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Prospects for Operational Efficiency of European Regional Airports in Passenger Air Transport

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Declaration:
Hereby I declare that this doctoral dissertation, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for doctoral or an equivalent academic degree.

Allan Nõmmik

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signature

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ALLAN NÕMMIK

KIRJASTUS

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List of Publications

The list of the author's original publications, on the basis of which the dissertation has been prepared to fulfil the requirements for the PhD degree of Tallinn University of Technology:

- Nõmmik, A.; Kukemelk, S. (2016). Developing gravity model for airline regional route modelling. Aviation, 20(1), 32–37. (ETIS 1.1.).
- Nõmmik, A.; Antov, D. (2017). Modelling Regional Airport Terminal Capacity. Procedia Engineering, 178: 16th Conference on Reliability and Statistics in Transportation and Communication, RelStat'2016, 427–434. (ETIS 3.1.).
- Pashkevich, A.; Nõmmik, A.; Antov, D. (2017). Competitiveness Analysis of Regional Airports Based on Location Planning Models: the Case Study of Finland. In: Proceedings of the 21st International Conference, Transport Means 2017, 754–761. (ETIS 3.1.).
- Nõmmik, A. (2019). Trends in development of aircraft for regional routes: impact on the european air transportation system. Conference proceedings: 13th Research and Education in Aircraft Design. Brno. (ETIS 3.1.)
- Nõmmik, A.; Antov, D. (2020). European Regional Airports: Factors Influencing Efficency. Transport and Telecommunication, 21(3), pp 211–220. (ETIS 1.1.).

Author’s Contribution to the Publications

Contribution to the papers in this dissertation are:

- Publication I. The manuscript’s original idea was generated, method developed and calculations as well as the essential part of both, theory elaborated and conclusions drawn by the author.
- Publication II. The manuscript original idea been created by the author. The research plan incl. goals been design in cooperation with the supervisor Dr Dago Antov. The data collection, analysis and result interpretation performed by the author.
- Publication III. The author of this dissertation contribution been in study design, incl. goals, theoretical background and data collection. The presentation of the results on the conference been done by the author.
- Publication IV. The author of this dissertation is the only author of this manuscript. The conference presentation was also made and given by the author.
- Publication V. The paper original idea was generated by the author. The research plan incl. goals were designed in cooperation with the supervisor Dr. Dago Antov. The data collection, analysis and result interpretation were performed by the author.

Introduction

The vital role of airports – to serve as access points in the infrastructure of air transport industry in today's economy – is confirmed by professional organizations, public institutions as well as by numerous scientific researches. The key function of airports in the transportation of passengers is paramount important not only for the economy but also for the functioning of the society as a whole.

Liberalization of the air transport market in Europe gave an additional impetus to the air transportation growth. By fostering competition not only among airlines but also among airports, the liberalization of the airline market has given rise to many changes such as the emergence and aggressive growth of low-cost carriers, bankruptcies and airline mergers (Burghouwt, et al., 2015). The above mentioned growth did not affect all airports in Europe and frequently the development and also existence of some regional airports were called into question (Lian, Rønnevik, 2011; Nõmmik, Antov, 2017). On the other hand, it has been found (Redondi, et al. 2013) that the importance of small European airports in ensuring people's mobility depends on the availability of alternatives, including other larger airports in the vicinity, and also varies from country to country. Small airports in countries on the periphery of Europe also play a particularly important role in ensuring accessibility, even though a small proportion of the population is affected which in turn raises the question of efficiency of regional airports.

Despite the liberalization of the air transport market, the air transport industry has been and remains highly regulated in terms of technical and operational aspects of its activities. This is based on the need to ensure the necessary safety, security but also the required level of service.

Nowadays' opportunities for benchmarking and simulation technologies doing ease the planning of airport infrastructure and operations planning process. However, it is essential to take into account the specificity of the planned infrastructure in order to achieve an adequate result.

The main goal of this dissertation is to analyse and to identify the main factors and parameters which can contribute to the efficiency of European regional airports and to specify their prospects from the passenger-carrying point of view.

The importance of this dissertation arises from its focus on the following considerations:

1. Airports are playing a great role for local economy. It has been asserted, in studies on the airports' role in economic development in specific circumstances (ICAO, 2005; Dusek, et al., 2011) as well as on the impact of different air services or on specific sectors (Button, Taylor, 2000; Button, 2010; Donzelli, 2010).
2. Legislation: The European Commission starts focusing on the regulation of public investments in European airports (European Commission, 2014) to ensure more private investments for renovation and development of the airports, which raises the question of the sustainability of airport operation with improving of air connections to the local communities (European Commission, 2017) where efficiency plays a key role (European Commission, 2015).
3. Recent studies highlight the loss of traffic at small airports (Dziedzic, et al., 2020; Červinka, 2019) or the difficulty of launching air traffic in Europe (Kazda, et al., 2017).
4. Relatively low regional airports' efficiency. Several studies have highlighted relatively low regional airports' efficiency (Adler, et al., 2013; Augustyniak, 2009; Curi, et al., 2011).

5. All Estonian airports could be classified as regional airports. That is why this study has direct practical value for the development of the Estonian air transport system.

In accordance with the main goal set for this dissertation, the following research tasks (RT) were formulated:

1) to analyse the variations of term "regional airport" used in scientific and specialized aviation literature to determine the object of research (RT1);

2) to propose and implement the models for evaluation of airport perspective based on airport location (RT2);

3) to identify the factors that affect the operational efficiency of regional airports. (RT3).

The working hypotheses of this dissertation (H-null) were formulated as follows:

H1: The prospects of a regional airport in terms of passenger transportation can be described both, in terms of location relative to settlements, and as a potential destination in the air transport network.

H2: The peculiarity of European regional airports is affected by industry specifics, including the impact of regulations, returns to scale effect and industry trends.

H3. Heterogeneity can be characterized not only by spatial factors but also by operational features of regional airports.

The scientific novelty of this dissertation is the multilateral identification of factors affecting the effectiveness of regional airports, with the introduction of practical and regulatory aviation aspects. The research models and approaches proposed in the dissertation as well as the collection and analysis of empirical data was compiled in accordance with the possibility of subsequently building complex models of passenger service through regional airports using a simulation software.

Based on the aforementioned, this research gives an overview of different approaches to regional airport classification and comprehensively examines the issues of infrastructure planning and operations of regional airports, which includes the following: assessment of the location of airports and air routes planning; airport terminal capacity and airport capacity with its returns to scale effect; impact of aircraft development trends, traffic characteristics and regional airport business profile on operational efficiency.

Abbreviations

ACI	Airports Council International
APM	Air Passenger Movements, served passengers (departed and arrived)
ATM	Air Traffic Management
DEA	Data Envelopment Analysis
EU	European Union
FAA	Federal Aviation Administration (US)
EPRS	European Parliamentary Research Service
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
LCC	Low Cost Carrier
LOS	Level of Service (IATA/ACI concept for airport terminal facilities)
MRO	Maintenance, Repair, Overhaul
MTOW	Maximum Take-Off Weight
OMGWS	Aircraft Outer Main Gear Wheel Span
PSO	Public Service Obligation
RT	Research Task
SARP	Standards and Recommended Practices
SFA	Stochastic Frontier Analysis
SLOT	permission given to airline for the purpose of landing or take-off at airport on a specific date and time
TM	Air Traffic Movements
US	United States of America

1 The research structure and theoretical framework

1.1 Research structure based on the publications

This dissertation is based on 5 publications cited earlier. The relationship of research tasks with publications is shown in Figure 1.

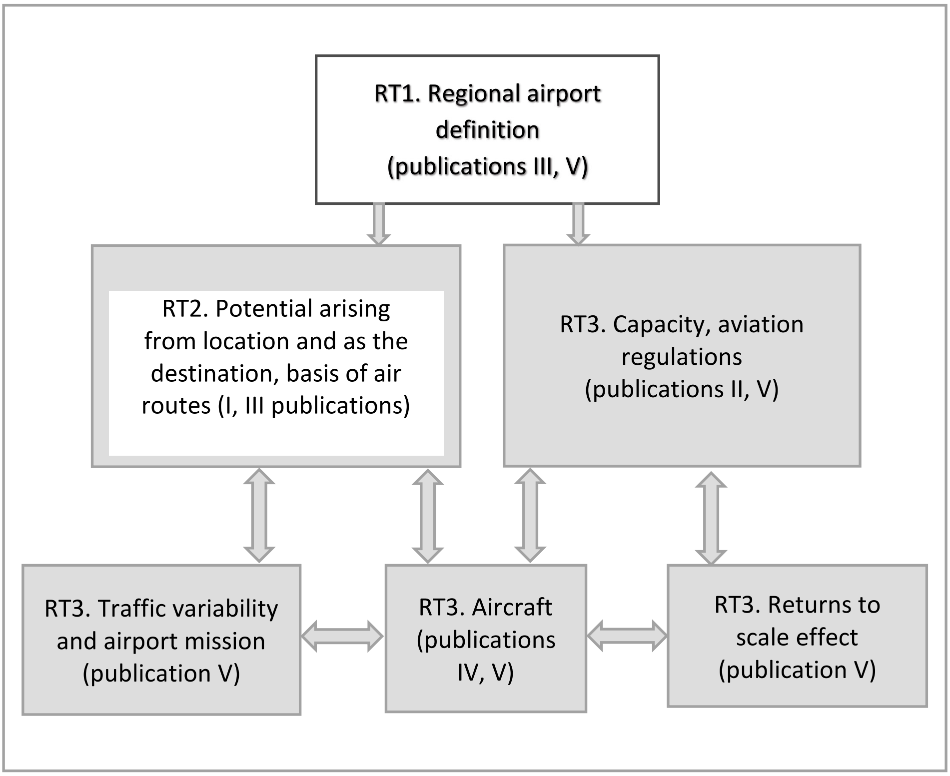


Figure 1. Structure of the research based on RTs and author publications (author's compilation).

In accordance with the main goal of this dissertation, **publication I** (see Appendix) describes the structure of air transportation with gravity model, which can give different uses: an opportunity to determine the regional airport potential in air transport network and be the basis for assessing the impact of the fleet on the number of routes to the destination airports and/or the frequency of air traffic. The scientific novelty is the use of the gravity model in the conditions of a deregulated air transportation market. Also tested the possible uses of this model when the distance is measured both in kilometers and in flight time. Along with a quantitative study, the publication considers theoretical issues of applying the gravity model, including from the point of view of scientific philosophy. A discussion was also presented on the applicability of the gravity model for the analysis of air traffic and the planning of routes from a regional airport.

Publication II is directly related to the throughput capacity of the terminal of a regional airport, which was examined by the example of departing passenger service. Along with the description of the specifics of regional airports and the recommendations of IATA (International Air Transport Association) which done in LOS (level of service) concept, special attention was paid to the behavioral characteristics of passengers based on the profile of their trip. In addition to collecting and analyzing empirical data, the study is structured so that the results can be applied to build simulation models of dynamic capacity for passenger service in regional airport.

The potential of the airport is the basis for both: a political decision on its feasibility as well as planning infrastructure for passenger transportation and for planning the operation of the airport as a whole. Two models have been proposed to assess the potential of regional airports in terms of location relative to the settlements of **publication III**. For test the models, Finland was chosen as a country with a large number of regional airports. As in the case of the gravity model in publication I, the main parameter characterizing the airport from the point of view of practical indicative potential is the annual passenger flow indicator APM (Air Passenger Movements), which facilitates the pairing of both models when building an integrated modeling of passenger flows. The theoretical part of publication III also presents material on the functionality of regional airports.

The focus of the study of **publication IV** is the problems of equipment – aircraft for regional routes. This article gives a historical excursion on the formation of a class of regional aircraft as a result of the liberalization of the transportation market, primarily in the US (United States), and generalizes the conditions for its formation at present. The dynamics of the evolution of aircraft of this class in terms of fuel efficiency in the category of regional aircraft and changes in the fleet of European airlines been presented. The differences between the US and European markets and the effect of the current situation on the air transportation network in Europe, including those which based on Public Service Obligation (PSO), also been given.

Publication V has the task of considering the effectiveness of regional airports as a publication that is binding and generalizing for previous ones describes the terms and concepts used in the scientific or specialized literature for regional airports. The operational efficiency of regional airports, which is the topic of this dissertation, is examined from different sizes: ICAO (International Civil Aviation Organization) SARP (Standards and Recommended Practice) for airfield planning, the returns of scale effect on the example of the airport' apron, the dependence of traffic seasonality on the airport profile, design trends of narrow-body aircraft and the impact of LCC (low-cost carriers).

1.2 Air transportation market liberalization and approaches for regional airport classification

Liberalization of air transportation market in some sources called deregulation (Goetz, Sutton, 1997) has played an important role in the modern spatial pattern of air transportation. Prior to liberalization, airlines were not free in many aspect of operations, including choosing of operating routes as well as of pricing, since this issues were administered by the relevant authorities (Button, 2001). The argument for this regulation were, in addition to the need of ensuring of aviation safety, been the opinion about the need for regulation of the market as such. Liberalization has its origins in the US air travel market, which began in 1978 (Goetz, Sutton, 1997) and was also extended to international routes from US in 1979 (Oum, et al., 2010). It should be noted separately that due to the earlier liberalization of the U.S. market, it is the influence of liberalization on the air transportation market that is the starting point for analyzing similar processes in other countries (Gudmundsson, 2011; Wang, et al., 2019). It should also be emphasized that due to the fact that the volume of the US market is commensurate with the

European air transport market, relevant comparative analyzes are often provided, for example, to assess operational performance of ATM (Air Traffic Management) systems (Eurocontrol, et al., 2019) or characteristics of airline networks in North America and Europe (Reynolds-Feighan, 2010).

In Europe, market liberalization took place later and in three stages (Button, 2001). A distinctive feature from the US market, where in fact there was a single market, air transportation between European countries was regulated by the so-called bilateral agreements, which implied the existence in each country as a national air carrier, as a rule, belonging to the state and airports, as a rule, the main airports through which international air transportation was possible. In this way, airports that were considered secondary or regional with the creation of a single liberal market in Europe received the opportunity to open international air traffic. On the other hand, if earlier national carriers, having exclusive rights on international airlines, had also obligations to serve the routes from regional airports in the prescribed volume, then under the new conditions, operating from regional airports has become a matter of a free market (Button, 2001), in other words, of commercial expediency. In addition to this, if earlier the question of the profitability of regional airports did not attract much attention, in the new conditions the question of their feasibility and efficiency has arisen more and more often in terms of competition between them (Pavlyk, 2012) as the development of high-speed rail traffic in Europe (Terpstra, Lijesen, 2015).

Table 1. List of regional airport definitions to specify the meaning of regional airport.

Concept	**Description**
Domestic	Airports which are servicing only domestic flights; in modern sources mainly used by US, Russia or other big countries
Destination	Airports whose business model consists in providing service for the local community
Feeder	Same as *destination* airport, servicing the feeder flights to the hub airports
Non-hub	Same as *destination* or *feeder* airport, which is opposite to the hub; with no or minimal transit or transfer traffic
Periphery	Located far from large centres of agglomeration, using the term *remote*/ the opposite of the core airport/ to denote smaller competitors servicing nearby hub airports
Remote	Airports in remote locations, which are separated from settlements with larger population either by distances, or / and due to lack of road and rail transport connections
Small	By some criteria: smaller than others, generally airports with lower volume of traffic, servicing small and medium-size settlements
Secondary	Either non-main airport or non-hub airport - the opposite of the main airports, oriented to servicing the own catchment area

Source: (Nõmmik, Antov, 2020; author's adoptions)

Airports that can be classified as regional may sometimes be referred to, using other terms, in different or even in the same text. The listed classification criteria are often interrelated. Possible designations of regional airports as well as their descriptions are listed in Table 1.

From a functional point of view, airports are divided into hub and non-nub airports. If hub airports with a significant number of transit passengers play a connecting role in the global air transportation network, then non-hub airports are finishing points serving their catchment area. Theoretically, if the airport has two routes to different destinations, then they can be interconnected and the airport can work as a hub (Grosche, et al., 2007). In practice, as a rule, especially in a liberalized air transportation market, the operation as a hub airport requires a number of conditions, such as the availability of the based airline which is working on a hub and spoke strategy, as well as a certain critical number of routes or traffic at all. Also, airports can compete for transit flows, either as a hub or for expanding the catchment area to neighboring airports, or simply for routes with other airports of similar profile.

When there is no traffic transfer at the airport, in terms of the air transportation system, the airport is a final destination. This means that at these airports passengers are transported on a point-to-point basis or the so-called feeder routes to hub airports.

From the point of view of airport location, it is understood that the regional airport is not located directly near large cities or metropolitan areas, or the city near which the airport is located is not a large center, or is itself on the periphery, which excludes work as a hub. Most often, from this point of view, the regional airport is on the periphery, including in places where movement with other modes of transport is complicated or the latter have low competitiveness in comparison with air transport. However, there may be differences when the location of a regional airport can be called significantly remote from large centers, and in this case it is understood that the airport in terms of functionality is not basic for a large center not so distant from it. But in both cases, a secondary role of these airports in the transport system can be implied.

Other approaches as summarised by Červinka and Matušková (2018) on sources (ACI EUROPE, 2017; ICAO, 2016), which consider the figures of annual traffic, the size or characteristics of the catchment area of an airport, are not valid indicators for defining the regional airport. Offered are the criteria, such as primary to serve routes like "short and medium" in hub and spoke network or "point-to-point destinations" (ACI EUROPE, 2017). Note that the absence of longer routes in this definition can be attributed to both, the inability to fill, as a rule, bigger, wide-body aircraft on designated routes, due to insufficient demand for point-to-point travel, and thus, the need to operate as a hub airport for these purposes. If, by definition given by Airport Council International (ACI) EUROPE (2017), a regional airport should be limited by the range of routes, then it can be assumed that there is a relationship between the size of the airport and the range of flights to destinations to which they can exist on a sustainable basis at that airport.

Table 2. Regional airport joint criteria and characteristics.

Criteria	**Characteristic**
Functionality	hub/non hub
Location	agglomeration/remote; core/periphery
Size	big/small number of passengers served
Role in air transport system	global/local; main/secondary.

Source: (author's compilation)

Considering the airports in terms of passenger transportation, these airports are divided by functionality, location, or size and traffic volume. Based on the above concepts, it is possible to characterize the regional airport in terms of four criteria parameters, which are presented in Table 2.

1.3 Airports' sustainability

These days the European airports are centres of transportation system providing both, much-needed mobility in the globalized world, and an objects for optimization of the airport network. If major airports meet the problems of ensuring the capacity (Balliauw, Onghena, 2020) the secondary ones, often called "regional" airports, are faced with problems of efficiency incl. operation (Augustyniak, 2009). The issue of existence of regional airports, unless they also perform other public functions, is highly dependent on political decisions, especially with regard to regional development, which includes the mobility of the population. In view of the possibility of achieving the above goals by other transport modes or with optimizing the number of airports, the question of airports' viability arises. One of the criteria may be a sustainable passenger traffic that helps the airport to cover its operational costs.

Table 3. Airport annual traffic and ability to cover the costs.

Annual passenger traffic, APM	**Ability to cover their capital costs**	**Ability to cover their operational costs**
up to 200 000	unable to cover costs to a large extent;	unable to cover costs to a large extent
from 200 000 up to 700 000	unable to cover costs to a large extent	unable to cover costs to a substantial extent
from 700 000 up to 1 million		unable to cover their operating costs to a greater extent
from 1 up to 3 million	able to cover costs to a greater extent;	able to cover the major part of costs
from 3 and up to 5 million	in principle, able to cover all their costs to a large extent	profitable at operating level
more than 5 million	usually profitable	

Source: (European Commission, 2014; author's adoptions)

The European regulation 2014/C 99/03 "Guidelines on State Aid to Airports and Airlines" classifies the airports according to their ability to cover their operations and capital costs. The summary of the regulation is provided in Table 3. Note that the category of airports with passenger traffic from 200 thousand passengers to a million, on the one hand, has proved its worth in terms of the ability to cover most of the current operating expenses, but on the other hand, it still depended on other financial resources. The criteria for classifying an airport can be summarized as follows (Adikariwattage, et al., 2012): functional role which the airport is going to play in transportation system in general, and in air transport, in particular; the size measured by traffic figures; geographical location of airport; competition conditions for airport. However, the criteria in this list are often interlinked.

1.4 Airports efficiency measuring and heterogency

Regardless of the situation, the ambitious plans for the regional airport or merely the task of minimizing costs, the issue of infrastructure's reasonable sufficiency as well as operational efficiency are the key questions for regional airports nowadays. They all have provided exemplary ground for research. From the point of view of airport development for efficiency of operations, the assessment of airport performance, taking into consideration the technical performance indicators, is widely used in research literature (Pabedinskaite, Akstinaite, 2014).

The efficiency indexes are constructed on the basis of input-output relationships (Pavlyk, 2014). The broad overview of the research related to airport efficiency has been given by Pavljyk (2015) that includes a review of 96 studies related to airports efficiency. The infrastructure-related indicators for measuring the input has been used for terminal area, runways' number or length or area, aircraft stands number or area and also the terminal infrastructure: number of gates, check-in desks and baggage belts. The indicator of output more frequently used for air traffic movements (TM) or air passenger movements (APM). (Nõmmik, Antov, 2020; Gutiérrez, Lozano, 2016; Pavljuk, 2015).

The research methods widely used for airport efficiency analysis are stochastic frontier analysis (SFA) and data envelopment analysis (DEA) (Pavljuk, 2015; Lo Storto, 2018; Carlucci, et al., 2018) Both approaches are popular for the estimation of efficiency (Hjalmarsson, et al., 1996). However, they are sometimes criticized for their ineffectual indication procedure, when inefficiency is indicated without identifying its causes, for sensitivity to the quality of input data (Barros, et al., 2013), or for explicit assumptions which occurs due to not taking due account of all technological and other features (Frohloff, 2007). Recent studies with applying SFA also have taken into account heterogeneity in spatial effects (Pavljuk, 2015), after which the results may have improved indicativeness but do not always show specific causes.

