the whole Baltic Sea region – the same as the number of airports surveyed. The *Delphi* method was selected for the survey of experts.

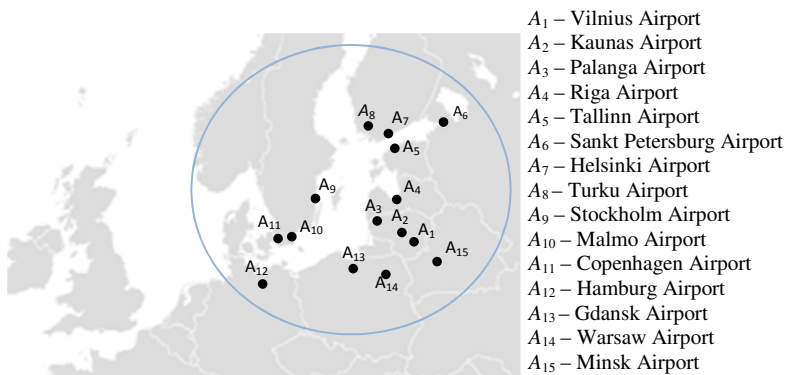


Fig. 3. The set of airports

Table 1. The first and second round expert panel results

round	indicator	Suggested by the author of dissertation								Suggested by experts in first round							
		PAX/LAND	AIR/LAND	AIR/TAXITIME	PAX/RW	PAX/RWA	FR/RWA	PAX/TAXITIME	AIR/DELTIME	PAX/TERMAREA	PAX/GATES	AIR/RW	AIR/RWA	AIR/TERMAREA	AIR/GATES	FR/LAND	FR/RW
I		5.67	7.33	4.67	5.87	4.33	2.13	0.20	0.00	2.47	3.47	6.67	5.20	3.80	2.07	0.53	0.60
II		7.00	9.13	4.53	7.33	4.33	n.r.	n.r.	n.r.	2.40	3.40	6.93	5.73	4.40	n.r.	n.r.	n.r.

n.r. – not ranked

In the first round of the survey by the *Delphi* method experts were provided with eight partial exploitation efficiency indicators: PAX/LAND, AIR/LAND, AIR/TAXITIME, PAX/RW, PAX/RWA, FR/RWA, PAX/TAXITIME, AIR/DELTIME. Here: PAX – number of passengers per year, AIR – number of aircraft movements per year, LAND – area of airport territory, RW – number of runways, RWA – max length of the runway, DELTIME – cumulative time of delays per year, TAXITIME – time of taxing. Eight additional indicators were added to the list by the experts: PAX/TERMAREA, PAX/GATES, AIR/RW, AIR/RWA, AIR/TERMAREA, AIR/GATES, FR/LAND, FR/RW, here GATES – number of gates, FR – volume of freight served, per year. In the second round of expert interviews the same fifteen experts were provided with a list of 10 indicators of highest ranks and experts were asked to rank the indicators again. Survey results are

presented in Table 1. The mean rate value is determined by the formula in both, the first and second rounds:

$$\bar{r}_n = \frac{\sum_{e=1}^E r_{en}}{E}, \quad (1)$$

t_{jr} – evaluation of n indicator by e expert, E – number of experts.

The compatibility of the experts' opinions was validated by calculating the Kendall's concordance coefficient W and its significance χ^2 .

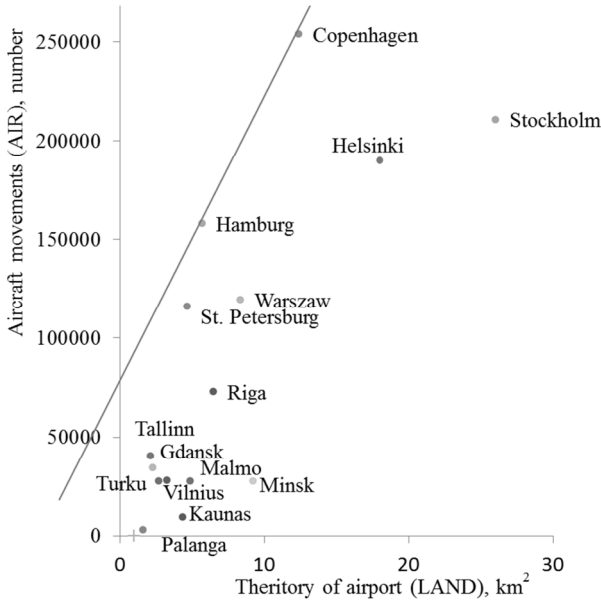


Fig. 4. Partial exploitation efficiency by ratio of aircraft movements and territory of airport