Comparing the data on a large number of different airports, conclusions are drawn on the efficiency of airports in different countries or/and different factors. Given the diversity of airport operating profiles and the varying operating exogenous conditions (Chaouk, et al., 2020) in the various countries and the different sizes of airports, they can be basically conditionally considered as operating under conditions of homogeneity. Moreover, in the case of regional airports, the share of passenger traffic compared to other activities may be much lower than at large airports. In such a situation, the issue of data uniformity also arises. Based on this assessment, conclusions must be drawn for a particular airport based on local circumstances where important details and reasons may not be provided by generalized analysis. Also, large-scale benchmarking raises also questions about data availability and quality as well as airport industry diversity and heterogeneity. As with any activity, it is important to consider the returns to scale effect of the industry.

At the same time, it is important to take into account the circumstances arising from the nature of the traffic. Previous studies (Zuidberg, 2017) have addressed various factors that may affect airport efficiency and profitability. Among them, the variability of traffic depends on the seasonality which is affected by the orientation of airports to serve inbound tourism or the profile of serving airlines like LCC whose activities are less affected by the seasonality of demand (Fernández, et al., 2018).

The concept of airport competition has also been expanded significantly. Competition between airports in the early research (Borins, Advani, 2001; Pavljuk, 2014) has been addressed on two levels which can be expressed as:

- transfer traffic through airport, which is a part of airline strategy or/and self-help hubbing;
- catchment areas by better connectivity or routes' network, improving accessibility, servicing LCCs, etc.

A wider approach taken by Jimenez, et al. (2014) offers more areas of competition for airport industry. In addition to those mentioned above and the competition with other transport modes, the new suggested areas of competition between airports are outlined as follows:

- attracting of airlines to use the airport like a hub or base;
- destination competition for inbound traffic, especially as a tourism destination;
- global competition for aviation and non-aviation tenants or other partners;
- competition for funding, especially if this is a government-owned company.

While in the earlier studies (Borins, Advani, 2001) it has been found, that privately owned airports were more market oriented and demonstrated higher growth efficiency and profit than the governmental ones, especially in small and recently privatized airports (Augustyniak, 2009). Other sources have stated that government-owned airports sometimes display higher efficiency (Scotti, et al., 2012; Gutiérrez, Lozano, 2016).

Due to airports' different ownership or management structure, aviation and other activities, size and operational environment, the ACI (2012) concludes that for individual airports different performance indicators have to be applied. However, the activities' profile incl. specific activities are the basis of airport planning (Medvedev, et al., 2017; Rotondo, 2019).

Airports can carry out various commercial as well as other tasks that could conditionally be listed as:

- passenger transportation by scheduled and charter flights;
- transportation of cargo;
- servicing business and VIP aviation;
- servicing training flights;
- offering the infrastructure for non-business aviation or for private general aviation;
- servicing agricultural aviation;
- offering aircraft parking for leasing companies and MROs;
- other functions, listed below.

Other functions can be added to those above, as well as base or back-up for the activities such as:

- medical and search and rescue flights;
- firefighting and environmental monitoring flights;
- law enforcement and border patrol;
- military aviation.

All of the above activities can use both, similar and special types of aircraft. Different types of activities have their own profile in terms of the activity of using the infrastructure of the airport, such as the runway and aircraft stands. Also, different activities in different environment can differently generate aeronautical and non-aeronautical revenues. Of the other activities listed, especially air cargo sometimes is highlighted (Beifert, 2015) as important for improving efficiency, but this market niche cannot be taken into account to all regional airports (Nõmmik, Antov, 2017) due including, therefore, the preference of shippers to use larger airports due to a greater number of destinations and flights but also better service (Alkaabia, Debbageb, 2011). Additionally, just passengers transport will be usually for regional and ineffective airports the basis for decision making for existence and subsidizing from government or municipalities (Debyser, 2016; Rodrigue, 2017).

1.5 Requirements for airport infrastructure and operation

Despite the fact that the air transport market in the EU has been liberalized, airport infrastructure and operations have been, are and will remain largely regulated by different requirements and airlines' service standards.

The main international aviation document is Annex 14 of The Convention on International Civil Aviation (ICAO, 2018), in which, among other standards and recommended practice, the minimum technical requirements for aerodromes' infrastructure for servicing aircraft are formulated. In this document, the planning of airport infrastructure is based primarily on the need to ensure the required operating conditions for the aircraft. For example, the aerodrome reference code, aircraft outer main gear wheel span (OMGWS), or aerodrome categories for rescue and firefighting shall be determined according to the aircraft characteristics which the airport plans to serve. Table 4 gives the aerodrome reference code system which is based on the critical aeroplane (aircraft) "characteristics for which the facility is provided" (ICAO, 2018). For airport design, this code shall be selected, which is based on the aircraft with "highest value of the aeroplane reference field lengths" and the aircraft with widest wingspan that the airport is going to serve (ibid).

Table 4. Aerodrome reference code system.

Aerodrome code (number)	**Reference field length (m)**	**Aerodrome code (letter)**	**Wingspan (m)**
1	Less than 800	A	Up to but not including 15
2	800 up to but not including 1 800	B	15 up to but not including 24
3	1200 up to but not including 1 800	C	24 up to but not including 36
4	1 800 m and over	D	36 up to but not including 52
		E	52 up to but not including 65
		F	65 up to but not including 80

Source: (ICAO, 2018)

Airport terminal planning is not as strictly regulated as the aerodrome infrastructure. However, there is a recommended document Airport Development Reference Manual which issued and is developing by IATA. This document contains recommendations for optimum service level as well as for the design and operation of the airport terminal (IATA, 2015). The established LOS for different passengers' service stages are measured in terms of space and/or time for service. However, this document is more applicable to substantially larger than regional airports. The difference between the latter lies in a number of features such as (Nõmmik, Antov, 2017): limited resources (terminal area, equipment and personnel), a relatively small passenger flow that limits the prospects for non-aviation revenues in the passenger terminal, as well as the relatively worse quality of connecting the airport with the catchment area by public transport.

Airport infrastructure and operational planning are closely related to the aircraft to be serviced. In addition to the operating conditions of the airport, it is the types of aircraft and their configuration that determine, for example, runway parameters (Nõmmik, Antov, 2020). Also, in accordance with international civil aviation regulations, aircraft parameters are the basis for example, for taxiway and apron planning (ICAO, 2018).

The number of departing or arriving passengers on a single flight for a limited time is an input for airport capacity planning. Consequently, the size of the aircraft and traffic characteristics also plays an important role for the regional airport terminal and operation planning.

1.6 Conclusions of Chapter 1

This section summarizes the main outcomes of the preceding chapter. It should be noted that there are no uniform definitions of regional airport (RT1). It has been found, as described in various sources, the aforementioned airports may be classified differently. However, it is possible to cite such general factors as the lack of significant transit passenger traffic and the volume of traffic that meets the conditions of specific studies or is in accordance with the paradigm or purpose of the documents drawn up.

Methods for calculating the effectiveness, such as SFA and DEA, suggest some uniformity as regards the research object. From this point of view, the market should provide conditions for efficient operations. With regard to the regional airports, the key element is availability of aircraft with necessary characteristics and suitable dimensions in the fleets of airlines – potential airport users.

It has turned out that an indicator such as the number of passengers served per year determines the airport's ability to cover the costs of infrastructure investments and financial operations from its own resources. It is worth noting that, based on the European classification, most of the airports in Estonia, with the exception of the Tallinn airport, with an APM passenger traffic of less than 200.000 are in a position where they are unable to cover, with their income, not only investment costs but also their operating expenses. From the point of view of the prospects for the development of these airports, the experience of other airports with a large passenger traffic has been drawn.

Given the heterogeneity of regional airports' missions and conditions of operation, on the one hand, and common regulations on the other, we are interested in how this is reflected in the effect of returns to scale in airport infrastructure and operation planning.

In the conditions of financial deficit, there is a need to increase the efficiency, both in the use of the infrastructure as well as in the operation. In the case of regional airports, although flexibility must be taken into account, still from the point of view of long-term planning, we need to determine the growth potential of the airport in terms of passenger numbers but also in terms of frequencies and destinations. The success of today's airports largely depends on a number of factors, including competition between airports and general trends in the air transport market.

Accordingly, the results of widely used research methods, which require uniformity of airport operating environments, will only be indicative in nature, which often does not indicate the reasons for inefficiency. It is possible to find a solution by carefully selecting the object for benchmark based on the mission of the airport, geographical conditions and the business profile of the operating air carriers. Based on this, we are interested in the parameters of the aircraft, the traffic variability during the year, and the behavior of the passengers due to different travel purposes.

It was found that international aviation requirements for aerodrome infrastructure do not differentiate between airports according to size but is based on the characteristics of the aircraft served. At the same time, international recommended materials for airport passenger terminal planning are, rather, oriented to large airports, and their application is also based on aircraft size, i.e. the number of passengers that should be served for a limited period of time.

2 Research design and results

2.1 Airport potential

2.1.1 Location and access

Ever since the past century, the studies have found (Rodoman, 1981), that the higher the connection speed of the transport mode, the more this transport mode contributes to the territorial concentration of economic activities. Based on this, it can be assumed that the location of the airport determines its positive impact on the economy, including through the effect of agglomeration. On the other hand, the population of the catchment area is the customer base for the airport itself which is important for determining its prospects. However, some research has revealed that the efficiency of the airport has no strong connection with the catchment area of the airport (Dziedzic, et al., 2020) and in some cases even the opposite effect has been found (Merkert, Mangia, 2014). The same research has also revealed that subsidies do not always have a positive effect on airport efficiency.

Based on the definitions of regional airports and the paradigm of competition between them, an assessment of its location is important for determining the prospects of a regional airport. To do this, the following conditions must be provided:

- the research space could be considered conditionally homogeneous, including the conditionally identical level of economic development of the territories as well as the absence of administrative obstacles to the choice of the airport by potential passengers;
- the number of regional airports should be large enough to satisfy the data processing conditions by statistical methods.

Pashkevich, et al., (2017) investigated the potentials of 18 regional airports in Finland in terms of their location relative to settlements. For the research methods P-center and P-median, the distance based facility location planning models, were selected. The P-center model assumes that passengers are using the nearest airport. The P-median model considers that the function minimizes the demand-weighted total distance (Hakimi, 1964; Pashkevich, et al., 2017).

Table 5. Correlation between APM per airports and results of P-center and P median models.

Methods	p-center model without population	p-center model with population	P-median without population	p-median model with population
Spearman's rank correlation coefficient (r_s)	0,24	0,61	0,33	0,46

Source: (author's compilation)

The models have been applied in two different ways: with and without taking into account the size of population in the settlements. The results of the comparative analysis obtained, referred to Pashkevich, et al., (2017) involving the theoretical assessment of the location of airports and their potential expressed with APM by using the Spearman ranking (1), are given in Table 5.

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} d_i^2}{k\,(k^2-1)} \quad (1)$$

where: r_s – the coefficient of correlation, d_i – the difference between the rank of received the theoretical values and ATM observation**.**

The best result is the figure obtained with the P-center model, also by taking into account the population quantity in the settlements. However, one can state a weak correlation between theoretical results and practical ranks of regional airports.

The result is consistent with other research findings and assumptions by which the size of the catchment area depends on the services provided at the airports (Lieshout, 2012). In addition, it is important not only to improve the overall accessibility (Rothfeld, et al., 2019), but also, according to destination-specific passenger profile, there is a need to study in depth the demographic and economic characteristics as well as to assess airport accessibility (Fotheringham, Webber, 1980) for private and public transport from each small town (Gillen, Hazledine, 2015). It should also be noted that all of these factors can change over time, including, dependence on whether and how airports affect the catchment area, which is also heterogeneous in nature (McGraw, 2020), due differences in airport mission and economic or social characteristics of the airport catchment area.

An airport access system is also essential to increase the attractiveness of its services. This system should correspond to the behavioural characteristics of passengers and have sufficient versatility and quality. However, a significant difference was found in terms of passenger preference for arriving at the airport for the connecting flight. It is known, that business passengers from one hand are more sensitive to the travel time at the airport and less sensitive to the price (Pels, et al., 2003a), but from the other hand due the higher penalty for missed flights, they are oriented to larger safety margin compared to those passengers who arrive to connect to flights for non-business, i.e. other purposes (Tam, et al., 2008). The study conducted within the framework of this dissertation (Nõmmik, Antov, 2017) showed a significant difference in the case of regular feeder flights, which are also used by business customers and leisure charters. However, customers of regular flights usually arrived at the airport later than in the case of a holiday charter.

2.1.2 Airport potential for route planning

Along with assessing the location of an airport in terms of determining its prospects, there is also an important role to assess it in terms of potential for air routes. To do this, we need to use the model not only to assess the attractiveness of airports but also to describe the interaction between them.

To study the transportation network or plan new transport connections, provided the data on the destination points are unavailable, a gravity model has been widely used in scientific research and development projects. Like in physics, the gravity model takes into account the potentials of destinations and the distance between them and, generally, looks like the formula (2) shown.

$$F_{ij} = k \frac{P_i^{\alpha} P_j^{\lambda}}{R_{ij}^{\beta}} \quad (2)$$

where: F_{ij}– APM from area of origin to destination area j, P_i and P_j – potentials of the locations i and j; R_{ij} – distance between the locations i and j; k, α (alpha), β (beta), λ (lambda) – empirical constants.

The gravity model is applied in a different way (Grosche, et al., 2007), but can be distinguished from the two main approaches used for air traffic analysis or to predict the success of potential air routes. In the first case, the potential is the number of inhabitants in the catchment area of the airports, which, however, requires the definition of passenger profile. In the second case, however, a parameter characterizing the operation of the airport, such as APM, is taken as a potential. In the latter case, the model takes into account the nature of the passenger as a given parameter.

It should be noted that the modeling based on demographical potentials sometimes does not lead to a positive result (Gillen, Hazledine, 2015) and requires model calibration for each connection. It is necessary to determine the potentials of the locations to attract and generate movements and “friction of distance” or "efficiency of transport between locations" (Rodrigue, et al., 2017). This could explain the nature of demand but requires further, sometimes long-term research of the characteristics like the age, gender, income and consumers’ preferences (Rodrigue, et al., 2017).

On the other hand, those calibrations when excluding a detailed research can be interpreted as subjective and, thus, difficult to replicate for new air routes. New air connections are able to generate more APM but inevitably compete with the existing ones. However, the potential of airports cannot, by their nature, grow indefinitely in the short term while new routes are being launched and, therefore, the variables have to be redefined to characterize the demand. In addition, there is competition between neighboring airports, which, due to the “airport leakage” effect (Suzuki at al. 2003), causes uncertainty in determining the catchment areas of airports, which in turn will complicate the use of this application.

However, a good result is often reached when using the gravity model – an alternative approach, which takes into account the potential number of APM at the airport (Doganis, 2002), essentially moving away from the definition of passenger (Nõmmik, Kukemelk, 2016). In this case, the variables are easily calibrated for all air routes of the same business profile including, for a certain period of time, for also the type of airport being scrutinized. In fact, it has been found that the attractiveness of the airport as a destination depends on the APM indicator and remoteness from the airport of origin, measured as the distance or time of flight (Nõmmik, Kukemelk, 2016). In this case, the potential of the destination airport reflects not only the attractiveness of traveling to and from the airport catchment area, but also for the hub airport, its attractiveness as a transfer point in air transportation system. On the other hand, this application enables to find destinations heaving greater potential, yet blunders when it is necessary to determine the regional airport's own potential. It holds especially true if there is a reason to believe that the potential of the airport catchment area is not reflected in the regional airport APM indicator or that there is no air traffic during the period under review, or it is negligible.

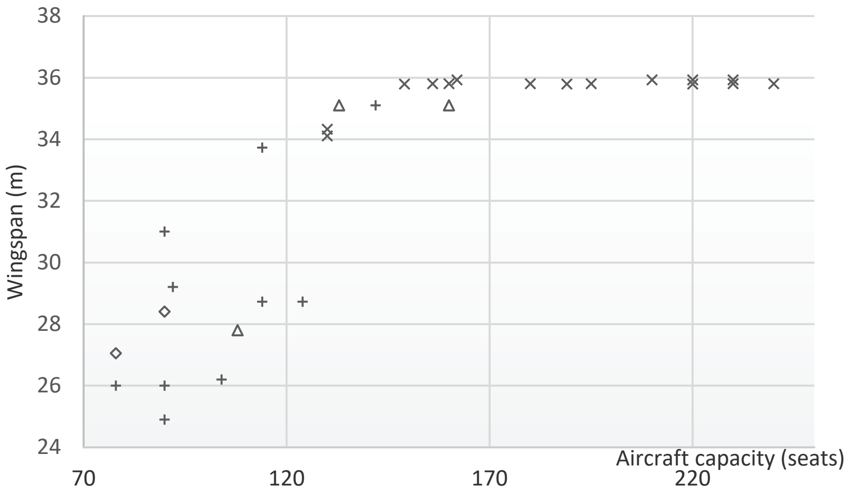
2.2 Aircraft for regional routes

2.2.1 Aircraft and airfield infrastructure

Aircraft characteristics, including the size, are crucial for planning of airfield. Also, the number of seats of the aircraft is an important input for planning the infrastructure and operation of the passenger terminal. Aircraft servicing at the airport, including departing and arriving of passengers, occurs at a limited time. At a certain time period, the airport terminal has to be able to let through and, thus, also provide enough space for serving passengers at different stages of service in accordance with the recommended practices described, for example, in IATA (2015) LOS and on the basis of agreements with airlines.

From these points of view of infrastructure planning, as well as the activities of the airport as a whole, it is necessary to determine what type of aircraft to focus on. Regarding the regional air transportation, it makes sense to pay attention to the design trends of the respective aircraft as well as to the composition of aircraft fleets in airlines – potential operators.

The figure 2 shows a comparative characteristic such as wing span, of the narrow-body aircraft which are currently used or planned to be taken into operation as this characteristic is one of the parameters for planning an airfield.



× - 6 abreast seating aircraft; Δ - 5 abreast seating aircraft; + - 4 abreast seating jet aircraft; ◊ - 4 abreast seating turboprop aircraft.

*Figure 2. Narrow body aircraft wingspan by maximum number of sea*ts. (Nõmmik, Antov 2020).

Note that the wing span of all aircraft with 70 to 240 seats fits in the range from 24 to 36 meters. It can be concluded that if an airport plans to serve 70-seater aircraft or much larger ones, with seating capacity of 200 and up, for airfield infrastructure planning the same reference code C has to be considered (see Table 4). On the one hand, this facilitates the planning of infrastructure from the point of view of multi-functionality and flexibility. However, on the other hand, it should be noted that from the point of view of measuring efficiency, the airports servicing aircraft with a large number of seats and operating a comparable number of TMs, as well as airports oriented to servicing aircraft with smaller capacity, have the prerequisites for greater efficiency by using APM as the indicator of output.

2.2.2 European airlines' fleet development

The emergence and formation of the global fleet of regional aircraft in the form in which we know it today is inextricably linked with the process of liberalization of the air transportation market, which began with the US. It was the deregulation of the market that created the prerequisites for, on the one hand, strengthening of the network model of hub and spoke with growth of hub airports and competition between air carriers and their business models on the other. From the set point of view, determining the perspectives of European regional airports, we are interested in the peculiarities of the structure of air transportation, especially the differences between the US and European markets.

An analysis of Eurocontrol, at al., (2019), which compared the performance of air transport in the United States and Europe shows that with comparable volumes of transportation, there are significant differences. For example, as in 2008 the average number of seats per scheduled flight parameter was 25% higher in Europe, including EU member and associated states, then by 2017 the difference reached 31% (Eurocontrol, et al., 2019). To clarify the reasons, based on the data obtained from the annual forecasts of the Boeing Corporation (2009-2017), an analysis of the change in the amount of regional jet aircraft with less than 100 seats (Nõmmik, 2019) was presented in the figure 3. In recent years, there has been a significant decrease in the number of the aforementioned aircraft in the fleet of European airlines with the stability of this indicator in North America. It was found a number of factors that may affect this process, which ultimately leads to low competitiveness of these aircraft in the European market:

- earlier liberalization of the US market and as a result, regional jet aircraft manufacturers' orientation to the US market;
- North America as the largest market for these aircraft in the world has distinctive features, such as the division into major and regional carriers with different levels of expenses;
- higher profitability of US airlines as well as lower yields on the regional routes in Europe;
- Higher competition from high-speed railways in Europe.

As a result, for example, the fuel efficiency of regional aircraft including aircraft with turboprop engine over the past 30 years has not changed significantly, which on the one hand satisfies the North American market but negatively affects the competitiveness of these aircraft to European market (Nõmmik, 2019). In addition, the existing structure of relations between US airlines and trade unions is an obstacle to the development of this sector, including the negative indirect impact to implementation of new, more environmentally friendly technologies (Nõmmik, 2019).

For comparison, Figure 3 shows the ratio between narrow body aircraft and a regional jet in the fleets of airlines in Europe, North America, based on the Boeing (2009-2017) and extrapolated up to the year 2020, using the time-series method. The growing imbalance in the fleets of European airlines can be noted. As a result, in the fleets of European airlines we witness an increase in the number of mainline aircraft consisting of aircraft of the A320 and Boeing 737 families and the precondition that aircraft of different sizes are available on the market, including those for operating at regional airports, is not complete truth. Similarly, based on the data provided by Eurocontrol, et al., (2019), the average number of seats on aircraft operating on intra-European routes was 149 in 2017, which was increased by an average of 2.1% per year between 2008 and 2017. The corresponding figures for the US market were 114 seats and 1.6%, respectively.

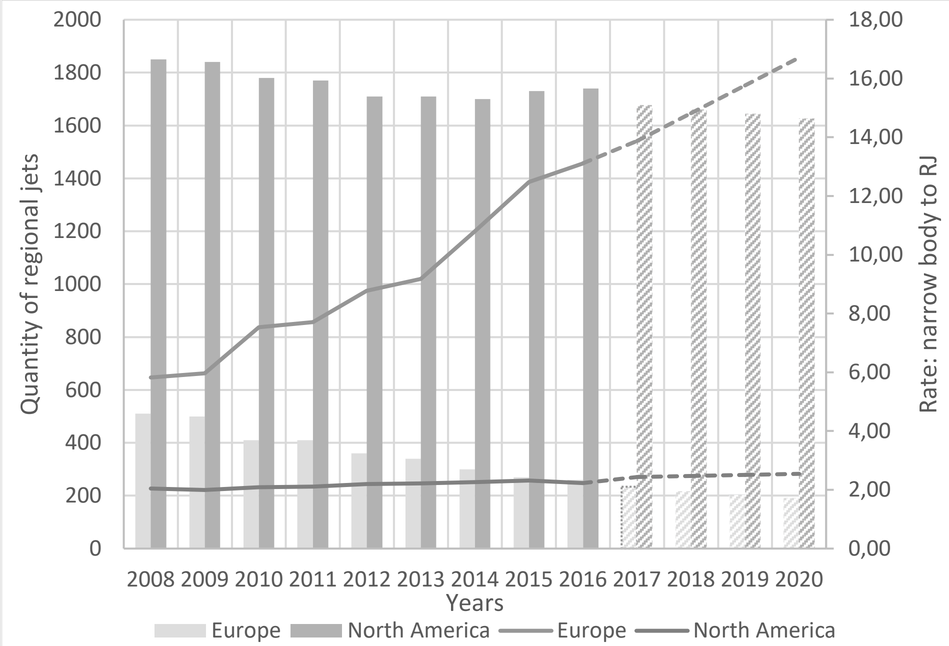


Figure 3. Dynamic of changes regional jet aircraft fleet (Boeing, 2009-2017, authors' compilation).

2.3 Factors affecting airport efficiency

2.3.1 Traffic variability

Seasonality of demand is both an important factor affecting efficiency indicators as well as necessary in planning to ensure airport capacity during peak periods. The research of Reynolds-Feighan (2018) cited data from Official Airline Guide over 20 years shows that the seasonality of traffic in Europe still the highest comparing with world continents.

The main segments of the passenger transport market for regional airports are the following: feeder flights, point-to-point flights, – as a rule serviced by LCCs, and leisure-driven flights (ACI Europe, 2017). Based on the main task of public passengers' transport, the model should exclude other possible activities that airports may be engaged in (Nõmmik, Antov 2020) such as:

- national aviation missions, including support to military flights or SAR and medical operations,
- other commercial aviation activities such as cargo transportation flights, co-operation with MROs and aircraft leasing operations, training flights and other flights linked with business and general aviation.

The analysis provided by ACI EUROPE (2017) concludes some important factors, such as relatively high cost per passenger at small airports and therefore low efficiency at small regional airports while classifying them into three groups: regional airports located in a very competitive area, located in an outermost region of the EU, and regional airports with high seasonality. If the factor related to the location must be taken into account but it is the starting point for the airport, then the issue of traffic variability requires additional consideration as a factor that may depend on the business model of the regional airport. As a rule, forecasts of traffic indicators APM or TM are made on the basis of annual features. However, additional characteristics, such as traffic variability due to seasonality, are needed to plan the airport infrastructure.

Seasonality of demand could be measured in different ways depending on the focus of research. In addition, to popular technique in scientific research as Gini indexes often used coefficient of variation as the ratio between the standard deviation to the mean and seasonality ratio which can be found by dividing the highest value by the average value (Þórhallsdóttir, Ólafsson, 2017). In this case, seasonality ratio is applicable as an indicator of seasonality as helping to identify maximum demand values for infrastructure planning as well as for comparisons with other studies. Note that when adopting a unit for measurement, consider its use in other sources. The Eurocontrol, et al., (2019) analysis on the 2017 data shows that the seasonal variability of air traffic in Europe are less than 1.2.

The seasonality can be an important factor problem both in ensuring efficiency during a low period and in the ability to cope with the increased amount of both TM and APM during the high season. Also the possibilities for reducing costs but also for increasing aviation charges are limited (ACI Europe, 2017).

For the purpose of benchmarking, airport planning is sometimes sufficient as a single, most suitable example. It is important to identify possible differences that bring different business profiles of the airport to the variability of traffic.

In the publication by Nõmmik and Antov (2020), the goal was to compare the seasonality of airports that are specified for various missions. In accordance with the tasks of this dissertation, the airports were selected based on their annual passenger turnover of APM from 200,000 to 1,000,000. In accordance with the regulations of the European Union (European Commission, 2014), the lower level of APM was set as a marker of vitality of operation, and the upper level of APM indicates the regional airports which are still grappling with difficulties to cover their costs solely by transporting of passengers. Likewise, the regional airports that belong to this category have been identified as ineffective, including those with high seasonality of traffic, discussed in the other research (Curi, et al., 2011). While developing this dissertation the following airport groups (Nõmmik, Antov, 2020), were formulated:

(1) 'Remote' airports with their particular geographic location, which complicates competition from other airports. This may include island airports or airports in locations where accessibility by other modes of transport is relatively difficult;

(2) 'Tourism' regional airports which are mainly oriented to servicing incoming tourists oriented;

(3) 'Without LCC' regional airports, which are for a variety of reasons, including inappropriate operating conditions, including high tariffs or excessively modest demand, do not serve LCCs or the operation volume of the low cost carries is relatively small;

(4) 'With LCC' regional airports like a most common, servicing mostly or to a large extent low cost carriers;

(5) 'AL with LCC' regional airports, where specialization is servicing low cost carriers providing competition to nearby airports, including larger hubs. From the lower fares competitive advantage, these airports benefit higher traffic in APM which coming from the so-called airport leakage effect. For this group of airports, the upper limit was raised to the level of 3,000,000 APM per year.

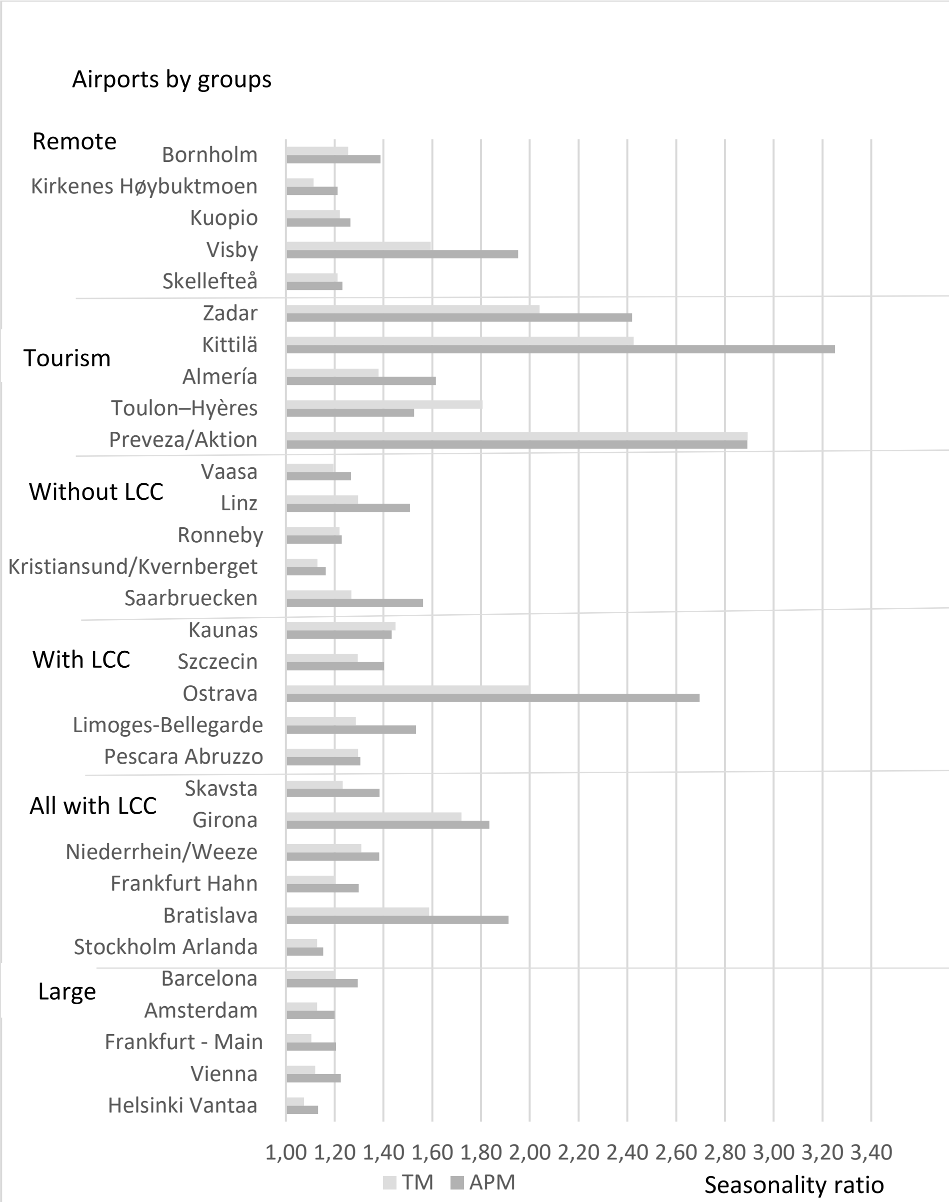


Figure 4. Seasonality in European airports 2012-2019 (author's compilation).

A group of large airports was also assembled, for some of which the regional airports of the 'AL with LCC' group can be considered as competitors. When creating this group, the aim was to compare seasonality indicators with regional airports both, in general, and with the neighbouring regional airport, in particular.

It should be noted that it was difficult to find the appropriate airports in Europe for the "without LCC" group. From this we can conclude that regional airports with the passenger flow indicated in this study usually cooperate with low-cost airlines. This breakdown is conditional as the situation may change over time. Remote regions can eventually be connected with high speed rail links. LCCs may lose interest in some airport as a destination or vice versa (Wit, Zuidberg, 2012). At the same time, tourism-oriented airports may start serving more LCCs instead of seasonal charter flights (Budd, et al., 2014).

The seasonality factor can be a serious problem both, in ensuring efficiency during a low period and in the events of coping with the increased volume of both, operation and passenger traffic during the high season. For the analysis, the Eurostat data have been used – by implementing also the same data processing techniques – yet, by adding data from two more years, in addition to those from the years 2012-2019 that were analysed in Nõmmik and Antov (2020). The results are shown in Figure 4. The highest seasonality indicators were found at airports that are oriented to seasonal tourism in the service area. However, in the present study it has been observed that there is higher variability in APM and TM in regional airports, than in the main airports. Relatively unexpectedly, it turned out to be exceptional that the highest seasonality indicators are possessed by APM not in the south of Europe but in the north, in Kittilä.

Note the differences in seasonality indicators at different airports in each individual group, which indicates the need to carefully select examples for comparative analysis. In the research, it was also noted that the servicing LCC operators have not significantly reduced the variability in the chosen airport group, that is consistent with other research (Fernández, et al., 2018). It can be explained by the fact that in this case the LLC airlines often operate from regional airports as competitors or as replacement for the seasonal charters' flights. It should be noted that there is a very high seasonality at the airport in Ostrava. This suggests that not only arriving but also outgoing tourist traffic can significantly affect seasonality indicators. It should be mentioned that no Estonian airport met the criteria of the study. However, for comparison, the analogous calculations with the data of Tallinn Airport show that the variability values due to seasonality were 1.12 for TM and 1.24 for APM, respectively. The relatively small values of variability are, rather, characteristic of large airports.

2.3.2 Return to scale effect for apron efficiency

In addition, the important aspects for all airports include the ensuring of smooth operation of flights and minimizing aircraft delays. For regional airports the ensuring of extremely high probability of aircraft service is due to the following factors:

- pressure to serve flights at all possible times and to all customers due to underutilization and limited ability to cover their own operating costs;
- pressure from stakeholders to justify the existence of regional airports;
- competition between airports for air connections under which, in the case of non-PSO flights, airlines have bargaining power for the arrival and departure times of the flights.

In order to avoid accounting for inconsistent data, we consider the theoretical model from the point of view of the airport that is transporting only passengers on regular and charter flights.

The model is based on the following conditions:

- the time of arrival of the aircraft is a function not depending on the airport. In the long run, any established flight schedule, even for years, can change, just as an aircraft can be late for reasons independent of the airport, as an example;

- arrivals of aircraft at the apron are independent of one another. In this case, we neglect the possible time for separating the aircraft that are simultaneously approaching incl. the time for the aircraft using runway and taxiway is much shorter than the time needed for service on the apron.

Based on the previous assumptions, we can present the airport apron as a multi-channel Erlang B queuing system (3) (Nõmmik, Antov, 2020). The time of aircraft arrival is a random variable whose probability depends only on the length of time. In this model, the airport's operating time has been limited to 18 hours (from 6 a.m. to 24 p.m.). The average length of aircraft turnaround time is offered as 40 minutes as average of another research (Mirkovic, 2011).

$$p = 1 - \frac{\rho^n}{n!} p_0 \quad (3)$$

for what:

$$\lambda = \frac{TM_f}{T}$$
$$\rho = \frac{\lambda}{\mu};$$
$$p_0 = \frac{1}{\Sigma \frac{\rho^n}{n!}}.$$

where: p – probability of aircraft serving, p_0 – the probability that the channel is free, or a fraction of the idle time of the channels, ρ – utilization factor, μ – service rate, λ – arrival rate, n – number of aircraft stands.

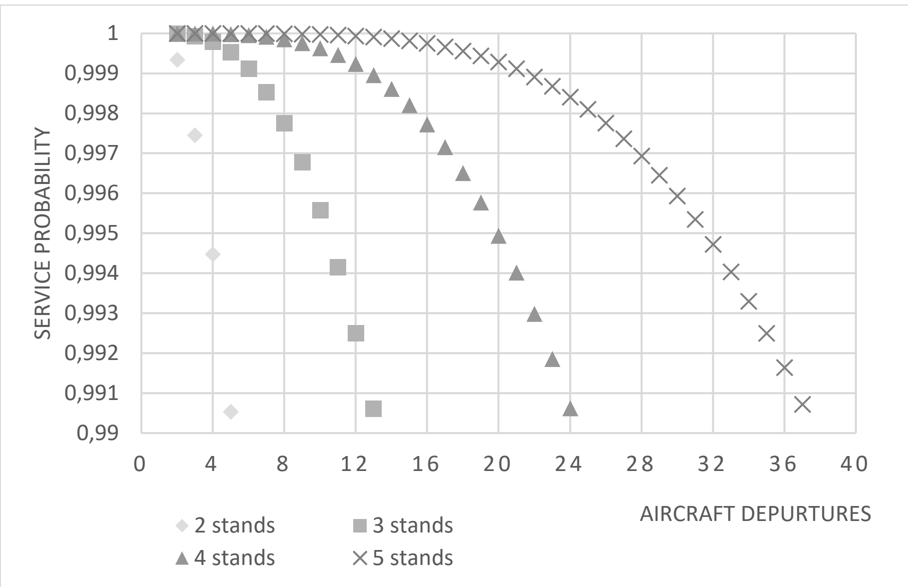


Figure 5. Airport returns to scale effect: aircraft service probability dependence on the number of aircraft stands on the apron (author's compilation).

The results for systems with 2 to 5 aircraft stands are presented graphically in Figure 5. Based on their results, one can see the returns to scale, i.e. the greater ability to service aircraft with higher rates.

To measure the efficiency, been used the formula (4) for calculating the potential channel utilization rate by service (K).

$$K = \frac{\rho * p}{n} \tag{4}$$

The result of the calculation of this model under the condition of very high probability of aircraft servicing (p ≥ 0.995) is shown in Figure 6. It can be noted that by the return to scale effect the higher quantity of aircraft stands allows the airport to serve more aircraft per stand with the same probability of the aircraft getting serviced. There is also a clear effect on the system's capabilities through the efficiency indicator such as the utilization rate of aircraft stands.

From the point of view of the practical application of this model, it is necessary to consider the frequently encountered cases whereby the airport system does not satisfy the conditions, where the flow of aircraft is not uniform and stationary. Based on the structure of air transportation, especially the topology of the airlines' network in the hub and spoke system, the aircraft could be sent from hubs to overnight parking at regional airports (Zeigler, et al., 2017). In this system, the number of aircraft stands should ensure the reception of all aircraft arriving at the regional airport for night-stop, regardless of how many operations are carried out at that airport during the daytime. This condition, in turn, may adversely affect the efficiency of the airport apron.

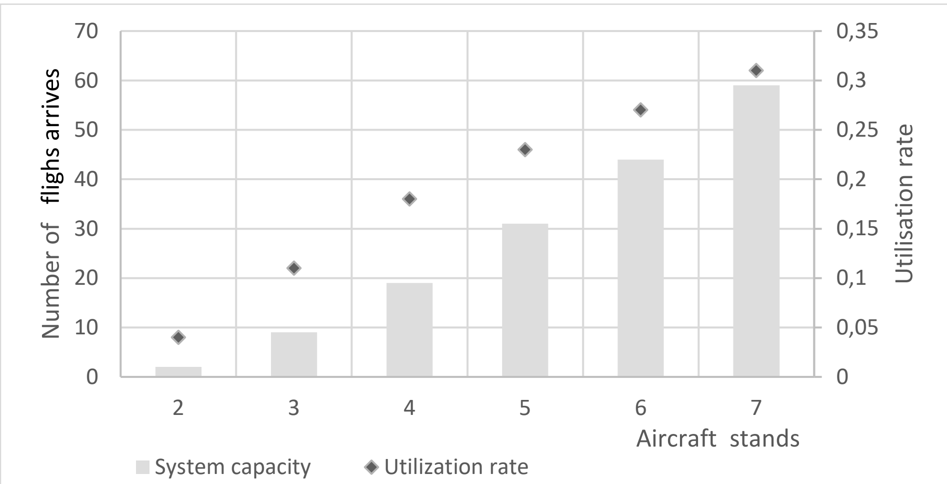


Figure 6. Airport returns to scale effect: aircraft service probability dependence on the number of aircraft stands on the apron. (author's compilation).

It must be admitted that we applied the model in conditions where all activities other than passenger transport have not been observed. In this case, any airport activity of the same scale other than passenger traffic, be it transport of air cargo where the flight intensity is generally lower than in passenger traffic, or co-operation with MRO, which generates relatively less TM but requires aircraft stands on the apron, larger airports have less impact on indicators than smaller airports.

2.3.3 Terminal efficiency and access system suitability

The airport planning issues discussed in the previous paragraph are directly related to the airport terminal. The terminal must ensure the smooth service of both departing and arriving passengers and their baggage, up to the airlines' requirements including the recommended service levels for airports.

It could be noted, that in addition to the requirement for space for passengers and baggage, it is necessary to take into account the possibilities for accommodating the equipment and various services to ensure additional non-aviation income for the airport which, however, is not considered in this dissertation.

Currently, there are many new technological solutions for various stages of passenger service offered in the airport terminal. Their assessment remains beyond the scope of this research, nevertheless, it is worth noting, based on the heterogeneity of airports, that a number of features and conditions affect both, the choice and the rationale for the application of the technological solutions:

- the legislative environment, such features as, for example, the requirement to recognize the identity of the departing passengers or peculiarities which proceed from the airport security program;
- traffic characteristics and other features that can determine the economic feasibility of applying various technological solutions;
- the requirements of airlines the airport must comply with, e.g., service standards, etc.

Based on the recommendations such as LOS (IATA 2015) and empirical studies in terminal planning (Nõmmik, Antov, 2017) at different stages of passenger and baggage service, it is necessary to proceed from:

- capacity of service points measured in time of service;
- the required space in different zones of airports measured in square meters per passenger.

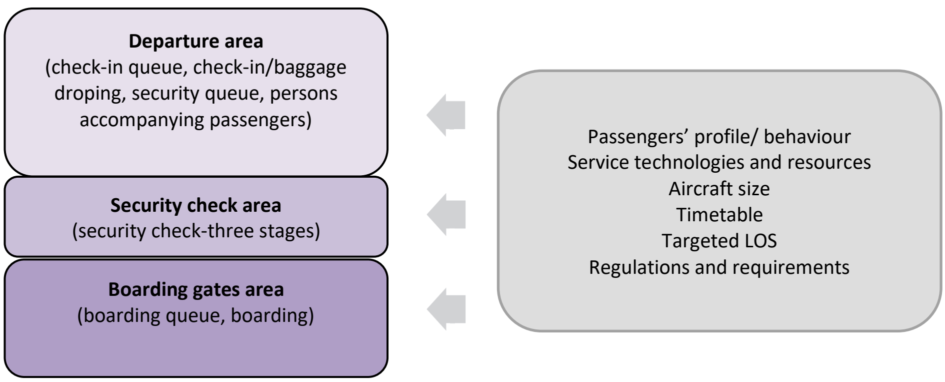


Figure 7. Terminal scheme: departure. Factors influencing service capacity. (Nõmmik, Antov, 2017; author's adoption).

Figure 7 shows a simplified scheme of an airport terminal with its key service stages and factors which are influencing the service capacity. In accordance with the terms of service, we have been interested in the bandwidth on time of servicing, such as check-in for flights and baggage drop, time spent on security control and on boarding operations.