Then according to each partial exploitation efficiency indicator through data envelopment analysis methodology and the author's method presented in the second chapter, two most effective airports are identified with the exploitation efficiency of 100 % which is measured by a given partial exploitation efficiency. The remaining airports are ranked from 0 (lowest operational efficiency rating) to 100 by vector distance from the threshold exploitation efficiency line. The data for each of the partial exploitation efficiency indicator are presented graphically, and the vector distance from the threshold exploitation efficiency line for each airport is presented in the tables

below the graphs. At the same time the tables show recalculated exploitation efficiency values in the system of 100 points. Figure 4 shows an example of DEA partial efficiency (according to one of the ten indicators: AIR / LAND). A similar analysis was performed of all partial indicators. Table 3 presents the calculation results of β_k or β_{100kn} for AIR / LAND indicator.

Partial exploitation efficiency results in the system of 100 points are relative values reflecting the ratio of partial exploitation efficiency indicators between the airports and this relationship can be estimated by the sum of the partial exploitation efficiency values according to the formula (2).

Table 2. The DEA by partial AIR/LAND indicator

Indicators	Vilnius	Kaunas	Palanga	Riga	Tallinn	St. Petersburg	Helsinki	Turku	Stockholm	Malmö	Copenhagen	Hamburg	Gdansk	Warsaw	Minsk
β_k	6.69	9.11	6.76	6.77	4.69	1.95	10.06	6.13	16.61	8.33	0.00	0.00	5.26	5.35	12.70
β_{100kn}	60	45	59	59	72	88	39	63	0	50	100	100	68	68	24

β_{T100k} for each k -th airport, as calculated by n -th partial index obtained from the formula:

$$\beta_{T100k} = \frac{\sum_{n=1}^N \beta_{100kn}}{N}. \quad (2)$$

Table 3. Non-weighted indicators of partial exploitation efficiency of airports

Airports ($k=1, 2, \dots, K$)	partial indicators of exploitation efficiency										β_{T100k}
	$\beta_{100kn}; n=1, 2, \dots, N.$										
	AIR/ LAND	PAX/ RWA	PAX/ RW	PAX/ LAND	AIR/ RWA	AIR/ TAXI	PAX/ RWA	AIR/ TERM AREA	PAX/ GATES	PAX/ TERM AREA	
Copenhagen	100	100	100	100	100	17	100	100	100	100	92
Hamburg	100	96	97	100	49	62	49	91	53	100	80
Helsinki	39	53	34	30	80	100	71	100	100	95	70
Stockholm	0	68	69	0	99	40	100	79	91	80	63
St. Petersburg	88	65	64	88	24	61	24	61	67	62	60
Riga	59	100	100	57	53	78	49	39	16	34	58
Warsaw	68	68	62	65	32	92	29	59	29	54	56
Turku	63	67	60	59	92	100	83	15	2	2	54
Vilnius	60	67	72	62	91	83	88	11	1	7	54
Gdansk	68	72	78	71	70	55	69	18	21	17	54
Palanga	59	48	58	65	100	90	99	0	0	0	52
Tallinn	72	76	73	70	51	76	46	21	6	11	50
Malmö	50	0	0	53	68	89	67	14	11	13	36
Kaunas	45	53	65	51	24	55	28	3	2	5	33
Minsk	24	66	69	24	0	0	0	7	9	0	20

Non-weighted indicators of partial exploitation efficiency of airports are presented in Table 3. Weighted indicators of partial exploitation efficiency of airports are presented in Table 4. Having evaluated 15 airports under the improved data envelopment analysis, the largest comparative exploitation efficiency was obtained from Copenhagen airport – $\beta_{T100k-leverage} = 514.6$, the lowest - Minsk airport – $\beta_{T100k-leverage} = 141.2$. Vilnius airport 7th ranking, $\beta_{T100k-leverage} = 328.6$, Palanga airport $\beta_{T100k-leverage} = 312.8$ (11th ranking), Kaunas airport $\beta_{T100k-leverage} = 213.4$ (13th ranking). Although Kaunas airport serves more passengers and cargo than Palanga airport, but given their infrastructure exploitation efficiency, it is worse than Palanga.