Between the above service points, it is necessary to provide space for airport customers. Prior to check-in and security check, it is necessary to provide a place for passengers and mourners, between security check and boarding for departing passengers, a place for arrived passengers who are waiting for their baggage. Also in addition to this, luggage rooms should provide opportunities for storing the departing baggage and the baggage conveyers should be able to accommodate the baggage of arriving passengers. It should be noted that the LOS concept materials focus on the work and infrastructure of large airports. In addition to this, in order to build an uninterrupted service system consisting of infrastructure, technology and personnel, besides recommendations also empirical data are needed.

The publication of Nõmmik and Antov (2017) examined the possibilities of modelling the operation of an airport terminal in order to agree on key stages of service to ensure dynamic capacity of departing passengers. The basis for modelling comprised the comprised the measurements to determine both the behavioural characteristics of passengers and the time they spent at different stages. Proceeding from circumstances, resolutions were suggested which should be considered for building a service system in the terminal of regional airport (Nõmmik, Antov, 2017):

(1) a discrepancy in the passenger profile in terms of arrival time at the airport terminal and the amount of baggage taken in accordance with the flight features such as charter or regular flight, as well as airline policy;

(2) to measure the time it takes for passengers to pass through the security control, it was proposed to divide this stage into 3 parts: preparation, the inspection itself and the collection of belongings the security-cleared passengers. However, it is important to point out the last, third part, separately because the empirical data obtained show that it takes the passenger up to 3-fold the amount of time that they spent in the first stage (Nõmmik, Antov, 2017). In addition to this, the time of the service at the second stage will depend on the probability of each passenger and the baggage being sent to undergo additional security procedures;

(3) the boarding time is much shorter than the time spent on passing the security check, which reduces the ability to coordinate both processes and, therefore, eases the requirements for the waiting space for boarding passengers;

(4) at service points, it is possible to increase the capacity by installation of additional equipment or/and the involvement of additional personnel. In both cases, this entails the need to provide more space in the relevant parts of the terminal.

2.3.4 Impact of aircraft size

Aircraft servicing at the airport, including boarding and deboarding of passengers, occurs at a limited time. This means that at a certain time period, the airport terminal must provide bandwidth as well as accommodations for serving passengers at different stages of servicing according to the recommended practices. Based on the foregoing, we are interested in the question of how the trend towards using aircraft of ever larger sizes has an effect on the efficiency of regional airports. Nõmmik and Antov (2020) presented a comparison with the theoretical values of runway capacity where it was shown that even if a regional airport operates with one runway, the performance indicators are much lower than the maximum theoretical.

Hereby, we can draw an example. Let us consider a model in which there is a regional airport and a number of potential destination airports. The routes could be profitable at standard load factor for all sizes of aircraft. Let us suppose that over a period of time, the potential of the regional airport is equal to Q and constant. Based on the dependence of the passenger flow at destination airports on their potential and the distance between the origin and destination airports (Nõmmik, Kukemelk, 2017), the possible passenger flows differ in size, which means that they need an aircraft of the required capacity.

In this case, possible destination airports can realize their potential through the passenger flow only if there is an aircraft suitable for servicing this line taking the competition into account. Otherwise, when there are only larger aircraft on the market, only destinations with a relatively large potential passenger flow may be served. Similarly, one can be modelling the effect of aircraft capacity according to flight frequency.

Provided on the condition that the airport's potential preliminary demand for air travel may be constant over some period of time then the larger the size of the aircraft operating, the less likely it will be to open routes to different destinations or to lower the frequency of flights.

However, taking into account that not only the competitiveness of the airport, but also its influence on the served region depends on the flight frequencies and the number of airlines, we can conclude, that it in its turn can affect the attraction of passengers.

Different types of aircraft have different dimensions, which directly affects the required sizes of aircraft stands and the requirements for the runway system. To simplify modeling, some study, for example, take into account the indicator e.g. stands designed for aircraft of a given size (Mirkovic, 2011). However, in a situation where the number of small-size aircraft designed for regional air routes decreases in Europe, this means that regional airports must plan the apron, based on the same types of aircraft as large airports do, having more intensive traffic. However, taking into account that not only the competitiveness of the airport, but also its influence on the catchment area, depends on the flight frequencies and the number of routes, we can draw a conclusion of the long-term negative consequences affecting the prospects of the regional airports.

The study referred earlier (Nõmmik, 2019) note both a decrease in the number of aircraft of less than 100 seats in Europe as well as an increase in the number of seats in the main line of narrow-body aircraft, which affects the need to develop infrastructure even without increasing the passenger traffic. Thus in case of an airport terminal, the throughput depends on that the critical service points such as a security check and the capacity of passenger waiting areas, which should provide enough space for passengers in accordance with LOS. Proceeding from the above mentioned, the higher number of passengers on a flight, arriving during a short period of time to the airport terminal, binds a higher requirement for airport (Figure 7). This means that with the larger aircraft operating, the regional airports are in worse condition, in terms of efficiency indicators of the airport terminal. Proceeding from the above mentioned, the higher number of passengers on a flight, arriving during a short period of time at the airport terminal, binds a higher requirement for airport capacity. This means that if the larger aircraft operating, the regional airports are in worse condition, in terms of efficiency indicators of the airport terminal is.

2.4 Conclusions of Chapter 2

The second chapter of this dissertation focuses on the factors influencing the efficiency of regional airports. The issue of efficiency of regional airports has been analysis from different perspectives. This research has been focusing on the efficiency of regional airport infrastructure solely from the perspective of passenger transport, excluding any other duties or business models.

The location of the airports is one of the foundations for determining their prospects (RT2). It was found that the p-center method can be used to determine the potential of an airport due to its location. However, the correlation coefficients show not high values. On the other hand, it was noted that the number of passengers served (APM) could be an indicator of the attractiveness of the airport as a destination. In support on this, from the point of view of airline planning, the airport's potential as a destination is characterized by the airport's passenger flow rate.

To choose the type of aircraft to be focused in infrastructure planning as well as in airport operations at a large scale, it is necessary to take into account the composition of the aircraft fleets of the potential operators. From a comparative characteristic of the narrow-body aircraft currently used or planned to be taken into operation, the wing span is one of the parameters for planning an airfield. Note that the wing span of all aircraft with 70-240 seats fits in the wing span of 24-36 meters. Could be concluded that if it is planned to serve the airport infrastructure with 70-seater aircraft or with much larger ones, that have 200 or more passenger seats, must comply with the same reference code C, based on the ICAO SARP. On the one hand, this facilitates the planning of infrastructure from the point of view of flexibility. On the other hand, there is a clear variation in the load on the terminal, which can be exerted by passengers on a single aircraft (RT3).

Based on the tasks (RT3) of the dissertation, we are studying the seasonality of air traffic, as well as in other possible reasons for the low efficiency of regional airports. When selecting data for benchmarking, the mission of the airport, which is close to the type of the planned airport, should be precisely defined. For analyzing a particular airport, it is necessary to consider its specific users. In the course of these studies it was complicated to find an airport that would meet the above conditions and where LCC airlines or same size of aircraft for charter flights would not be represented. It was found that there was no significant difference in seasonality at airports that are more focused on service the LCC and those airports where the LCC are not or unrepresented. Therefore, such regional airports were selected that differ in terms of location or activity profile. For comparison, seasonality indicators were examined and large hubs of airports were taken into consideration. With some exceptions, regional airports showed higher rates of traffic seasonality, both in terms of APM and TM. It should be noted that Estonian airports were not included in the sample because they did not meet the criteria set.

For airport planning, it is of key importance to consider the impact on aviation standards on efficiency (RT3). The runway size or the size of aircraft stands cannot be always optimized by taking into account the needs of efficiency. That is why the runway efficiency measures indicator TM per runway, which could be replaced for one runway airport with TM, has also limited value for benchmark. It can be considered as an indicator that provides input for planning taxiway(s) configuration in order to minimize construction and operational costs. It can also serve as an indicator of the need to find secondary activities for the airport.

To estimate the returns to scale on the efficiency of the airport apron, a theoretical model was constructed based on the Erlang B multi-channel queuing system. A significant increase in the capacity for servicing flights with an increase in the number of parking spaces was shown. It was found that the above circumstance significantly affects the corresponding efficiency indicators (RT3).

It is necessary to note the key role of the influence of aircraft size on airport efficiency (RT3). In this case, the tendency to growth of the size of aircraft in the fleets of European airlines has effect on both, realizing the potential of the airport as it leads to a reduction in possible air connections to various hubs as well as on a decrease in flight frequencies, which means that it reduces the attractiveness of the airport for passengers. In the long run, it reduces the positive impact on the catchment area, which in turn affects the prospects of the regional airport. Serving more and more spacious aircraft, with a lower frequency of flights, from the one hand, affects the efficiency of the airfield as it imposes additional requirements on the prospective capacity of the airport terminal, which, if the flight frequencies are reduced, can also lead to low efficiency indicators of the airport terminal. In addition, it was found that in order to ensure the required LOS in regional airports, it is important not only to analyse in detail the capacity of the different service stages in airport terminal but also to take into account the passenger profile.

3 Results and Discussion

The scope of this dissertation focuses on regional airport efficiency characteristics, including passenger logistics. However, it is the responsibility of the airport infrastructure and also the operation to meet the demand.

The previous research focusing on this subject of regional airports indicate the low efficiency of regional airports, but does not investigate its causes. DEA and SFO methods are often used to assess the effectiveness of airports. However, the aforementioned analysis models, which are gaining popularity, have an indicative value and limited practical application for planning the infrastructure of individual regional airports due to the excessive generalization or subjectivity of the above methods and taking into account the heterogeneity of the regional airports themselves.

In this dissertation, the following tasks were completed, which also serves to explicate the established working hypotheses:

(1) A review of existing approaches to regional airport definition and meaning (RT1). It is concluded that there is more than one definition and meaning of regional airport. The views on the definition of a regional airport vary according to the context or the objectives pursued.

(2) The models for evaluation of airport location and routes potentials are proposed (RT2). Also the ability of applying of gravity model for route planning from regional airport and P-center model for evaluation of regional airport location has been shown (H1).

(3) The factors that affect the operational efficiency of regional airports, (RT3) are determined. They are including the following (H2; H3):

a) resulting from returns of scale;

b) limited possibilities for infrastructure optimization as impact of aviation SARP and LOS;

c) arising from the specifics of the European air transport market, including European airlines fleet;

d) the seasonal variability of traffic;

e) the passenger behavior and airport mission.

It has been shown that the parameters most commonly used to measure the efficiency of the airports are less subject to airport control. In addition to the outputs, such as TM and APM, the inputs, or airport infrastructure, are affected by aviation standards and recommended practices and requirements on the one hand, and trends in the aviation market, on the other.

It has been found, that the population indicators, such as potential passengers residing in the airport service area and the distance from the settlement to the airport are related to the turnover of the airport passengers but the relationships are not significant. Based on other studies, it can be argued whether the factors such as the income of a given population, the structure of the economy by employment as well as accessibility of specific airports play an important role. Added to them may also be the ability of competing modes of transport alone, and through them, the ability of other airports to substitute regional airport services.

Estimation of the location of the airport based on the distance to the location of the potential passenger did not reveal a strong correlation. It can be concluded that in addition to the competition between airports as a phenomenon of its own kind, it is important to determine the different prospects of an airport. These include a number of several other factors, such as airport accessibility (Badanic, et al., 2010), which ensures the airport's competitiveness but also the local economic structure that the airport is a part of.

In addition, the application of the gravity model as described in this dissertation, presupposes the isotropy of the operating environment, allows relatively easy determination of the prospects of new air connections from a regional airport, and helps to understand the nature of air routes. In a system where the airport potential Q is held constant, it is shown that with the increase in aircraft size as well as occupancy, the number of possible routes and frequencies decreases, which in turn reduces the airport's efficiency with TM. In this case, using a larger aircraft will reduce the number of possible routes and thereby reduce connectivity. However, this model does not help to determine one's potential, especially when it comes to regional airports where traffic has stalled for some reason. Consequently, in the latter case, a comprehensive market research will be inevitable.

The barrier for today's European air transport system emanates from the market failure on the world regional aircraft market. The assumption on which many studies are based, that there are different sizes of aircraft available on the market for each air route, including operating at regional airports, is not completely true. The downside is that the well-established situation, whereby the market for aircraft with less than 100 seats prevails, is primarily oriented to the North American market, given this particularity. Realizing the greater potential of the airports of destination by launching a route will not only improve flight connections to and from the regional airport, but will also improve the connectivity of the airport, including through it, thanks to transfer opportunities.

For airports with low traffic volume any short-term change in demand significantly affects the indicators of variability. In this regard, we can consider the comparatively higher seasonality at regional airports as expected. More significant is the conclusion that LCC airlines do not affect traffic by a smoothing effect. This can be explained by the trend (Williams, 2001) of the gradual replacement of leisure-driven charter flights by LCC airlines in the European market, described earlier.

Theoretically, implementing the SLOT system at regional airports would ensure efficiency gains, but in practice this could in turn reduce the attractiveness of airports for potential airlines. This conclusion is consistent with the results of other studies (Pels, et al., 2003b) where the time restrictions have a been found to have negative impact on the efficiency of airports.

It has been found, that planning the aerodrome for aircraft for the ICAO reference number C, the airport can serve aircraft with 78 seats but also with 240 seats. On one hand, it could be seen as flexibility. However, at the same time, it is a challenge and part of choices for the airport infrastructure, including terminal capacity planning. If the single regional airport is oriented, according to its business mission, to the activities, such as LCC services or holiday charters, it is reasonable to target at the longest versions of B737 or A320 aircraft families for infrastructure planning.

The research carried out within the framework of this dissertation provides the basis for benchmarking as well as the creation of the basis for regional airport operations as a complete simulation. In addition, the issued publications lead researchers in the field closer to the practical challenges of a regional airport, where the results of the dissertation would also be implemented into the research to be conducted in Estonian airports, including the organization of the airport accessibility system, infrastructure planning and operational planning. In the framework of the preparation of this dissertation, factors significantly affecting the efficiency of airports were comprehensively worked out, which have practical importance for further scientific and practical projects in the field of infrastructure planning and airport operations, including using of simulation. However, some of the areas of the research can be extended, including:

(1) there is a prospect for further research of the potential of airports from the point of view of determining prospects, choosing airports for comparative analysis, as well as route planning;

(2) developing of simulation and design models related to airport capacity which has been uncovered in the dissertation, as well as testing of service technologies and calculating commercial efficiency, given the heterogeneity of specific airports;

(3) behavioural preferences of passengers also deserve attention in terms of the prospects for further research. The revealed discrepancy in the behaviour of passengers in terms of arrival time at the airport for a departing flight suggests that there is a tendency for passengers, particularly for the business passengers, to take advantage of a small airport from the point of view of a small terminal, even while taking some risks of being late for the flight. However, this may be due to circumstances that in the waiting areas of regional airports there is relatively little entertainment as the waiting conditions are generally unpretentious, but also because of the fact that the ground access system to regional airports is less prone to traffic jams. On the other hand, the orientation of passengers of charter flights to arrival at the airport two hours before departure indicates the trainability of passengers;

(4) considering the orientation of regional aircraft manufacturers to the North American market, it makes sense to consider in more detail the measures on the attractiveness of the European market for this market segment. This is important not only in terms of the effectiveness of regional airports or spending resources on EU projects such as Clean Sky 2, but also in increasing the throughput of the European transport system.

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Abstract

Prospects for operational efficiency of European regional airports in passenger air transport

Studies on airports efficiency show low figures for small, regional airports. The linear methods used in comparative studies in operations research of the efficiency of regional airports are indicative, but cannot often give a direct input into infrastructure planning and do not point out the relatively low reasons for the efficiency of regional airports. The aim of this work is to identify the reasons for the inefficiency of European regional airports.

The five publications on which this dissertation is based are focusing on identifying the perspectives and inefficiencies of regional airports.

The first publication deals with air routes planning at regional airports by using the gravity model.

The second publication looks at the terminal capacity at regional airports.

The third publication uses mathematical methods to assess the prospects of regional airports in terms of their location in relation to settlements.

The fourth publication focuses on regional aircraft development and the trends of implementing them.

The fifth publication summarizes the topics covered in the preceding publications. In addition, it addresses the definitions of regional airports and the efficiency factors such as seasonal variability and return to scale.

Having examined, how regional airports are comprehended in different sources, it was concluded that there is no uniform definition or understanding of the regional airport as an object under investigation or description. Synonyms such as “peripheral airport”, “small airport”, “secondary airport”, “non-hub airport” and others are often used.

The potential of the airport was considered from two perspectives. First, the prospects of the airport in terms of its location in relation to settlement points were examined. The best result was obtained by the p-center method when the number of inhabitants of settlements was also taken into account. However, the links between theoretical and practical results are not strong. It was concluded that the discrepancies found between the theoretical and actual results could be explained by additional, broad-based studies that would assess not only the profile of potential passengers but also the accessibility of airports. Secondly, in order to understand the nature of the connections and the prospects of scheduled flights, a gravity model based on the potential of the destinations was proposed, depending on the number of passengers served and the distance between the airports of departure and destination, measured by flight distance or flight time.

To investigate the returns to scale effect, a theoretical model was developed based on the Erlang B distribution. Using this model, it was shown that on an apron with a larger number of aircraft stands, it is possible to serve a significantly larger number of flights under the required high service reliability conditions.

As part of the analysis of airport terminal capacity planning, it was found that the existing international recommendations are aimed primarily at larger airports. Within the framework of the research, the factors of passenger service in the terminal were mapped at different stages and the importance of taking into account the profile of different passengers for the planning of the regional airport terminal was pointed out.

Analysing the variability of traffic due to seasonality, it was found that regional airports operate in conditions of greater variability of traffic compared to big airports. The variability in traffic depends primarily on the niche market in which the regional airports operate, rather than on the business model of the airline whose flights are served.

The issue of aircraft development has been highlighted as a key. It has been found that the niche aircraft in the regional airline market today are being developed, taking into account in particular the North American market and also taking into account its specificities, which in some cases are not suitable for the European market. Therefore, for example, the number of turbofan-powered aircraft with less than 100 seats in Europe shows a declining trends. The work concludes that the creation of competitive aircraft for regional routes and their acquisition by European airlines is crucial to ensure the prospects of European regional airports in terms of operational efficiency.

This dissertation has two main output directions. Firstly, the reasons for the inefficiency of regional airports are highlighted, which can be an input for the development of a European Union air transport policy, but also for future research in this regard. Secondly, the methodological basis for creating complex simulations of airports has been created within the framework of the dissertation, by the way, critical factors are carried out that should be taken into account when planning regional airports, as well as Estonian ones.

Lühikokkuvõte

Reisijate lennutranspordi tõhususe väljavaated Euroopa piirkondlikes lennujaamades

Uuringud, mis käsitlevad lennujaamade efektiivusust, toovad välja madalad tõhususnäitajad just väikeste, piirkondlike lennujaamade puhul. Samuti on kasutusel olevad meetodid piirkondlike lennujaamade efektiivsust võrdlevates uuringutes sageli pigem indikatiivse väärtusega, nad ei suuda tihti olla otseseks põhjendatud sisendiks infrastruktuuri kavandamisel ning ei too enamasti välja piirkondlike lennujaamade madala efektiivsuse põhjuseid. Käesoleva töö peaeesmärk on analüüsida ja välja selgitada peamised tegurid ja parameetrid, mis avaldavad mõju Euroopa piirkondlike lennujaamade tõhususele reisijateveo seisukohast vaadatuna.

Viis doktoritöö raames avaldatud publikatsiooni keskenduvad piirkondlike lennujaamade perspektiivide ja ebatõhususe põhjuste väljaselgitamisele.

Esimene publikatsioon käsitleb lennuliinide planeerimist piirkondlikes lennujaamades.

Teises publikatsioonis võetakse vaatluse alla piirkondlike lennujaamade terminali läbilaskevõime.

Kolmandas publikatsioonis hinnatakse matemaatiliste meetodite abil piirkondlike lennujaamade perspektiive tulenevalt selle asukohast asustuspunktide suhtes.

Neljandas publikatsioonis keskendutakse piirkondlike lennuliinide õhusõidukite arengutendentsidele.

Viies publikatsioon viib kokku eelnevates publikatsioonides käsitlevad teemad. Lisaks käsitletakse seal piirkondlike lennujaamade definitsioone ning selliseid tõhusust mõjutavaid faktoreid, nagu liikluse sesoonsusest tulenev varieeruvus ja mastaabiefekt.

Nimetatud uurimiseesmärgi täitmiseks püstitas autor järgmised uurimuslikud ülesanded:

1) analüüsida teaduses ja lennunduse erialases kirjanduses kasutatud mõiste “piirkondlik lennujaam” variatsioone uuritava objekti määramiseks;
2) pakkuda välja ja rakendada mudeleid lennujaama perspektiivi hindamiseks, lähtudes lennujaama asukohast;
3) selgitada välja tegurid, mis mõjutavad piirkondlike lennujaamade tegevuse tõhusust.

Uurides, kuidas piirkondlikke lennujaamu käsitletakse erinevates allikates, jõuti järeldusele, et puudub ühtne definitsioon või arusaam piirkondlikust lennujaamast kui uuritavast või kirjeldatavast objektist. Tihti on kasutusel sünonüümid nagu “perifeerne lennujaam”, “väike lennujaam”, “sekundaarne lennujaam”, “põiklennujaam” jt.

Lennujaama potentsiaali käsitleti kahest vaatenurgast. Esiteks, vaadeldi lennujaama perspektiive tulenevalt selle asukohast asustuspunktide suhtes. Parima tulemuse andis *p-center* meetod juhul, kui arvesse võeti ka asustuspunktide elanike arvu. Siiski tuleb tõdeda, et seosed teoreetilise ja praktilise tulemuse vahel ei ole tugevad. Töös tehti järeldus, et avastatud hälbeid teoreetiliste ja tegelike tulemuste vahel on võimalik selgitada täiendavate laiapõhjalike uuringute abil, mis hindaksid lisaks potentsiaalsete reisijate profiili, kuid ka lennujaamade liigipääsetavust. Teiseks, mõistmaks lennuühenduste olemust ja regulaarlennuliinide perspektiive, pakuti välja gravitatsiooni-mudeli rakendus, mis põhineb sihtkohtade potentsiaalil ja mis sõltuks teenindavate reisijate arvust ning kaugusest läht- ja sihtlennujaamade vahel, mõõdetuna kas lennuteekonna pikkuses või lennuajas.

Mastaabiefekti uurimise eesmärgil koostati teoreetiline mudel *Erlang B* jaotuse alusel. Antud mudeli abil näidati, et suuremate lennukite seisukohtade arvuga perroonil on võimalik teenindada oluliselt suuremat arvu lende ette antud teeninduskindluse tingimustel.

Lennujaamade terminali läbilaskevõime planeerimise analüüsi raames leiti, et olemasolevad rahvusvahelised soovitused on suunatud eelkõige suurematele lennujaamadele. Uurimistöö raames kaardistati reisijate teenindamise tegurid terminalis protsessi erinevatel etappidel ning toodi välja erinevate reisijate profiiliga arvestamise tähtsus piirkondlike lennujaamade terminali planeerimiseks.

Analüüsides sesoonsusest tulenevat liikluse varieeruvust leiti, et piirkondlikud lennujaamad töötavad suurte lennujaamadega võrreldes märgatavalt suurema liikluse varieeruvuse tingimustes. Liikluse varieeruvus sõltub eelkõige turunišsist, kus piirkondlikud lennujaamad töötavad, mitte niivõrd lennuettevõtja ärimudelist, kelle lende teenindatakse.

Võtmetähtsusega asjaoluna on toodud välja õhusõidukite arendamise küsimus. Leiti, et tänapäeval arendatakse piirkondlike lennuliinide turunišši õhusõidukeid eelkõige Põhja-Ameerika turgu arvestades, võttes arvesse sealseid eripärasid, mis aga kohati ei sobi Euroopa turu jaoks. Seetõttu näitab näiteks turboventilaatormootoritega töötavate ja alla 100 kohaliste õhusõidukite arv Euroopas näitab langustrende. Töös tehakse järeldus, et konkurentsivõimeliste õhusõidukite loomine piirkondlike lennuliinide tarbeks ja nende kasutuselevõtt Euroopa lennuettevõtjate poolt on määrava tähtsusega Euroopa piirkondlike lennujaamade perspektiivide tagamiseks opereerimise tõhususest lähtuvalt.

Käesoleval uurimistööl on kaks olulist väljundit. Esiteks, on välja toodud piirkondlike lennujaamade ebaefektiivsuse põhjused, mis saavad olla sisendiks Euroopa Liidu lennutranspordi poliitika kujundamisel, kuid ka sellega seonduvate edaspidiste uuringute kavandamisel. Teiseks, doktoritöö raames on loodud metoodiline alus lennujaamade komplekssete simulatsioonide loomiseks, muuseas tuuakse välja kriitilised faktorid, mida tuleks arvestada piirkondlike, sealhulgas Eesti lennujaamade planeerimisel.

Appendix

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DEVELOPING GRAVITY MODEL FOR AIRLINE REGIONAL ROUTE MODELLING

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Abstract: the gravity model is a method that is used by transportation researchers, airline network planners and analysts to explain how traffic is distributed between city pairs in correlation to the distance or travelling time between them, which as a result indicates the behaviour of travellers or the performance of the transport connection. However, the applicability of the model depends on the reliability of the results, which poses a major issue for researches. The major difficulty is to obtain comparable qualitative insights into the key parameters that are selected. This paper presents a possibility study for the use of the gravity model for regional route planning from the scientific point of view and suggests possibilities of gravity model calibration for airline network analysis including alternative methods for estimating the gravity potential of destinations and measurement of the influence of distance on the potential. The focus of the research is the ability to explain and forecast the development of regional air transportation routes in the commercial aviation network when there is a lack of recorded booking demand data.

Keywords: air transportation route planning, gravity model, regional aviation.

1. Introduction

The gravity model or law gets its name from physics; it is referred to as the modified law of gravitation. Gravity equations have a long history of use in social sciences for transportation planning, describing and forecasting the movement of people, goods and services (Truscott, Ferguson 2012). One of the implication areas, developed in the second part of the 20th century, is the use of the model in transport geography for assessing and predicting the total number of trips for the whole population. For example the time-geographic concept of Torsten Hägerstrand which consists of the gravity model "relate to how and why individuals, in one or more populations, link to each other and move (or are moved) between places which are the cornerstones of transport research" (Ellegård, Svedin 2012). Various sources define the gravity like effect of spatial interaction differently; however, they model it similarly. There are some differences in formulas and approaches towards the research depending on the task, the researcher`s background and area of research (Ellis, van Doren 1966; O'Kelly 1983; Weber, Sen 1985).

"As the aviation market is an industry which in 2008 had a 425 billion USD direct annual revenue and an indirect 1540 billion USD annual impact" (Gossard 2011), it is fair to call aviation a mature industry. As in every well-developed field there are numerous methodologies and tools developed to simplify processes and ensure the best financial outcome.

2. Practical uses of the gravity model in network planning

Due to high expenses and the dynamic nature of the aviation market, regional airlines need some instruments which could be based on a certain methodology. According to the classical theory, the market should be segmented into three main categories: business trips, leisure trips and trips for visiting friends or relatives. The demand is dependent on the population, the size of salaries, the structure of economy and historical or demographical factors, etc. The key criteria for planning for a pre-defined region would be the assessment of the current services at destination *j* and comparison of their correspondence to the real needs of destination *i*.

In the last 10 years all over Europe it has been observed that passengers do not always choose the closest airport for their travel but rather an airport where the costs of services are lower, which could have be triggered by low cost carriers. In aviation that is called surface leakage, and just for that reason the gravity model is needed in modern network planning, it can be used to understand what would be the potential provided that similar services would be available to the customer at the nearest airport.

Business traffic is mostly driven by the number of frequencies offered for a place as businessmen have a tight schedule, and cold therefore make the best use of their time, whereas leisure travellers are driven by the number of seats offered – more seats mean a lower cost – as they are price sensitive.

In all mature markets like Western-Europe or North-America, it is not so challenging to understand the demand between bigger city pairs as they might be dominated by a certain group and have been served with the same capacity for the last 10–20 years (Maertens 2011). However, developments can be challenging to new markets (no previous operations) due to having not sufficient data about the market size, demand segmentation, seasonality and schedule preferences.

One way out could be the use of some classical approach involving a market survey. However, it has been found that in the case of airline route planning the surveys do not give a realistic picture due to the difficulty of gaining access to the target group since respondents are not responsible for taking actual commitments. Changes in the operational environment also affect research models and methodology, as the results of the carefully completed surveys cannot be fully implemented. The factors that influence the results significantly are:

- changes in the market situation, like joint-ventures, code-share agreements or special prorate agreements;
- changes in the function of passenger's willingness to pay due to previous experience with low cost or high level airline services; changes in traveller's real income; society's trends for travelling behaviour;
- changes in politics, like a state joining some political or economic union or decisions for preference of or development of some transportation mode.

Philosophically, in transportation, the movement of people in space can be defined as the direct implementation of a material connection or the material connection process between settlements (Mereste, Nymmik 1984). For social sciences different forms of gravity models are very common as the amount of related data is easier to access (Paas 2000). A pre-defined collection of data could be used for example in the assessment of economic systems or for explaining traffic development using different factors, such as attractions at the origin and destination cities in addition to the distance effect (Jin *et al.* 2004). Route planning is one of the key pre-requisites for successful airline operations; therefore, the gravity model is one of the methodologies that network planners use for forecasting:

- demand of new routes which could be started;
- possibilities of increasing the capacity of existing routes;
- development of existing routes due to market changes.

In recent years, the gravity module has seen surge a in its applicability due to the rapid pace of development in the information technology sector which directly influences the commercial distribution process of airlines (Bilegan *et* al. 2007). Conventional methods include the use of historic data on booking trends called the MIDT (Marketing Information Data Tapes) and an overview of the number of sales through the IATA revenue sharing scheme (Kukemelk 2012), which in general demonstrates the different methods for obtaining the number of passengers travelling between certain cities. However, getting access to such systems is costly for regional airlines and airports due to a high investment cost and the limiting factor that they only provide qualitative insights into the past behaviour whilst not taking into account future trends or implications for areas where there have been constraints. Regional and peripheral airports where passengers use more than one transfer station are especially problematic, as the accuracy of the systems to predict multi-stop journeys is relatively low, hence distorting true market sizes and reducing the attractiveness of a regional airport in the eyes of potential newcomers (Kukemelk 2014). If it is believed that a destination has peripheral characteristics then the gravity module is amongst the more preferred options for revealing the true potential of the destination for all possible airlines.

For analysing or forecasting the flows of travellers *F* or planning the transport capacity for serving them, the model takes into account the combination of the population sizes and the underlying distance between them (Eq. (1)).

$$F_{ij} = k\frac{P_i^{\alpha} P_j^{\lambda}}{R_{ij}^{\beta}}, \quad (1)$$

where the constants are as follows:

P_i and P_j – importance of the location of origin and the location of destination;

R_{ij} – distance between the location of origin and then the location of destination;

k – a proportionality constant;

α (alpha), β (beta), λ (lambda) – empirical constants.

Before the gravity model can be used for the prediction of current travel demand, it must be calibrated. The calibration has to take into account the operational environment dependent on geo-economic factors or factors that fall outside the control of airlines and service dependent factors (Srinidhi 2010) which may not be truly independent components of the airline product.

The calibration consists of finding the value of each empirical constant of the model to ensure that the estimated results are similar to the observed flows. If it is not the case, the model is almost useless, as predictions have no value without context. It is impossible to know if the process of calibration is accurate without comparing the estimated results with empirical evidence (Kukemelk 2012). From this point of view, some researchers have offered a solution for calibrating, by indicating that the empirical parameters α, β, λ should describe (Rodriguez *et al.* 2009):

β – transport friction related to the efficiency of the transport system between two locations; for airlines this could be described by either offer or production.

λ (lambda) – potential to generate movements. For movements of people, lambda is often related to an overall level of welfare. Lambda could also be described by the GDP per capita levels.

α (alpha) – potential to attract movements (attractiveness), related to the nature of economic activities at the destination. It should be a combination of attractiveness and accessibility. It can also be partly described by the number of UNESCO World Heritage sites in the area or the number of tourist nights spent per fixed period.

Passengers are not rational and do not make decisions based on *ceteris paribus*. Usually models in social sciences imply that customers behave rationally. It is assumed that they have all the information on the services offered. Every passenger who has to choose faces a dilemma: to buy the cheapest product or the one caters best for the client's needs.

The main tools used today for new route planning collect historical market data and based on that try to simulate what would be the most likely outcome of a new flight or frequency. This data, however, does not include a complete data set any more, as the booking figures of low fare carriers (LFC) are just an estimation due to non-compliance with traditional carriers' rules of reporting. To come up with better quality data and ensure sustainable development, network planners are looking into alternative methods. One of the methods looked at is the gravity module with its various implications.

One additional field of attention is the application of external factors such as wars, unrest and terror. For example, people who would usually take their winter vacations in Egypt will change their preference due to elevated terror threats and reduced offers of airlines. However, once the crisis is over and people could go back for holiday, the companies tend not to offer these destinations (at least in the beginning) as they have no previously recorded data. Whereas passengers who spent the holidays somewhere else, for example in the Canary Islands, which is the main alternative resort for winter getaways from Europe, might start looking back to the Egyptian market, which triggers an illogical decline of demand in the Spanish market. The same reasoning could be applied when analysing the spent attractiveness of one city to the passengers another city. Attractiveness can also be one sided – meaning that people only visit one place and there is no both way traffic.

From the point of view of humanism, it is impossible to study human behaviour with methods coming from natural sciences. Traffic forecasting has to take into account the objective of a passenger's trip, individual value judgment, inclinations and preferences. Predicting people's decisions is of upmost challenge and might not be possible through models at all.

Offers which are provided for customers by airlines involving transfers at hubs might not always be reasonable for passengers due to the travel costs or travel time. Some alternatives, like using a combination of air transport and other modes of transportation could be preferred. Additionally, passengers plan their trips themselves and may use a combination of several LFCs flights. As a result, passengers travelling from one airport to another do not necessarily just travel between the operated city-pair or municipalities located in the immediate vicinity of the airports. From the point of view of the gravity model for airline network analyses, the attractiveness of the cities is not expedient. That means that the air transportation network is being viewed like a phenomenon in its own right, which is often not associated with the local population density or local economy.

Redrafting Bertrand Russell's (Russel 1994) opinion about the relativity theory of Einstein, it could be stated similarly that the more accurately researchers determine the profile of a passenger the less accurate is the production which passengers are offered; the more accurately we determine the preferred destinations, the less accurate will be the profile of passengers.

3. Development of the gravity model to highlight the implications of the market

The choice of airport is mostly influenced by the airport's attraction, but resistance of distance could be measured by both kilometres and time (Legeza *et al.* 2010). However, distance can also be substituted with the travel time as the key parameter for making a choice. Airports' attraction could be measured by the number of passengers served by the airport (Nõmmik 2003).

The airline pricing policy is effectively developed based on the competition in the market. Airlines which cater for the needs of the business sector have to offer high frequency services; therefore, they tend to have smaller aircraft and lower load factors. As a result, this increases the airlines' need for higher revenue. Whereas, low fare airlines tend to fly bigger aircraft more seldom and, as such, have lower production costs, which results in the ability to provide lower fare levels and, through reduction of fares, the ability to stimulate extra demand.

For our research, traffic from Tallinn airport during 2013 and 2014 was used. Tallinn Airport was chosen as a good example of a regional airport in the European Union as it is a member airport in the European Union Transportation Commissioner's Aviation Platform (European Commission) 2010. In order to minimize the effects of temporary demand fluctuations, the discount data was analysed annually.

Table 1. Traffic data according to destinations for 2013 and 2014.

Airport	Passengers 2013	Passengers 2014
Frankfurt Main	58,036,948	59,566,132
Amsterdam Schiphol	52,569,250	54,978,023
Moscow Sheremetyevo	30,765,078	31,567,974
Copenhagen	24,029,205	25,590,674
Oslo Gardemoen	22,955,723	24,068,955
Stockholm Arlanda	20,706,411	22,462,028
Brussels	19,105,398	21,904,723
Helsinki	15,272,573	15,943,276
Warsaw Chopin	10,683,706	10,590,473
Kiev Borispol	7,926,964	6,890,443
Riga	4,793,045	4,813,959

The criteria for choosing the analysed destination airports (Airport Council International 2014, 2015) for the study, provided in Table 1, were:

- regularity of servicing the routes served during the year at least 4 times per week to highlight only the core routes which have significant implications on the true air service demand of the airport;
- international routes to the hub-airports not longer than the Great circle distance, 1852 km (1000 nm), or short haul routes which could be accepted like regional flights, or block-time of a route not longer than 2 h 30 m (Tallinn airport. Timetable. 2014;
- routes which have been served for at least two years in a row to highlight the potential they have obtained;
- destinations served only by low cost carriers were excluded to avoid specific gradients of movement based on the significantly low prices.

For the calculation of the gravity effect of every destination in Tallinn airport (Tallinn Airport. Timetable 2014; Tallinn Airport 2015), Equation (2) was used, where P_i indicates the airport and i – attraction, measured by the passengers served by the airport. For the calibration of the model, data of 2013 and random combinations of k, α and β were used until one which has a minimal P_n^m deviation was found (Eq. (3)).

$$F_i = k\frac{P_i^{\alpha}}{R_{ij}^{\beta}}, \tag{2}$$

$$\Delta_F = \frac{\sqrt{\sum_{i=1}^{n}\left(f_i - F_i\right)^2}}{n-1}, \tag{3}$$

where: n – number of destinations, f – real market share of the route for destination i, F – theoretical market share for destination i.

For testing the adaptability of the gravity model, passenger flows to the destinations were forecast using the Spearman rank Equation (4).

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n\left(n^2 - 1\right)}, \quad (4)$$

where: r_s – the coefficient of the correlation, d_i – the difference between the rank of *f* and *F* for the observation of *i*. During testing we found that the difference between the theoretical and real rank for Riga airport was very high. Therefore, two separate analyses were conducted: one with Riga airport (r_{sR}) included and one without Riga airport (r_{sO}).

Table 2. Correlation of real and calculated market shares

	Great circle distance (km)		Block time (min)	
Year	r_{sR}	r_{sO}	r_{sR}	r_{sO}
Traffic in 2013	0.54	0.75	0.55	0.76
Traffic in 2014	0.55	0.75	0.56	0.76

The calculation results can be seen in Table 2. When assessing the relevance of block-time versus range, the analysis revealed that using the distance in kilometres for the calculation of the influence on range resulted in approximately the same results as the usage of block-time for traffic without Riga airport.

4. Discussion and conclusions

A conscious application of the laws of science allows the adjustment of both empirical and theoretical knowledge of the process of cognition (Nymmik 1981). From the point of view of transport planning, we have to create models which would be able to project these subjective choices. This is also the key goal of the article – an effort to try to model the behaviour and reasoning of individuals who do not follow exact rulings. Such research is faced with a lot of uncertainties, like measurement of freedom in travel time or choice of numbered destinations. Travelling could be understood as a human right or as a legal privilege.

The very high difference between the theoretical and real rank of Riga airport could be explained by the specific role of this airport in the air transportation network of the Baltic States in the time period analysed. The objective reason here could be the fact that the Baltic market is relatively small and is suffering from a lack of connectivity, and, as the main carrier in Riga airport has pre-defined all Baltic States as its home market, it is natural that there will be extended sales efforts to ensure high market penetration. However, such active sales and marketing activities cannot be taken into account in the model and have to be calibrated later based on the actual demand and supply ratio.

The applications allow to project theoretically the demand between any two points on the planet; however, calibrating the results for the whole world would be so time consuming that once they were ready the model (as data gets old) would not be applicable anymore. Passengers are not completely free in choosing the way, time and mode of travelling and no airline would ever be able to provide an offer for everyone according to their exact needs. This is especially true for regional or peripheral airports where the demand is quite often dictated by supply. The analysis showed the adaptability of the gravity model for regional route planning where the role of potential is played not by the population size but the number of passengers served at destination airports.

This research focuses on the application of the gravity model for all passengers who actually need to use air services. To solve this problem, the determination or description of the passenger is not a priority. The number of the passengers served at the *j* airport characterizes the potential of the airport as a final destination and the potential for transfer traffic as well. It will be assumed that the system of gravity relations between airports has extensive characteristics and covers all airports around the world. If it is needed, the potential for transfer traffic could be calculated separately taking into account the transfer traffic or traffic of some airlines operated at *j* airport.

In general, after a careful examination of different models, including the gravity model, it is clear that theory cannot provide complete explanations which could be acceptable for research focused on passengers' behaviour yet. Additionally, it is impossible to evaluate the stimulation effect of market growth which would be generated by a new air route. From the point of view of the airline, it is difficult to obtain a realistic picture of the market using a survey.

The gravity model shown in this paper does not take into account the knowledge about passengers' profiles. Researchers agree that the information about every passenger's preferences is important, but such a level of sophistication could be considered once positive results are observed for the applications of the current study of gravity module implications. Two approaches like "contemporary positivism and humanism are motivated by parallel ideals of enlightenment-through-science, by a concern with reliable social knowledge as the basis for rational public policies" (Tibbetts 1982). From this point of view, a highly accurate determination of the profile of demand is not an only-begotten approach for forecasting the demand of a route.

In this paper, we have shown that the calibrated gravity model, based on the presented approach, could be an efficient and simple tool for an airline's route planning dependent on service factors. For preparing the forecast of demand for some routes, the planners will have to take into account the already existing forecasts for airports prepared by airport's authorities without having to conduct their own time-consuming and often costly databases. The gravity model gives a primary answer which does not exclude additional market research with the purpose of finding out the passenger's' profile in general and by routes. The goal of this research would be to improve of revenue management processes and service concept to ensure the achievement of the forecasted demand for air transportation routes.

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Modelling Regional Airport Terminal Capacity

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Abstract

Effectiveness of operation and avoiding of over-design of infrastructure become key factors for ensuring regional airports' existence at the beginning of the 21st century in Europe. Due to the operational profile, regional airports in Europe have a limited capability to increase the non-aviation revenue. On the other hand, aviation revenue has been under pressure due to low-fare trends and competition – not only between airlines but between airports as well. Furthermore, to be flexible at the airlines' suitable times of operations the size of the largest aircraft for operations at regional airports is changed. This study is an analysis the regional airport terminal capacity with its application based on the Ülenurme Airport at Tartu, Estonia. The aim of this research is ascertainment of the regional airport specificities and possibilities for optimising the capacity of regional airport terminals that provide services at a reasonable level. The results and findings of this research should be implemented as the input for the regional airport terminal modelling. Also possible measures for increasing regional airport terminal capacity are offered.

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Keywords: regional airport; airport terminal capacity management; airport level of service

1. Introduction

Liberalisation of air transportation markets and the development of high speed railways created a need for optimisation of infrastructure and operations that has become a critical factor for the existence of regional airports in

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Europe. To better understand the process of airports spatial pattern development it is useful to follow the US experience where liberalisation of the air transportation market occurred earlier. The research by Goetz and Sutton (1997) shows that due to the air transportation market deregulation in the US "service frequencies and enplaned passengers concentrated in the core". In 1978–1993, smaller airports in US witnessed a decrease in their number of operations, received the smaller growth in enplaned passengers. At the same time the growth of employment in smaller airports was higher than that in hubs. This can be interpreted as a sign of small airports operational inefficiency. A similar phenomenon can be observed in Europe where due to the competition between airports the regional ones are losing air traffic (Lian and Rønnevik, 2011). The research done by Merkerta and Mangia (2014) shows that the efficiency of airports, regardless of the catchment area size, plays the main role for an airports' success. A paper by Ingledew (2010) asserts found, that the regional airports have to focus on for changes and improvements "to ensure a sustainable future". Besides direct competition between airports, the development of the networks of high speed trains has the impact on the regional airports (Chiambaretto, 2013).