Table 4. Weighted indicators of partial exploitation efficiency of airports

Airports ($k=1, 2, \dots, K$)	partial indicators of exploitation efficiency										
	$\beta_{100kn-svert}; n=1, 2, \dots, N$										$\beta_{T100k-svert}$
	AIR/ LAND	PAX/ RWA	PAX/ RW	PAX/ LAND	AIR/ RWA	AIR/ TAXI	PAX/ RWA	AIR/ TERM AREA	PAX/ GATE S	PAX/ TERM AREA	
Copenhagen	860	750	700	690	570	76	430	420	340	310	514.6
Hamburg	860	721	679	690	280	281	210	384	182	310	459.7
Riga	510	750	700	394	304	350	212	162	54	104	354.0
St. Petersburg	759	488	448	610	134	273	101	255	227	193	348.8
Helsinki	339	397	237	207	455	450	307	420	340	293	344.5
Gdansk	587	537	547	491	401	247	297	77	72	54	331.0
Vilnius	514	500	501	426	517	375	378	48	4	23	328.6
Turku	542	500	423	409	524	450	358	62	8	7	328.3
Warsaw	583	507	432	447	183	415	126	247	98	169	320.7
Tallinn	617	570	513	480	291	343	197	87	19	35	315.2
Palanga	510	364	408	447	570	403	426	0	0	0	312.8
Stockholm	0	512	486	0	565	179	430	334	309	247	306.2
Kaunas	388	398	452	353	139	250	119	14	5	16	213.4
Malmo	429	0	0	364	386	400	287	60	38	41	200.5
Minsk	202	499	485	164	0	0	0	31	31	0	141.2

Palanga airport with lower infrastructure (shorter runway, less gate, smaller airport area) creates a higher comparative exploitation efficiency of its infrastructure.

General conclusions

1. The literature review conducted on the airport exploitation efficiency assessment methods showed a problem of identifying a range of indicators as well as fixing data retrieval that may be addressed by appropriate use of value theory and non-parametric evaluation methodology. The assessment of exploitation efficiency by non-parametric data envelopment analysis

method according to partial indicators is being developed by scientists, but a scientific problem remains to compare the airports by combined indicators. The DEA method proposed and improved by the author of the dissertation allowed to compare airports by applying the DEA method according to combined indicators, and this has been proved experimentally.

2. The infrastructure exploitation efficiency of airports is defined by a range of indicators, where each of them has a different weight. The expert evaluation of two rounds by applying Delphi method in a 10 point system determined that in a range of the explored airports the most significant indicator is the annual number of serviced aircraft per airport area with its significance index 8.6. Other most significant indicators selected during the study are as follows: the ratio of the number of aircraft served to the number of runways (significance coefficient is 7.47); the ratio of the number of passengers served during the year to the number of runways (7.00); the ratio of the number of passengers served during the year to airport surface area (6.87); the ratio of the number of serviced aircraft over a year to the longest runway length (5.73).
3. The comparative exploitation efficiency calculations according to DEA by combined indicators method without applying weight coefficients determined that in all the assessed airports from the Baltic Sea region, the highest exploitation efficiency was observed in Copenhagen airport - indicator value 92. Vilnius Airport ranked as 7–9 in experimental airport range (indicator value is 54), Palanga airport – 11 (52), Kaunas airport – 14 (33), the last – 15th ranking – Minsk Airport (20).
4. The comparative exploitation efficiency calculations according to DEA by combined indicators method applying weight coefficients determined that of all the assessed airports from the Baltic Sea region, the highest exploitation efficiency was found in Copenhagen airport - indicator value 514.6. Vilnius Airport ranked as 7th (indicator value is 328.6), Palanga airport – 11th (312.8), Kaunas airport – 13th (213.4), Minsk Airport was the last – 15th ranking – (141.2).
5. The introduction of DEA relative index enables to escape from the dimensions, which being different for different exploitation efficiency indicators would cause a problem of a partial exploitation efficiency aggregation to the total comparative exploitation efficiency according to combined indicators. The introduction of a relative weight index of leverage, allows a more accurate assessment of the total exploitation efficiency by combined indicators.