The paper by Pao-Yen Wu and Mengersen (2013) reviews the existing models of airport passenger terminal planning. These authors found, that "existing models have not considered in depth the usage scenarios and capabilities, their requisite modelling requirements". On the other hand, several researchers (Button *et al.*, 2010; Halpern and Bråthen, 2012) found the importance of air connections to the regional economies. All in all, the reasons for the existence of regional airports are as follows:

- Ensuring of accessibility to airport catchment area, with business purposes including business and / or leisure trips to the region.
- Enhancing the quality of life in peripheries by offering due to possibilities for travelling for visiting friends and relatives, for using leisure flights opportunities, etc.
- Ensuring of employment opportunities at the airport and in other businesses and companies within the neighborhood or region.

By accepting the role of airports and by understanding that small airports unable to cover extensive operating and development costs in order to deflect undue negative impacts on competition and trade, the European Commission has issued compatibility conditions for aiding (EC 2014/C 99/03) however, they will be a challenge for some airports.

The authors of this research hold that a regional airport is an airport where Annual passenger traffic is below 700 000 and which lacks prospects for growth due to the parameters of catchment area and/or intensive competition between airports. Moreover, airport could service some limited regular routes and charter leisure flights. For example, 18 airports of 22 in Finland (Finavia, 2016) served 10,000–700,000 passengers in 2015. Additionally, the factor of the highest population of regional airport catchment area is not always the key of the airport success (Merkert and Mangia, 2014).

Hopes, that Low Cost Carriers (LCCs) will ensure the regular connections for regional airports, are shattered. For example, the Ryanair, the biggest LCC in Europe, reduces air connections in Scandinavia (YleUutiset, 2015) and focusing mainly on the main airports.

Regional airports are mainly oriented to offer the passenger traffic with some alternatives in carrying air cargo as well (Beifert, 2015a). One of the solutions for enlargement of catchment area for cargo flights is developing the road feeder system (Beifert, 2015b). But the cargo operations need investments and this business cannot be a solution for all regional airports due to competition and geographic factors. Air cargo specialisation does not exclude the need the optimisation of passengers' terminal design and operation.

This paper is analysing the process of operation effectiveness of a regional airport's passenger terminal. The data have been gathered from Tartu Ülenurme airport (as was mentioned by the authors somewhere earlier) which has only one regular connection (one flight per day) in 2016. Tartu Ülenurme Airport is the second largest airport in Estonia, with passenger turnover 21,117 in 2015. (Tartu airport, 2016) Due to the small traffic at Tartu airport some empirical data were gathered and observations of processes conducted also at Tallinn Airport.

2. Methodology

The airport terminal capacity as defined by (Young and Wells, 2011) as "optimal nominal capacity can be achieved if infrastructure development and synchronized for the ability to accept the passengers, cargo and aircraft that an airfield generates". The introducing material by (Rodrigue, 2016) highlights two types of transport capacity: static and dynamic capacity. The static capacity is based on the availability of space: land or terminals or roads. The static capacity cannot "be easily changed without expanding the facility". According to the same source the dynamic capacity "relates to infrastructure, labor and technology" (ibid).

In this research the static capacity is defined as the ability to accommodate passengers in some terminal area at any time. As a rule, this capacity is indicated in square meters per passenger. Dynamic capacity of airport terminal can be measured in number of passengers per given time and defined as ability to serve the departing passengers over a period of time. At a regional airport with limited dimensions of terminal it strongly depends on the airport's ability to serve passengers in a given period.

One of the basic methodological materials for airport terminal planning is the IATA Airport Development Reference Manual (ADRM, 2015). This document consists recommendations for the design of airport infrastructure and establishing also the Levels of Services (LOS) measured in space or/and time. Airport planners can follow LOS measurements for all parts of airport terminal or offered the principle of additivity the airport design needs data and information attained by (Correia *et al.*, 2008).

The modelling of the airport capacity, including the functioning of an airport passenger terminal, has been is subject of research. For example, the paper by (Maiorov and Fetisov, 2014) describes the airport mathematical simulation model which was legalised with AnyLog software. The model is based on the viewpoint, that the terminal of an airport "can be argued as a multi-channel queuing system". Characteristics of a queuing system for airport the airport in the research by (Mehri *et al.*, 2008) is divided into "three parts: arrival characteristics or inputs to the system, waiting line characteristics, and the service facility".

In practice for airport design is needed the inputs like the data and previous research which taking into account the regional airport specificity. The specificity can be characterized as follows:

- Due to the service of single flights per day, regional airports have limited equipment and personnel.
- A regional airport has a simple compact terminal with minimal distance for a passenger for reaching the gate of departure.
- Low traffic volume gives regional airports only limited opportunities to increase the non-aviation revenue.
- A regional airport usually has comparatively bad connections with the catchment area of public transport.

As a result we meet the system where regional airports are servicing single flights; the number of passengers is limited and previously known. Frequently, only one security lane and one boarding gate are in practical use. These actions are provided also during limited time before flight departure. The facts varied above restrict the using of already developed models for regional airports.

3. Analysis

3.1. Terminal system

The conditions of the terminal system in regional airports have some specificity. The time for passengers moving from check-in desk to security or from security to gate is minimal and passing through takes much shorter than the time the passengers need to wait for check-in procedures and security screening. Also, due to the short distances the way finding problem in regional airports is not actual.

Fig. 1 a simple scheme of terminal areas is shown. The departure passengers' area is occupied by passengers and their accompanying persons who are waiting for the check-in desk (CD) services or are serviced by CD or by the departing passengers lining up for security screening. As common practice, the CD services could be opened 2h before and closed, according up to the airline requirements, as a rule 35 or 40 minutes before the flight departure.

Security checks area is occupied by passengers who undergo the security screening. The boarding area is occupied by passengers waiting for the boarding.

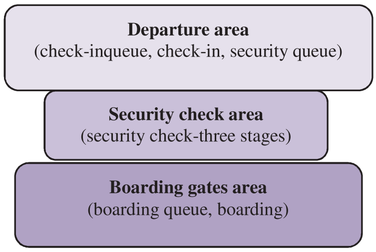

Fig 1. Terminal scheme.

3.2. Check-in services

Check-in services organisation is depends to a great extent on the technology used. Currently, the world's airports are implementing several new technologies. These are besides the traditional CD, the may be mentioned self-check-in kiosks (SSK) and check-in through the internet (WEB). Research which done by (Stolletz, 2011) described that "the service quality at check-in stations is mainly driven by the number of available check-in counters, the dynamic arrival rate of passengers, and the distribution of the processing time". The research done by Marintseva (2014) analysed SSK technology that helps to improve the level of services in airport and found that passengers prefer to check-in for flights at the check-in counters which takes less time as well. "According to traditional queuing theory, waiting-times are also directly related to how long it takes each server to process customers" (Kokkinoua and Cranageb, 2013). The impact of SSK implementation also will depend on the utilization of the system and the skills and experiences of customers. The SSK are often not applicable in regional airports due to the purchasing and operation costs including costs for connection to the Global Distribution Systems and low efficiency. The efficiency of using SSK is related to airlines' policies. The data collected from Tallinn airport show that if an airline gives all free options for check-in, passengers prefer the WEB or CD (Kepp, T., personal communication, 14–18 July, 2016). Besides, WEB technology requires printing of boarding card or equipment in airport for reading boarding cards from smart-phones. Both WEB and SSK do not solve the problem of dropping baggage. Separated self-service baggage drop-off equipment can take the same space similar in size to that of CD. The experience of Tallinn Airport GH, ground handling service provider in Estonian airports shows (ibid) that the preferences of passengers for different check-in options very widely according to a particular airline's check-in policy, departure time and passenger profile. For example, a considerable part of WEB check passengers would contact the CD for printing their boarding cards etc. In regional airports the check-in desk operations include also printing boarding cards, baggage registration and dropping, receiving payments for extra services purchased from the airline, dissimilation of information related to passenger's flight and airport services.

For modelling of check-in operations the key role is played by the behaviour of arriving of departing passengers. The passengers' behaviour at arriving in the terminal of regional airports can be characterized as follows:

- Passengers are arriving during a set period of time – as a rule this period occurs during 1h 25 minutes. This follows from the working time of check-in desk from 2 hours to 35 minutes before aircraft departure.
- The number of passengers limited by number of seats of departing aircraft.
- Passengers are arriving in different numbers, including individually, but also in groups. This process has the important factor – the local transfer, e.g. local bus arrival and requirements for the passengers from airline or tour operator.

Fig. 2 shows the results of mapping of passengers' arrival at the airport before departure. For regular flights shown the mean of four flights observed in Tartu airport. Leisure flight observed include barely from Tallinn airport. The difference is coming from the tour operator which requires that passengers to the flight arrive at the airport at least 2 hours before departure. For regular flights such an early arrival notices often given only as a recommendation.

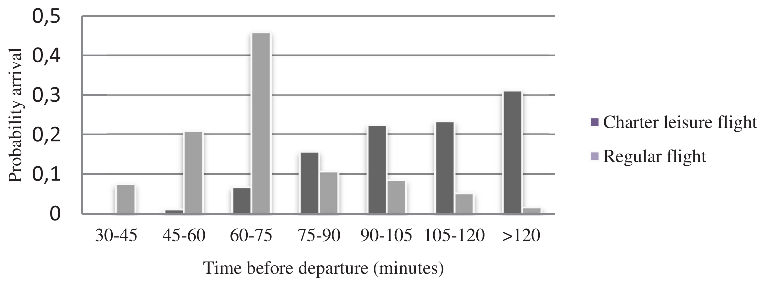

Fig. 2. Arrival of passengers.

During the observations we found, that unless the queue the ground handling staff frequently focuses on customer service incl. conversation with passengers and time which going for service of passenger longer than in the case with the queue. This is consistent with the fact which has been brought out by (Mehri *et al.*, 2008) that “life and quantitative analysis are complicated by the fact that people have been known to balk and renege”. That's why; the service time was measured only if the check-in desk had at least 3 passengers in queue. During the summer of 2016 measured ten regular flights at Tartu airport and two charter flights fat Tallinn airport. The results are given in Table 1. The time length of servicing each passenger at the CD was measured, including the printing of boarding cards or dropping off baggage only. The shorter time of servicing passengers for charter flights could be explained as follows: they were direct flights and there were standard procedures for all passengers.

Table 1. Check-in service time.

	Mean (seconds)	Standard deviation (seconds)
Regular flight	51,5	28,1
Leisure charter*	35,0	6,7

3.3. Security check

The security check processes could be divided into three stages. Let us consider the system with one security lane. The time T_s which taken by the check-in process or the time it took a passenger to pass through the security screening, can be calculated as follows:

$$T_s = T_{s1} + T_{s2} + T_{s3} \,, \qquad (1)$$

where T_{s1} – designates the time needs for passenger preparation for security check including placing outerwear on the trays, removing liquid and electronic devices from hand luggage, etc.; T_{s2} – time for going through the security point including screening of baggage; T_{s3} – time starting from when the passenger has cleared security and collects belongings from the trays etc.

* – measured in Tallinn airport

As passengers pass through different points of the security screening process one after another, for smooth passage through the security check, the following condition shall be met:

$$C_{s1} \sim C_{s2} \sim C_{s3} \,, \quad (2)$$

where C_{s1} – designates the capacity of the first stage of security check, C_{s2} – capacity of the second stage of security check, C_{s3} – capacity of the third stage of security check. Additionally, we can argue that the capacity of security lane C_s based on the condition:

$$C_s = min(C_{s1}, C_{s2}, C_{s3}) \,, \quad (3)$$

the capacity of different stages is calculated as follows:

$$C_{s1} = f(n_{s1}, T_{s1}), \quad (4)$$

where n_{s1} – designates the number of passengers who can prepare for security procedure simultaneously

$$C_{s2} = f(n_{s2}, T_{s2}, T'_{s2}, T''_{s2}, p_l, T'_{s2}, p_p, p_s) \quad , \quad (5)$$

where n_{s2} designates the number of passengers who can pass through the security point simultaneously, p_l – probability of additional check of the passenger's hand luggage, p_p – the probability that the security system alarms during the passenger is passing through the screening, p_s – the probability that the security system lead the passenger to pass additional security check which is related to the airport security program or software of security equipment, T'_{s2} – the time for additional luggage check, T''_{s2} – the time for additional security check of passenger.

Due to the confidentiality of the information, we cannot disclose the values which are related to the capacity C_{s2}, but we note that the process can be significantly accelerated if for additional security procedures the airport administration hired additional security persons. This helps to increase n_{s2} but with restrictions from the airport security procedures.

$$C_{s3} = f(n_{s3}, T_{s3}), \quad (6)$$

where n_{s3} – number of passengers who can finish security procedure simultaneously.

Table 2. Temporary values of security check.

	Mean (seconds)	Standard deviation (seconds)
T_{s1}	40.6	15.4
T_{s3}	81.6	33.6

During the observations the values of T_{s1} and T_{s3} were measured. The results are shown in Table 2. Note that according to the condition (2) to ensure smooth passage through the security check the space for the passengers cleared from the security check has to be approximately two times larger more than the space for preparing passengers.

3.4. Boarding

The boarding procedure in regional airports is one of the easiest and takes a very short time. A regional airport, as usual, is not equipped with boarding bridges and mostly do not use buses for transporting passengers to the aircraft. Passengers can walk straight to the aircraft via the apron. Our observation revealed that it takes far less time than the security procedures, from 4 to 7 seconds per passenger, depending on the airport ground handling personnel qualification, passengers' readiness and technology used. From the point of view of management of capacity, this fact becomes essential for airports with two or more security lanes.

Conclusion

Modelling could be a helpful method for airport infrastructure development and optimisation of operations. We have to admit that previous studies have a limited consideration of regional airports specificities. Planning based on the modelling of airport terminal dynamic capacity which is coming from the specificity of regional airports can be a substrate for the design of airport terminal, decision-making in personnel management as well as choosing technologies to be used. This way the limits in lengths of queues due to LOS will serve as the input for dynamic capacity planning and the results of dynamic capacity optimisation with the required square meters per passenger will serve as the input for terminal planning from the point of view of static capacity.

Maximization of the effectiveness of using facility and personnel can be linked with contradictory terms from the point of view of LOS: procuring the queues at any stage of the service. At the regional airport capacity planning a considerable role is played by the arriving time of local commuter or transfer bus. Such a tool could be especially easily applied if provision of this service is supported by local authority. From the point of view of modelling, the arriving time of the transfer bus is not the value of probability but the tool of airport capacity management and could be investigated in terms of the probability of arrival at the given time.

To ensure the efficiency of dynamic passengers flow through terminal, the LOS in boarding gates area has to be attractive so that passengers proceed immediately to the security check. Hereby, the airport terminal authorities could expand the seating capacity for passengers, or contract with service vendors who will open a café, children's play area, etc.

The results of modelling are useful as they benefit the regional airport infrastructure and operations planning, including the separation of departing flights, if necessary. The scenarios applied are in normal condition, without uncertainties such as aircraft long-time delays, check-in security equipment failure etc. For according the uncertainties the airport administration has to prepare backup plans and procedures or have risk analysis to be made.

The results of modelling must be implemented along with cost analysing, where the costs related to improving dynamic capacity have to be compared with the costs of infrastructure development and maintenance.

The fact that a compact infrastructure allows us to streamline processes in the simulation by excluding the passenger moving times in terminal practically serves as a competitive advantage of regional airports and has partly been realized. Often airlines demand that the airport's ground handling close the check-in 35 or 40 minutes before any departure. This in caused by the need of completing the loading sheet for departing aircraft. Minimizing of this time could reinforce the regional airport competitive advantages and create additional opportunities for capacity optimisation.

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Publication III

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Competitiveness Analysis of Regional Airports Based on Location Planning Models: the Case Study of Finland

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Abstract

Airports are playing an important role in transport system. As a result of different investment projects, a number of regional airports were opened all over Europe during the last decade. Experience shows, that most of them are still unable to sustain themselves. As a consequence of air transport market liberalization, some European airports lost regular air connections altogether. This fact started an active discussion about necessity of some regional airports and their development during last years, which is still in process. The main goal of this article is to assess the competitiveness level of each regional airport in Europe and to compare these airports between themselves. The methodology for to realize such kind of evaluation is based on the numerous location planning models and their comparison. The article also analyzes the airports' main parameters. These parameters of regional airports will be used to create a basis for decisive criteria and, thus, to adapt standard models that meet the needs of competitiveness analysis.
KEY WORDS: *regional airport, location planning, competitiveness*

1. Introduction

Air transportation in Europe has been undergoing a significant period of development after air transport market liberalization. A lot of attention was paid to the impact of market deregulation, to the airports' as improvement of land infrastructure and, especially, to airports of higher demand.

Before market liberalization, domestic airports had only limited possibility to accommodate regular routes abroad. That is why, on the one hand, the regional airports have been related with feeder flights to the main hub, point-to-point internal flights or charter flights. On the other hand, the airlines, which were state-owned "flag carriers", received subsidies [1], and enjoyed the exclusive rules for operating international regular routs. But flag carries had to operate the flights to regional airports in their own countries as well.

Also the state-owned airports' network expanded. Airports are considered not only as an infrastructure element to ensure the mobility, but also as an approach to increase the economic competitiveness of regions, where they are situated. Not all plans have been successfully realized, because due the impact of market liberalization numerous regional airports are losing or have already lost their traffic. Serving as examples of recent unsuccessful development projects are the airports in Ciudad Real Central, Castellón or Łódź [2-4].

At the same time, the European Commission starts to focus on the regulation of public investments to European airports to ensure more private investments for renovation and development of the airports [5]. In competitive environment it means that some regional airports will lose municipal or state support and can stop their operation altogether. However, an unbiased methodology is needed for decision making. The aim of this research is to consider regional airports as competitors for passengers and, thereby, also for funding.

2. Regional Airport Theory

Generally, numerous studies are focusing on the concept of regional airport as self-evident. But some admit that this is problematic [6]. Frequently, the regional airport is related to productivity of region and it has importance for local economic development.

There are several viewpoints on the definition of regional airport. For example, one part of research works associate regional airports with regional aircrafts or aircrafts, which are used by regional (feeder) airlines. Another part of research studies discusses the regional airport as a part of "multiple airport region" (so-called MAR), where the focus of research is on regions with numerous airports. But it does not rule out "the need for the study of the individual airports" [7].

Regional airport could be understood as a non-hub airport, without transfer traffic. But, theoretically, if an airport has two different routes, it is possible to connect them. In practice, the timetables and airlines' policy have to support transfer traffic. For example, the Gothenburg Landvetter airport services more than 6000000 passengers annually [8], but there are no airlines, which are focusing on this airport as a hub for their transfer traffic.

The USA methodology for airports classification is based on the statistics of enplaned passengers in airport [9]. Table 1 shows the results of applying this methodology for the European environment [10]. This study was done for year 2015 and took into account the situation that the number of enplaned passengers is equal to the number of the arrived ones.

Table 1

US Federal Aviation Administration methodology of airport categories for Europe environment

Part of article	Common Name	European airports*
Large: 1% or more	Large Hub	More than 9.18 mil
Medium: at least 0.25%, but less than 1%	Medium Hub	At least 2.30 mil, but less than 9.18 mil
Small: at least 0.05%, but less than 0.25%	Small Hub	At least 0.46, but less than 2.30 mil
Non-hub: more than 10,000, but less than 0.05%	Non-hub Primary	More than 20.000, but less than 460.000
**amount of served passengers at 2015*		

Source: [10]

European approach to identify the limits, which are used by decisions to cover airport's operating costs as well as airport investments by public funding, classifies all airports according to their passenger turnover. Based on such a simple idea, this method establishes investment rates and relative financial viabilities of airports depending on their size, which are presented in Tables 2 and 3, respectively [5]. The main problem here is that regional airports "most often rely on public support to finance their operations" and development instead of setting goals to achieve profitability.

Table 2

Investment rates depending on size of airports

Size of airport based on average passenger traffic (passengers per year)	Maximum investment aid intensity
>3-5 million	up to 25%
1-3 million	up to 50%
<1 million	up to 75%"

Source: [5]

Table 3

Categories of airports according to their financial viability

Passengers	Description
Up to 200000	May not be able to cover their operating costs to a large extent
Between 200000 and 700000	May no be able to cover their operating costs to a substantial extent
Between 700000 to 1 million	Should in general be able to cover their operating costs to a greater extent
Between 1 to 3 million	Should, on average, be able to cover the majority of their operating costs.
Above 3 million	Usually profitable at operating level and should be able to cover their operating costs.

Source: [5]

Thus, on the one hand, the European Commission did the step need to fix up the airports' network in Europe. On the other hand, European countries have the opportunity to arrange the regional airports for sustainable support of regional development funds.

Based on the established hierarchy of US airports and the EU legislation, this research investigates into the airports in Finland, which are serving more than 20000 and less than 3000000 passengers annually. In such case, the lower level – less than 20000 passengers per year – includes only very small airports with limited capability for transportation, whose costs are covered by state/local budget. The higher level – more 3000000 passengers annually – includes airports, which have strong possibilities to be a hub and to achieve profitability with the help any additional support.

3. Airports in Finland

Finnish airport network is considered as a research object for the case study. Finavia is a state-owned company, which is responsible for maintaining. supporting and developing this network. Its airports are recognized worldwide for their Snow-how, which means expertise on dealing with harsh snow conditions at airports [12]. By the early 2017, Finavia's network consisted of 25 airports, which were, theoretically able to service domestic and international flights:

- 18 civil airports;
- 4 joint operation airports (Jyväskylä Airport, Kuopio Airport, Rovaniemi Airport, Tampere–Pirkkala Airport);
- 3 military airports (Halli Airport, Utti Airport, Kauhava Airport).

It must be added that within the scope of airport network correction Varkaus Airport was closed in 2016. It was due to the lack of flight connections. [13] Also there is an important decision to be made with regard to Helsinki-Malmi Airport: on the one hand, in the year 2014 it was decided to transfer the property of the airport land to the City of Helsinki [ibid], but, on the other hand, the initiative to save Helsinki-Malmi Airport was submitted and thoroughly discussed in the Finnish Parliament in the beginning of 2017 [14].

Official statistics concerning the number of passengers who passed through all these airports during 2014-2016 are presented in Table 4. [15] Data of passenger traffic in airports in Finland provided by Finavia and presented in Table 4 as well as in Fig. 1 shows that there has been an increase in the volume of passengers, who arrived to or departed from the Finnish airports in both domestic and international connections. Also it must be mentioned that the largest part of

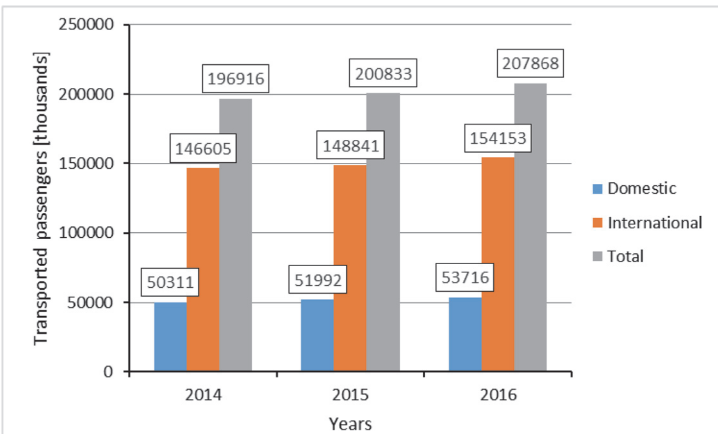
Finnish passenger air traffic emanates from international transportation. In 2016 the total number of passengers travelling to and from Finland was 20,786,846. There were two airports with passenger turnover more than 1 million per year. On the top of the list there was Helsinki-Vantaa International Airport, which gathered more than 17 million passengers. It is 82.67% of the total passengers, who passed through this Nordic country.

Table 4

Passenger traffic in Finnish airports, 2014-2016

	Name of airports	IATA codes	2014	2015	2016
1	Helsinki-Vantaa Airport	HEL	15948760	16422266	17184681
2	Oulu Airport	OUL	960547	982723	1027495
3	Rovaniemi Airport	RVN	444561	478347	487857
4	Turku Airport	TKU	297858	312105	324077
5	Vaasa Airport	VAA	325886	282437	288520
6	Kittila Airport	KTT	234792	226819	257545
7	Kuopio Airport	KUO	260364	232267	227194
8	Tampere–Pirkkala Airport	TMP	412609	357082	208930
9	Ivalo Airport	IVL	142719	155208	179627
10	Joensuu Airport	JOE	138219	133726	122543
11	Kokkola-Pietarsaari Airport	KOK	68669	88039	88766
12	Kajaani Airport	KAJ	71854	84029	85853
13	Kuusamo Airport	KAO	73432	68905	76848
14	Jyväskylä Airport	JYV	55706	61844	62448
15	Kemi-Tornio Airport	KEM	59040	56342	61314
16	Mariehamn Airport	MHQ	52097	59336	59544
17	Enontekiö Airport	ENF	19468	21390	22273
18	Lappeenranta Airport	LPP	89551	35792	0
19	Pori Airport	POR	24983	11066	9629
20	Savonlinna Airport	SVL	10458	13533	11600
21	Halli Airport	KEV	0	14	54
22	Helsinki-Malmi Airport	HEM	0	17	34
23	Utti Airport	UTI	0	10	14
24	Kauhava Airport	KAU	0	0	0
25	Varkaus Airport	VRK	20	0	0

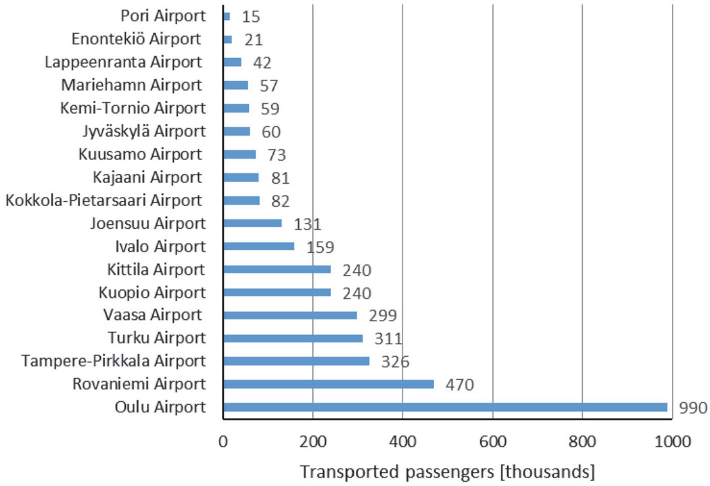
Source: own work based on [15]



Source: own work based on [15]

Fig. 1 Amount of passengers passed through Finish airports, 2014-2016

In the case of Finland, the airport network is more logical compared to those of Norway or Sweden, as Finland there is no dense concentration of airports in one single area and, instead, the airports are distributed more evenly all over the country. In any case, from this point forward, only the airports with higher figures than 20 000 passengers will be studied. Thus, 18 out of 23 airports will be considered as real competitors – alternatives for passengers willing to travel to and from Finland. It must be mentioned that this set includes such airports as Lappeenranta Airport and Pori Airport, which do not fully fit into the frame of requirements set. On the one hand, they both lost passenger traffic during recent years. The first one was temporarily closed starting from the year 2016 because of Ryanair resignation, but an average value of served passengers from 2014 till 2016 is still more than 20 000. The second airport started to grapple with problems just in 2015, when the traffic decreased first time - reaching below 20 000 passengers. On the other hand, Lappeenranta Airport as well as Pori Airport have a well-developed infrastructures and, therefore, potential to be competitive. Therefore, they will be included in calculations. The Figure 2 presents average volumes of passengers served by the selected airports. Average values were calculated based on three years: 2014, 2015 and 2016.



Source: own work based on [15]

Fig. 2 Average amount of passengers passed through selected Finish airports

4. Location Planning Models

The good location of a regional airport is one of the key factors, which has influence on its competitive performance: has a good location with regard to potential clients in mind, there are more opportunities for sufficient passenger traffic. To assess the locations of competing airports, the facility location models could be used. Problems arising when attempting to assess some air transport infrastructure appropriate models has given topics for several studies. Their main focus was oriented to finding a suitable place to build an airport as a new infrastructure element. The first study in this field was done by Omer Saatcioglu in 1982 [11]. Nowadays, the optimization of the created airport networks starts to be the main issue. But, at the same time, there is still a lack of studies, which apply location planning models to assess competitive performance of airports.

According to the classification proposed by Current et al. [16], basic facility location models can be divided into problems based on maximum distance and problems based on total (or average) distance. Distance could be considered here not only as measure of length, but also as measure of travel time or cost. Within the scope of this research paper, one model of each type was chosen. An important point here was the possibility to determine an acceptable number of facilities, which can be opened based on calculation results.

The P-Center model was selected as the first approach. [17, 18] It minimizes the maximum distance of each node from its closest facility, or in other words from the one it is assigned to. There are two possibilities for solving it. If the facility has to be on the node, then it is called a Vertex P-Center problem. On the other hand, if it can be located anywhere along the arcs, it is called Absolute P-Center problem. Both cases can be either weighted or unweighted. The difference between them is the following: by the weighted version, the distances to cover are multiplied by a factor, which represents the importance of that node ahead of its neighbors (commonly the level of its demand). Noticed that this minimum distance is determined endogenously [16]. The P-Center model can be described as follows:

Goal function:

$$Z = R \rightarrow min\,. \tag{1}$$

Constraints:

$$\sum_i x_i = p\,; \tag{2}$$

$$\sum_i y_{ij} = 1;\;\; \forall j\,; \tag{3}$$

$$y_{ij} - x_i \le 0;\;\; \forall i, j\,; \tag{4}$$

$$\sum_i d_{ij} \cdot y_{ij} \le R;\;\; \forall j\,; \tag{5}$$

$$x_i \in \{0,1\} \ \ \forall i \ ; \tag{6}$$

$$y_{ij} \in \{0,1\} \forall j \ , \tag{7}$$

where d_{ij} is a distance from demand node j to facility i; x_i takes the value 1, if a facility is located at candidate site i, otherwise it is equal 0; y_{ij} take the value 1, if demand node j is assigned to facility i, otherwise it is equal 0.

The objective function (1) minimizes the demand-weighted total distance traveled. Constraint (2) defines a number p of facilities to be located. Constraint (3) requires each node to be served by only one facility. Constraints (4) assure that nodes are assigned only to open facilities. Constraints (5) state that the distance between any demand node and the facility which will serve it, must be less than the maximum distance between a demand node and its nearest facility. Finally, constraints (6) and (7) are standard integrally conditions.

The second approach is the P-Median model. [17, 18] It is one of the most popular models to solve the facility-planning situation. The model considers the weighted sum of all distance form each node to its nearest facility, and finds the suitable location of the facilities under the premise to minimize the distance mentioned above. The P-Median model can be described as follows:

Goal function:

$$Z = \sum_i \sum_j D_j \cdot d_{ij} \cdot y_{ij} \to min \ . \tag{8}$$

Restrictions:

$$\sum_i x_i = p \ ; \tag{9}$$

$$\sum_i y_{ij} = 1; \ \ \forall j \ ; \tag{10}$$

$$y_{ij} - x_i \le 0; \ \ \forall i, j \ ; \tag{11}$$

$$x_i \in \{0,1\} \ \ \forall i \ ; \tag{12}$$

$$y_{ij} \in \{0,1\} \ \ \forall j \ , \tag{13}$$

where D_j is a demand at node j; d_{ij} is a distance from demand node j to facility i; x_i takes the value 1, if a facility is located at candidate site i, otherwise it is equal 0; y_{ij} take the value 1, if demand node j is assigned to facility i, otherwise it is equal 0.

The objective function (8) minimizes the maximum distance between a demand node and its closest facility. Constraint (9) defines a number p of facilities to be located. Constraint (10) requires each node to be served by only one facility. Constraints (11) assure that nodes are assigned only to open facilities. Finally, constraints (12) and (13) are standard integrally conditions.

Table 5

Population of Finish counties

Names of counties	**Capitals of counties**	**Population of counties**
Åland Islands	Mariehamn	29214
Central Finland	Jyväskylä	276196
Central Ostrobothnia	Kokkola	69027
Kainuu	Kajaani	74803
Kymenlaakso	Kotka and Kouvola	177659
Lapland	Rovaniemi	180207
North Karelia	Joensuu	164085
Northern Ostrobothnia	Oulu	411150
Northern Savonia	Kuopio	247776
Ostrobothnia	Vaasa	181441
Päijänne Tavastia	Lahti	201685
Pirkanmaa	Tampere	509356
Satakunta	Pori	221740
South Karelia	Lappeenranta	130506
Southern Ostrabothnia	Seinäjoki	191860
Southern Savonia	Mikkeli	148975
Southwest Finland	Turku	475543
Tavastia Proper	Hämeenlinna	173781
Uusima	Helsinki	1008781*
**Population of Uusima county does not take into account inhabitants of the Finish capital – Helsinki*		

Source: own based on [19]

To adapt above-described models, selected regional airports will be considered as facilities. Capitals of Finnish counties will be considered as node or demand node. It is assumed that they are gravitation points of their administrative districts. Population of counties will be considered as demand or weight of county. At the moment, Finland is divided into 19 administrative counties, which are presented in the Table 5. Two additional important assumptions are following:

- Helsinki is not taken into account because of the immediate proximity to the Helsinki-Vantaa International Airport;
- Kymenlaakso has two capitals, which divide county population in accordance with their populations (Kotka – 68886 and Kouvola – 108773).

5. Results and Discussions

Both models, P-Center-problem and P-median-problem, were calculated for P equal from 1 to 18 taking and not taking into account the populations of counties. The results of calculations are presented below.

The ranking obtained in Table 6 shows unexpected results, as there is no evident correlation between location and annual number of passengers.

Lappeenranta Airport, which was funded by the Finnish national agency Finavia, is now funded as a private municipal company. The fact of not being under state control provides Lappeenranta with the opportunity to offer a range of connections and services that weren't earlier. Its location, which is ranked number 1 for its suitability in Finland, and its proximity to Helsinki and St. Petersburg, makes it attractive for tourists as well as for potential investors. Even though the airport has remained inactive for the past year, starting from September 2017, 12 new charter flights to international locations will still be available. [20] The airport has an appropriate runway to receive big narrow-body aircraft such as Boeing 737 or Airbus A320.

Another surprising find is that the Rovaniemi Airport, which has the 2nd highest traffic of passengers in Finland among the ones that have been studied, has been ranked in the 14th position. Even though Rovaniemi Airport is not ideally located, other factors such as touristic destinations come into play when analyzing this case. In fact, Rovaniemi holds Santa Claus village, which is one of the most demanding attractions of the Lapland region during winter season. On the other hand, Turku Airport, which had the 3rd highest number of passengers in 2016, has been ranked in 2nd place. Turku has the potential to increase its traffic due to its suitable location because it is less than 2 hours away from Helsinki by car, and for its proximity to Stockholm using ferry connections.

Table 6

Results of p-center model calculations

Finish airports	Basic ranking	Passenger volume	p-center model without population		p-center model with population	
			Model ranking	Points	Model ranking	Points
Oulu Airport (OUL)	1	990255	7	18	3	48
Rovaniemi Airport (RVN)	2	470255	14	7	8	9
Tampere-Pirkkala Airport (TMP)	3	326207	3	41	2	53
Turku Airport	4	311347	2	57	1	152
Vaasa Airport (VAA)	5	298948	6	27	4	22
Kuopio Airport (KUO)	6	239942	4	39	5	22
Kittila Airport (KTT)	7	239719	15	2	15	0
Ivalo Airport	8	159185	16	0	16	0
Joensuu Airport	9	131496	9	13	6	16
Kokkola-Pietarsaari Airport (KOK)	10	81825	10	12	9	8
Kajaani Airport (KAJ)	11	80579	12	11	12	2
Kuusamo Airport (KAO)	12	73062	17	0	17	0
Jyväskylä Airport (JYV)	13	59999	5	38	11	5
Kemi-Tornio Airport	14	58899	13	8	13	2
Mariehamn Airport (MHQ)	15	56992	8	17	14	2
Lappeenranta Airport (LPP)	16	41781	1	58	10	8
Enontekiö Airport (ENF)	17	21044	18	0	18	0
Pori Airport (POR)	18	15226	11	12	7	11

Source: own

The number of available connections has also been considered a key element in determining the passenger traffic, which also helps to explain the discrepancy between number of passengers and the ranking. In general, airports with traffic below 100,000 passengers operate domestic flights as a regular scheduled service. In most cases, these airports offer no seasonal or charter flights and those that do, do so based on touristic attractions. A good example of this situation is definitely Kuusamo Airport. Not being selected by the model but being the 12th in the total number of passengers, Kuusamo Airport basically attracts passengers due to the fact that nearby there is one of the biggest ski resorts in Finland and this airport is also used for visits to Lapland region. On the other hand, Jyväskyä Airport, which has been ranked in the 5th position but has had the 13th highest in traffic of passengers, lacks a proper public transportation network. The main reason to explain why it has been ranked in such a good position its location in the middle of the south side of the country, which allows reaching several destinations.

Table 7

Results of p-median model calculations

Finish airports	Basic ranking	Passenger volume	p-median model without population		p-median model with population	
			Model ranking	Points	Model ranking	Points
Oulu Airport (OUL)	1	990255	7	19	6	28
Rovaniemi Airport (RVN)	2	470255	10	12	7	12
Tampere-Pirkkala Airport (TMP)	3	326207	1	96	1	104
Turku Airport	4	311347	5	22	4	38
Vaasa Airport (VAA)	5	298948	3	36	5	36
Kuopio Airport (KUO)	6	239942	8	17	3	39
Kittila Airport (KTT)	7	239719	15	0	14	0
Ivalo Airport	8	159185	16	0	15	0
Joensuu Airport	9	131496	11	12	11	8
Kokkola-Pietarsaari Airport (KOK)	10	81825	13	6	13	6
Kajaani Airport (KAJ)	11	80579	6	22	12	7
Kuusamo Airport (KAO)	12	73062	17	0	16	0
Jyväskylä Airport (JYV)	13	59999	4	29	8	11
Kemi-Tornio Airport	14	58899	14	2	17	0
Mariehamn Airport (MHQ)	15	56992	9	16	10	9
Lappeenranta Airport (LPP)	16	41781	2	64	2	52
Enontekiö Airport (ENF)	17	21044	18	0	18	0
Pori Airport (POR)	18	15226	12	7	9	10

Source: own

Ranking generated by P-Center model has considerably changed when weighting the function with population. Unlike the first case without weight, it can be stated that the top 10 in suitable location are 8 of the highest passenger traffic airports. Thus, it can be considered that in the case of this Nordic country, there is a slight correlation between location and passenger traffic volumes. Nonetheless, in both cases, the model does not include Ivalo, Kittilä, Kuusamo and Enontekiö airports. Special mention must be made about Lappeenranta airport because in terms of population when the population has been considered, it has considerably dropped its position from the 1st in the ranking to the 10th position. This proves that even if it can be a priori well located, the number of population is a key element considered when locating an airport.

As it has happened with the P-Center model, the P-Median model does not select Kittilä, Kuusamo, Ivalo and Enontekiö airports (Table 7). This proves that these airports are not well located and should not be financially supported. In fact, Kittilä, Ivalo and Enontekiö airports are located in the Lapland county, a region with low population in comparison with the size of the county, which is the highest in Finland. Nevertheless, it is quite surprising that Kittilä Airport, which is ranked as the 7th highest in passenger traffic, is not selected. Analyzing its features, it can be mentioned that the airport has a strong dependency on seasonal and charter flights, which account for 88% of its current operations.

6. Conclusions

This work presents an approach for evaluation of regional airport location which is based on the location planning models. The background of the regional airports classification has also been given.

The objective of this article was to develop the methodology for assessment of regional airport location. Data of regional airports in Finland has been used for the analysis. For achieve the objective the authors evaluated the airports' locations with P-Center and P-median models and completed the airports' ratings. The data received was compared to the ratings that have been obtained about airports' passengers turnover. Inconsistencies in calculated ratings and ratings witch are based on the airport passengers' traffic volumes will be the subjects for further research. From this point of view, we can designate the future steps to develop the topic.

Firstly, other Scandinavian countries' data could be considered. It could give the wider picture of usability of the models and offer outcomes such as improvement of the classification of regional airports.

Secondly, some economic factors which have impact on the airports' success, such a structure of local economy and GDP per capita, could be considered.

Thirdly, more weight parameters, such as airport infrastructure features, availability of high speed railways and already existing regular international air connections, could be considered for assessing the airports' ability to be integrated into the global transport network.

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TRENDS IN DEVELOPMENT OF AIRCRAFT FOR REGIONAL ROUTES: IMPACT ON THE EUROPEAN AIR TRANSPORTATION SYSTEM

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Keywords: Regional aircraft, air transportation system, Public Service Obligations

Abstract: The beginning of the twenty-first century in air transportation is characterized by increasing competition between (regular, i.e. not low-cost) airlines, which in its turn affects the low cost airlines by necessitating for them the operating of aircraft with larger seat capacity also on local routes, with the goal of operating the aircraft at lower cost per available seat kilometer. Taking into account the importance of air connections for the regional economy, the local authorities are obligated to support regional airports and impose public service obligations on some routes. This study examines the regional aircraft development after the air transportation market liberalization, while also delving into the background of differences in environments of operation in Europe and United States. To evaluate the regional routes' equipment competitiveness, this research is focusing on to the regional aircraft fuel consumption which is the considerable factor for airline's operating costs. Analysis of the differences between operating environments in Europe and the United States is based on an earlier review of the research findings on development of the markets after liberalization, and the role regional aircraft in air transportation system. Also, the comparisons of the profitability and airlines' strategies in both regions are given. The results provide insights into the main drivers of regional aircraft design and development from the demand's point of view.

1 INTRODUCTION

One of the identified, key priorities of Aviation Strategy for Europe [20] focuses on "tackling limits to growth in the air and on the ground, by reducing capacity constraints and improving efficiency and connectivity". Its content is coherently linked with that of the other one; "improving services, market access and investment opportunities with third countries, whilst guaranteeing a level playing field" [20]. Factually, the steady growth in air transport has not affected all important airports in Europe.

Infrastructure of regional airports could be seen as an access gateway to the surrounding region for people mobility, for social equity and economic growth. At the same time, some smaller ones, e.g. non-hub airports or often also called regional or peripheral airports, will either lose their air traffic or get in a hurry of developing it for themselves. If there is no operator willing to provide scheduled services on some air route which is vital for regional development, “under the conditions imposed, the government may restrict a single carrier’s access to the route financial compensation to the carrier in compliance with the Public Service Obligations (hereafter PSO)”. [4]. This trend affects not only the EU outlying regions, but also Central European airports. For example, in 2017, two airports in Czech Republic were seeking potential carriers, with the help of PSO tenders. The Ostrava airport wanted to find an airline which could operate the air routes to Amsterdam and Helsinki; while the Brno airport was looking for airline to operate the route to Munich [21]. Several research articles have their focus on PSO effectiveness, [1, 4, 15, 16]. In some cases, it is also understandable as this applies to hard-to-reach locations, such as small islands. At the same time, there is noticeable interest for supporting international routes also under the rules of the PSO.