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ORO UOSTŲ INFRASTRUKTŪROS EKSPLOATACINIO EFEKTYVUMO VERTINIMAS PATOBULINTU DUOMENŲ APGAUBTIES METODU

Problemos formulavimas

Konkurencija oro transporte 1970 metais panaikinus valstybinį rinkos reguliavimą yra vis aštresnė. Oro uostai iš reguliuojamų valstybinių monopolijų persitvarkė į tarpusavyje konkuruojančius terminalus. Jei anksčiau oro uostų tikslas buvo teikti viešąsias paslaugas, tai dabar jie tapo grynai komercinėmis ir pelno siekiančiomis įmonėmis. Lietuvoje liberalizacija prasidėjo įstojus į Europos Sąjungą 2004 metais. Oro transporto rinka tapo nekontroliuojama valstybės, nauji skrydžiai atidaromi ir uždaromi veikiant tikrai rinkos dėsniams. Pigių skrydžių kompanijų atsiradimas rinkoje oro uostus verčia didinti savo turimos infrastruktūros efektyvumą, kad išliktų konkurencingi.

Didėjant skrydžių skaičiui, oro uostai siekia priversti plėtoti savo infrastruktūrą, kad patenkinti didėjančius rinkos poreikius, tačiau finansavimo resursai yra riboti ir plėtojami bus ne visi oro uostai. Oro uosto bendrasis palyginamasis eksploatacinis efektyvumas (OUBPEE) yra svarbus veiksnys pritraukiant investuotoją. Vieningos efektyvumo sampratos nėra. Nustatyti kaip eksploatacinio požiūriu efektyviai oro uostas dirba reikalingas techninių, eksploatacinių rodiklių įvertinimo modelis, kuris leistų pamatyti, kaip vieno dalinai eksploatacinį efektyvumą įtakančio techninio parametro pakeitimas lemia bendro eksploatacinio efektyvumo kaitą. Toks modelis taptų sprendimų priėmimą palengvinančiu įrankiu investuotojams, besirenkantiems į kurį oro uostą investuoti iš konkrečios oro uostų aibės. Šiuo metu tokio kompleksinio bendrojo eksploatacinio efektyvumo modelio nėra, o sprendimai dėl techninių parametrų gerinimo priimami bendrai nevertinant įtakos oro uosto eksploataciniam efektyvumui, o vertinant tik būsimą naudą iš pagerinto konkretaus techninio parametro.

Darbo aktualumas

Disertacijoje nagrinėjama problema yra aktuali Europos Sąjungos ir pasaulinio oro transporto organizacijų kontekste. Europos aeronautikos

mokslinių tyrimų patariamoji taryba *ACARE*, yra parengusi oro transporto viziją 2020 metams ir identifikavusi svarbiausias mokslinių tyrimų kryptis. Viena pagrindinių krypčių yra oro uostų eksploatacinio efektyvumo didinimas kartu mažinant neigiamą poveikį aplinkai, piginant oro uostų paslaugas ir trumpinant keleivių, krovinių, orlaivių aptarnavimo laiką. Tarptautinė civilinės aviacijos organizacija *ICAO* infrastruktūros efektyvumo problematiką, įvardina tarp svarbiausių veiklos krypčių, nes oro uostų eksploatacinis efektyvumas tampa reikšmingas didėjant oro uostų apkrovimui. Tarptautinė oro transporto asociacija *IATA* tarp savo darbinių grupių yra įkūrusi darbo grupę „Oro uostai ir navigacija“, kurios tarp svarbiausių uždavinių yra oro uostų eksploatacinio efektyvumo išmatuojamumas ir jo didinimas. Oro uostų eksploatacinis efektyvumas yra aktualus Europos Komisijos 7-osios Bendrosios mokslinių tyrimų programos Transporto tematikos tyrimo objektas. Disertacija yra aktuali dėl praktinio parengtų teorinių modelių pritaikomumo. Oro uostų eksploatacinio efektyvumo palyginimas su kitais oro uostais svarbus oro uosto vadovybei planuojant ir valdant oro uostų veiklą bei atliekant veiklos stebėseną. Eksploatacinio efektyvumo rodiklių nustatymas, įvertinimas ir palyginimas patobulintu duomenų apgauties metodu yra labai svarbus oro uosto savininkams planuojant investicijas oro uostų plėtrai, numatant oro uostų plėtros programas, suteikiant prioritetus investicijoms.

Tyrimų objektas

Tyrimų objektas – oro uostų infrastruktūros eksploatacinio efektyvumo rodikliai.

Darbo tikslas

Šio darbo tikslas – sudaryti ir eksperimentu patikrinti oro uostų bendrojo palyginamojo eksploatacinio efektyvumo pagal dalinius rodiklius įvertinimo modelį, kuris būtų praktiškai pritaikomas bet kuriai oro uostų aibei, ir kuriuo būtų galima naudotis siekiant nustatyti, kaip vieno iš techninių parametrų keitimas įtakoja oro uostų bendrąjį eksploatacinį efektyvumą tiriamos oro uostų aibės atveju.

Darbo uždaviniai

Darbo tikslui pasiekti suformuluoti šie uždaviniai:

1. Atlikti įvairių autorių oro uostų eksploatacinio efektyvumo teorijų analizę.
2. Sukurti oro uostų bendrojo eksploatacinio efektyvumo vertinimo metodą, vieno oro uosto eksploatacinio efektyvumo kitų oro uostų eksploatacinio efektyvumo atžvilgiu palyginimui.

3. Patikrinti sukurta modelį realiam uždaviniui spręsti. Eksperimentu įvertinti ir palyginti 15 oro uostų infrastruktūros eksploatacinį efektyvumą.

Tyrimų metodika

Mokslinio darbo tyrimo metodika pagrįsta mokslinės literatūros studija, duomenų apgaubties analizės metodika, ekspertine apklausa, svertiniu ir daugiatisliu vertinimu, statistinių duomenų apdorojimu.

Mokslinis naujumas

1. Sudarytas ir eksperimentu patikrintas modelis, kuriuo galima suranguoti, apjungti ir palyginti oro uosto skirtingus eksploatacinio efektyvumo rodiklius su kitų oro uostų apjungtais eksploatacinio efektyvumo rodikliais.
2. Modelis pagrįstas duomenų apgaubties analize pagal dalinius rodiklius patobulinant ją svertinių dydžių daliniams rodikliams įvedimu.
3. Sukurtas modelis leidžia įvertinti oro uostų bendrąjį palyginamąjį eksploatacinį efektyvumą pagal dalinius teigiamo ir neigiamo išdirbio rodiklius.

Praktinė vertė

1. Modelis yra patikrintas eksperimentinėje oro uostų aibėje ir gali būti taikomas oro uosto infrastruktūros plėtros sprendimų priėmėjų praktinėje veikloje.
2. Sukurtas oro uostų bendrojo eksploatacinio efektyvumo vertinimo metodas tinkamas eksperimentams su tikrais ir menamais parametrais. Sukūrus virtualius techninius oro uosto atskirus parametrus panaudojant modelį galima nustatyti jo būsimą oro uosto bendrąjį eksploatacinį efektyvumą kitų toje pačioje imtyje lyginamų oro uostų atžvilgiu.

Ginamieji teiginiai

1. Pateiktas originalus metodas oro uostų bendram palyginamajam eksploataciniam efektyvumui nustatyti ir vertinti. Pagal metodą eksperimentinėje oro uostų aibėje galima palyginti kelių toje pat aibėje esančių oro uostų bendrąjį eksploatacinį efektyvumą.
2. Duomenų apgaubties analizės metodo patobulinimas pritaikant *Delphi* metodą rodiklių atrankai ir svertinių dydžių įvedimas daliniais eksploatacinio efektyvumo rodikliais suteikia galimybę palyginti įvairaus dydžio oro uostų bendrąjį eksploatacinį efektyvumą.

Disertacijos struktūra

Disertaciją sudaro įvadas, 3 skyriai, išvados, literatūros sąrašas, publikacijų sąrašas ir priedas. Bendra disertacijos apimtis – 98 puslapiai, joje yra 22 paveikslai ir 22 lentelės. Pirmajame skyriuje pateikta oro uostų eksploatacinio efektyvumo teorijų analizė remiantis įvairiais užsienio autoriais. Išanalizuoti taikomų teorijų trūkumai, išnagrinėti naujausi mokslo pasiekimai duomenų apgaubties analizės srityje. Antrasis skyrius skirtas tobulinti duomenų apgaubties analizės metodą oro uostų bendrojo palyginamojo eksploatacinio efektyvumo nustatymui. Duomenų apgaubties analizė patobulinta vertės teorijos sprendiniais ir dviejų pakopų *Delphi* apklausos metodu. Trečiajame skyriuje pateikti atlikto eksploatacinio efektyvumo palyginimo patobulintu duomenų apgaubties analizės metodu eksperimento rezultatai 15 realių oro uostų aibėje.

Bendrosios išvados

1. Atlikus mokslinės literatūros, nagrinėjančios oro uostų eksploatacinio efektyvumo vertinimo metodus, nustatyta, kad egzistuoja rodiklių aibės nustatymo problema ir duomenų gavimo problema, kurioms spręsti tinkamiausia pasitelkti vertės teoriją ir neparаметrinio vertinimo metodiką. Eksploatacinio efektyvumo vertimas neparаметrinio duomenų apgaubties analizės metodu pagal dalinius rodiklius yra plėtojamas mokslininkų, tačiau oro uostų eksploatacinio efektyvumo palyginimas pagal apjungtuosius rodiklius lieka mokslinė problema, kuri ir sprendžiama šioje disertacijoje.
2. Oro uostų infrastruktūros eksploatacinį efektyvumą apibūdina aibė rodiklių, turinčių skirtingą svorį. Dviejų turų vertinimo ekspertiniu *Delphi* metodu metu dešimtbalėje sistemoje nustatyta, kad tirtų oro uostų aibėje reikšmingiausias rodiklis yra per metus aptarnautų orlaivių skaičius oro uosto teritorijos plotui, o jo reikšmingumo koeficientas yra 8,6. Kiti reikšmingiausi tyrimo metu atrinkti rodikliai yra per metus aptarnautų orlaivių skaičiaus santykis su pakilimo takų skaičiumi (reikšmingumo koeficientas yra 7,47); per metus aptarnautų keleivių skaičiaus santykis su pakilimo takų skaičiumi (7,00); per metus aptarnautų keleivių skaičiaus santykis su oro uosto teritorijos plotu (6,87); per metus aptarnautų orlaivių skaičiaus santykis su ilgiausio pakilimo tako ilgiu (5,73).
3. Palyginamojo eksploatacinio efektyvumo skaičiavimais duomenų apgaubties analizės metodu pagal apjungtuosius rodiklius nepritaikius svertinių koeficientų nustatyta, kad iš Baltijos jūros regione vertintų oro uostų didžiausias eksploatacinis efektyvumas yra Kopenhagos – rodiklio reikšmė 92. Vilniaus oro uostas 7–9-oje vietoje eksperimentinėje oro

uostų aibėje (rodiklio reikšmė yra 54), Palangos oro uostas – 11 (52), Kauno oro uostas 14 vietoje (33), paskutinėje 15 vietoje Minsko oro uostas (20).

4. Palyginamojo eksploatacinio efektyvumo skaičiavimais duomenų apgaubties analizės metodu pagal apjungtuosius rodiklius pritaikius svertinius koeficientus nustatyta, kad iš Baltijos jūros regione vertintų oro uostų didžiausias eksploatacinis efektyvumas yra Kopenhagos – rodiklio reikšmė 514,6. Vilniaus oro uostas 7-oje vietoje (rodiklio reikšmė – 328,6), Palangos oro uostas – 11 vietoje (312,8), Kauno oro uostas 13 vietoje (213,4), paskutinėje 15 vietoje Minsko oro uostas (141,2).
5. Santykinio indekso įvedimas analizuojant duomenų apgaubties metodu, leidžia atsiriboti nuo dimensijų, kurios būdamos skirtingos skirtingiems eksploatacinio efektyvumo rodikliams keldavo dalinio eksploatacinio efektyvumo agregavimo į bendrąjį palyginamąjį eksploatacinį efektyvumą pagal jungtinius rodiklius problemą. Santykinio svertinio indekso įvedimas, leidžia tiksliau įvertinti bendrąjį eksploatacinį efektyvumą pagal apjungtuosius rodiklius.

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ESTIMATION OF AIRPORT INFRASTRUCTURE EXPLOITATION
EFFICIENCY BY UPGRADED DATA ENVELOPMENT ANALYSIS

Summary of the Doctoral Dissertation
Technological Sciences, Transport Engineering (03T)

Ilona JARŽEMSKIENĖ

ORO UOSTŲ INFRASTRUKTŪROS EKSPLOATACINIO EFEKTYVUMO
VERTINIMAS PATOBULINTU DUOMENŲ APGAUBTIES METODU

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