The need to identify of the causes leading to the decrease of the number of regional aircraft in Europe, led to the two-fold goal to be reached in this paper: first, to assess the competitiveness of regional aircraft; and second, to examine conditions in US-EU the air transportation markets.

2 OVERVIEW OF MARKETS FOR REGIONAL AIRCRAFT

In the 21th century the world's air transportation system connects thousands of airports. Theoretically, each air route has its own demand characteristics, which is subject to changes over time. Firstly, each air route’s demand cannot be standard in size. Secondly, each air route’s demand cannot be constant and by considering the factors such as seasonality of demand, all extraordinary events, etc. have the impact on demand volatility over time. Sometimes these fluctuations of demand can be totally or partly flattened by revenue management tools if the demand has enough elasticity for price and is flexible in time. It means that at different times for every route one may require an aircraft with different dimensionality determined by the number of seats n, ($1 \leq n \leq x$). For obvious reasons, flights from smaller airports with a modest potential of catchment area could require equipment with suitable capacity or smaller size aircraft.

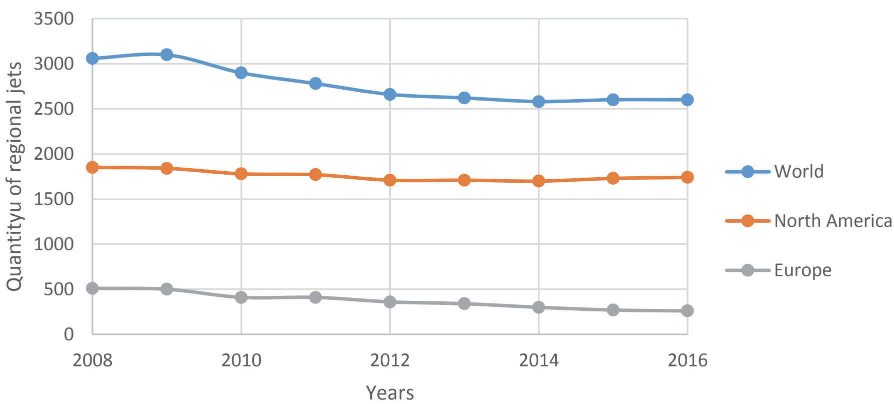

Figure 1. Regional jet aircraft quantity changes 2008-2016 in Europe and North America. Source: [19].

This paper focuses on aircraft size which is determined by number of seats *n* less than 100 ($n < 100$). The sample derives from the availability of statistical data from the given aircraft segment and from the fact that the difference in the capacity of these aircraft from mainline narrow body aircraft families (such as Boeing 737NG/737 MAX and Airbus A320/A320Neo) is about twofold or more. In terms of passengers’ capacity, the latter fact makes it possible to distinguish this aircraft market’s segment from widely used and popular narrow body aircraft. For testing of regional jet (hereafter RJ) aircraft with

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n<100 quantity changes in the world during 2008-2016, data has been collected from the Boeing CURRENT MARKET OUTLOOKS (from 2009 to 2017). Figure 1. shows RJ quantity changes in the world and accordingly in Europe and North America. In this market segment more than half of this size aircraft operated on the North America market alone. Although the number of regional jet aircraft in North America remained unchanged, their number in Europe was diminished by a half during the 8 years.

The circumstances that come to light in Figure 1 can be linked with the liberalization of the US air transport market which started in 1978 as one of the most important milestones determining today's air transport. One of the impacts given by the liberalization of air transportation market in the US, is the strengthening of the hub and spoke system which is measured according as the airport concentration enables the growing of one airline’s market share in hub airports [9]. This was achieved by increasing the frequencies and number of destinations to provide better connection opportunities. [12] For many routes, it was complemented by the introduction of smaller aircraft. [7] Main carriers recognized the using of regional airlines’ services at less profitable markets or in circumstances where the regional airlines had cost advantages [8]. Smaller aircraft, in comparison with larger ones, had lower operating costs, especially when the for regional flights specialized airline operator was a different one, often independent of the main carrier. Today these airlines in US market operate under long term outsourcing agreements [12] for one or more main carriers. [8] Savings are generated by regional airlines using various staffing principles, including salaries. Provisions in US major airlines’ pilot contracts that impose limits called “scope clause” on the operation of aircraft, are used by regional airlines. Under the scope clause, the summarized restrictions are [7, 13]:

1. number of seats in the aircraft, generally 76 seats or less;
2. aircraft Maximum Take Off Weights (MTOW), 86,000 lb (39 t) or less;
3. ratio of regional jets to mainline jets operating for the airline.

As a result of the ongoing transformation of the US air transport network, it became necessary to operate aircraft at larger distances, which required faster airplanes [3]. This time coincided with the low oil price period at the end of the last century [23]. The number of flights served by RJ increased several times, from 74 routes in 1996 to 1091 routes in 2005 [3].

European air transportation liberalization was a step-by-step process. [2, 11]. “The ‘Third Package’ of European Union air transport liberalization measures took effect on 1 January 1993 and has substantially reduced the restrictions on interstate flight operations. The EU commuter carrier sector is clearly at an earlier stage of development.” [11]. Comparing the liberalization processes in EU with that in the US one can find that “the EU liberalization package does not address the role and potential of smaller air carriers in the single market and accordingly does not attempt to redefine the role of air transport in linking smaller centres in the much larger European Union”. [11] In Europe, one must also take into account the fact that in the European Union there was an air transport system in which the Member States had their own national airlines, whose activities also supported separate bilateral agreements with third countries. Mainly, flag carries or subsidiaries have also been operators of RJ and turboprop aircraft, which in turn has prevented the creation of different working conditions for smaller aircraft personnel.

The earlier market liberalization in the US contributed to the emergence of nationwide air carriers operating in the single economic space where all airlines can see the whole US market like a home market. It has been found that “use of larger aircraft with lower flight frequency may constitute a better strategy in a slot-constrained European environment”. [6] This claim can be understood as highlighting the cost-effectiveness of large aircraft. Additionally, the bigger long haul aircraft using maximum high density seat configuration will be more fuel effective on shorter routes compared to the smaller ones [10].

However, the analysis [8] of regional air fares in different countries has revealed that in North America the regional fares are considerably higher than those in Australia, New Zealand, Norway and Sweden. The authors have observed the regional airlines as a strategic tool implemented by the network companies to compete against "less efficient airlines" and found that cooperation is based, in particular, on servicing business destinations, since leisure destinations have higher price elasticity. It has also been found that at markets it is the size that has impact on this cooperation: at small markets "cost advantage of the regional airlines is more significant". [8] Here, however, it can be understood that under the cost-effectiveness the authors have kept in mind the total cost of the aircraft operation.

It has been recognized that there are three windows of opportunity for the development of regional aircraft: market's demand, available technology and regulatory system. [14] The regulatory system for regional aircraft can be linked to the scope clauses and environmental regulations; the demand such as developing of US and EU markets, changes of oil prices, passenger preferences; the technological competitive advantages related primarily to new engines, but also to other innovative solutions such as development and use of new materials [14].

3 FUEL EFFICIENCY OF REGIONAL AIRCRAFT

Fuel consumption remains an important parameter for determining the competitiveness of the aircraft. The share of fuel cost may vary in the aircraft total operating costs. It depends on several factors, including fuel price, aircraft ownership costs, maintenance costs, flight crew costs, etc.

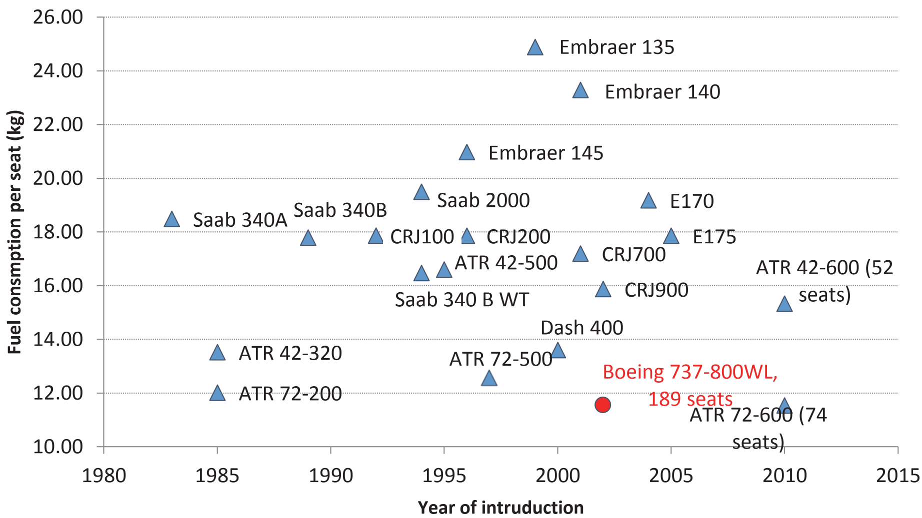

Figure 2. Fuel consumption per seat at the 300nm route.

Figure 2 shows the regional aircraft, turboprop and RJ (33≤n<100) fuel consumption per seat when operating at 300 nm route. The data were collected from articles published in Aircraft Commerce journal and open resources of aircraft manufactures [17-18, 25]. If the sources had left the fuel consumption data at close to 300 nm undisclosed, the results were obtained by interpolation. For comparison, the data of the mainline aircraft Boeing 737-800 (n=189) with winglets have been provided to serve as an example of common equipment of low cost airlines. The author has found, that despite the general tendency to reduce fuel consumption in air transport, the regional lines of the aircraft industry are not strongly in line with this trend. Only ATR 72-600 on shorter routes while, extremely rarely, using high density sitting layout can compete with a Boeing 737-800 winglets equipped configuration having 189 seats.

4 COMPARING THE US AND EUROPEAN AIR TRANSPORTATION MARKETS

Earlier studies on EU-US air transportation markets often focused on cost-effectiveness [7, 8, 10]. Profitability data of the US and EU airlines are given in Figure 3. It can be inferred that airline companies stably earn higher profits per passenger in the US market.

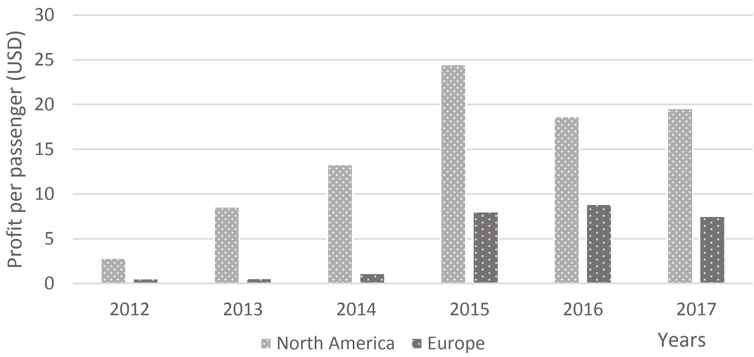

Figure 3. US and European airlines' profit per one air passenger. Source: [22]

To explain the factors affecting profits of US airlines, a comparison of the US and EU airlines has been made (see Table 1), to find out the revenues earned per passenger kilometer by airline companies. United Airlines data is provided both, in consolidated and also separately per each mainline and regional unit.

Airline	Passengers (thousands)	Passenger kilometers (millions)	Average passenger distance, total (km)	Yield in Euro cents (per RPK)
United Airlines consolidated (mainline and regional)	35,152	81,622	2322	8,53
United mainline	24,169	71,567	2961	7,61
United regional	10,983	10,005	911	13,87
KLM	28,562	93,228	3264	7,40
SAS*	26,941	30,561	1134	9,36

Table 1. Operation results of selected European air carries and United Airlines in 2015. Source: United Airlines Announces Full-Year 2015 Profit; KLM. 2015 Annual Report; SAS Annual Report 2014/2015. *- SAS operational year NOVEMBER 2014–OCTOBER 2015

As a rule, European carriers do not provide separate statistics on their regional units. In order to gain a more objective picture, two airlines KLM and SAS were selected in Europe. The passenger turnovers of both airlines are close to those of United Airlines. KLM has its own regional airline KLM Cityhopper. SAS is operating many regional routes in and across Scandinavia. Owing to its geographical location many flights have their destinations across the Baltic Sea, which reduces the competitiveness of other modes of transport. The currency exchange rates were obtained from European Central Bank (ECB) database. From the comparison shown in the Table 2, it appears that if at mainline the US and EU longer routes are almost equal, then on the regional routes, the US market indicator significantly exceeds the European one.

5 DISCUSSION

For bringing out the role of regional aircraft in US air transportation system, there were four motives of using RJ in the US air transportation market: reduction of capacity, frequency supplement, opening of new services and replacement of turboprop aircraft on the longer routes [7]. The lack of these aircraft may interfere with the performance of these functions in the European air transportation system. Two examples of constraints due to the lack of RJ in Europe have been collected from airlines' websites and shown in Table 2.

Route	Airline	Great circle distance (km)	Aircraft	Seats (n)	Scheduled block time
Prague (PRG) – Bucharest (OTP)	ČSA	1084	A319 ATR72-500	140/142/144 58/60/64	1h 55m 2h 45m
Helsinki (HEL) - Gdansk (GDN)	Finnair	768	ATR72-500	68/72	2h

Table 2. Examples of constraints due to the lack of RJ in Europe

The first example is related to airlines' flexibility in following the demand. The Czech national airline ČSA has no RJ aircraft in its fleet and it uses the fuel consumption effective aircraft ATR 72-500 (see Figure 2) for regional routes. This aircraft type is also sometimes used for the Prague - Bucharest route due to the demand characteristics and competition situation requiring smaller size aircraft. It is evident that due to the difference in block time, it is not possible to operate turboprop and mainline narrow body aircraft under the same flight plan (see Table 2). Secondly, thanks to the speed advantages, RJ airplanes could handle more flights per day on such long lines. The same ČSA behavior has been found at other air routes which could be suitable for RJ from Prague in 2018, e.g. Stockholm and Kiev.

The second example is related to the strengthening of the hub and spoke network in Helsinki Airport. Finnair is the national carrier of Finland which is focusing on connecting of European airports with destinations in Asia. In 2018 this airline had no RJ aircraft with n<100 in its own fleet. Consequently, this limits the ranges of the airline to operate possible routes between Central European regional airports and its own hub airport. Considering the operation efficiency, the longest route with Finnair code of ATR 72-500s aircraft is Helsinki-Gdansk (see Table 2).

Developing of technology, for example, within the framework of the European Clean Sky 2 program, is an important consideration while developing appropriate engines for regional aircraft, which would ensure the competitiveness of RJ compared to larger aircraft. By using allegations such as [14] model of windows of opportunity for development of regional aircraft and taking into account the results obtained, one can allege that the major demand as well as accompanying regulations in the form of scope clause, are directly related to the US market as the largest market of this segment aircraft. It can be argued that nowadays RJ aircraft design and production decisions are based on the circumstances of the US market, which, on the one hand, limits both the seats number and MTOW that impedes the application of new technologies. For example, the new but heavier engine for RJ aircraft, PW1200G/1700G is coming from PW1000G family, which was designed primarily for bigger, mainline aircraft, yet and alongside it has also been developed for RJ aircraft. With the reduction of bypass ratio from 12.5 or 12 to 9 for propelling the RJ the smaller engine turned out to be less effective in terms of noise insulation, emissions and fuel consumption than the bigger and more powerful models of the engine's family. [24] Additionally, the launch of the aforementioned engine-powered RJ aircraft will also be delayed due to its failure to fit into the preset scope clause' weight parameters. [13]

Looking at the market size of RJ aircraft, it can be alleged that new technologies can remain unused or their application delayed if the relevant market does not conform to the given aircraft. In order to find differences between US and EU air transport operating conditions, it is also appropriate to look at the competing modes of transport. From the viewpoint of vehicle speed, the high speed train is the biggest competitor to air transport. The analysis [5] "presented the trends in RJ aviation market and focused on main manufacturers: Bombardier of Canada and Embraer of Brazil" argue, that "Europe has different uses for RJs operation due to the extensive network of trains, which can be used on shorter trips". Actually, high speed railway network in EU is much larger that in US. Europe has 9.298 km of high speed rail vs 735 km in the US. [26]

It should also be taken into account that the availability of the regional aircraft in Europe is also limited. Therefore, in order to encourage airline companies to operate airplanes of the same size and using US experience of cooperation between mainline and regional carrier, contracts for the provision of PSO could be based on long-term agreements. Here, it should be taken into account that the PSO's compensation rate depends on the efficiency of the aircraft operation.

6 CONCLUSIONS

This study enabled to recognize regional airports' difficulties that emanate from shortage of regional aircraft in Europe. Despite the growth of air transportation, it turned out that in 2008-2016 the number of RJ aircraft with less than 100 seats decreased in Europe almost by half. At the same time, it has been found that the number of these airplanes, during the period under study in North America, did not make major changes and accounted for more than half of the RJ fleet globally. According to this study, there is reason to assert that the development of regional aircraft is based on North American operating conditions.

In the part of evaluation of competitiveness of RJ aircraft, these analyses focused primarily on the fuel consumption of aircraft, which has a clear impact on operating costs of the regional aircraft, as well as on emissions. The latter fact deserves more and deeper consideration. Here, fuel consumption has been used as a parameter to demonstrate technological development as a fact *per se*. Analysis of regional and mainline aircraft development showed that the fuel efficiency of the respective engines developed is more modest than that of regional aircraft, which is sufficient for the US market but does not fully satisfy European airlines. Comparison of the operation environments in EU and US shows higher profitability of airlines in US, which is partly based on the passengers' higher willingness to pay on regional routes in the US market. The study also revealed that in Europe there is high competition between high speed rail and air transportation. It was found that in order to design competitive aircraft for regional routes, it is also important to create conditions that may lead to an established market. The airlines' consolidation and long-term PSO agreements could be a prerequisite for development of the market for RJ or same size future analogs in Europe.

From the academic perspective, the diverse market research is very important for developing the new projects, such as those related to regional aircraft, in order to ensure future success.

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EUROPEAN REGIONAL AIRPORT: FACTORS INFLUENCING EFFICENCY

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During the recent decade a lot of research has been focused on identification of the importance of regional airport for the local economy and the measuring and predicting of the airport's efficiency. With regard to individual airport planning it turns out that airports are not free in the optimization of infrastructure due the need to comply international aviation standards and recommended practices, one the one hand, and the tendency of air transportation system development including aircraft design and airlines' fleet development, on the other. Furthermore, it is also important to take into account the specificity of each particular airport, including the traffic variability resulting from seasonality, with the airport's mission geared to it. We found, that one of the reasons for the relatively low efficiency of regional airports, given the general trend in the growth in the number of seats for narrow-body aircraft. Likewise, it has been found, that the seasonality of air traffic at regional airports is comparatively high. In addition, this paper spotlights the ways the theoretical model of returns to scale affects the efficiency of the apron of the regional airport and briefly discusses the different interpretations of the definition of regional airport.

Keywords: regional airport, airport efficiency, air traffic variability, regional aircraft

1. Introduction

The airports that were once constructed, sometimes in pursuit of objectives other than those of civil aviation, will eventually be facing the necessity of infrastructure renovation or complete reconstruction. This may arise from the need of increasing their capacity or efficiency, in order to bring airport infrastructure into line with the main focus of airport operations, on the one hand, and from the need of infrastructure renovation, on the other. For example, the International Civil Aviation Organization, hereafter ICAO, (2013) provides a range of depreciation periods, as follows: 15-30 years for runway, taxiways, aircraft stands and 20-40 years for buildings.

The lack of ability of regional airports to cover their operating expenses and invest in development has become general knowledge, reflected also in European Union legislation. The regulation 2014/C 99/03 "Guidelines on State Aid to Airports and Airlines" links the annual passenger turnover of airports with their ability to cover the costs of operation and, also, with their investment potential. At the same time, this document sets limits on state aid in the same areas. With this in mind, the importance of airport efficiency indicators such as input for airport infrastructure and operation planning become crucial.

A number of research works have been completed focusing on measuring and predicting of airports' operational and financial efficiency. For example, Gutiérrez and Lozano (2016) have provided a long list of literature on the inputs and outputs of airports' efficiency analysis. Pavlyuk (2012) gave an extensive review of research papers on this topic by calling attention to airports' spatial competition as a factor affecting efficiency. However, applied research shows, that irrespective of the ownership of airports, public or privatized, small airports have "very low efficiency levels" (Olariaga, Moreno, 2019).

Nowadays, there are many instruments available for airport planning, including simulation with the capabilities of modern software that enables the optimization of an individual airport infrastructure and operations based on forecasts. The data related to individual airport capacity and operational planning could be used as indicators on some extent but they do not reflect the real choices that the airport faces. However, for resolving the issues, it is important to know the demand characteristics. On the other hand, it is important to take into account the forecasts and aircraft size – the criteria emanating, which coming from the mission of airport and the potential aircraft for operating (De Barros and Wirasinghe, 1997).

The objective of this research is to examine the regional airports' efficiency from three perspectives. First, to consider the possibilities of optimizing the airfield according to international aviation standards and recommended practices on the one hand, and the trends in aircraft design, on the other. Second, based on benchmarking, to determine the variability of air traffic due to seasonal effects that arise from the regional airport's business missions in transporting passengers by air. Third, based on airport infrastructure and operational planning, to suggest other features that illustrate how the airport size can impact its efficiency.

2. Methodology

2.1. Regional airport definition

To make the research unequivocal, it is necessary to define the concept of regional airport. In various sources, instead of or in addition to the term *regional airport*, other terms are used as well. Table 1 below provides the varying explanations given to those different concepts or terms.

Besides, the Airport Council International, hereafter ACI, (2010) divides regional airports into two groups: regional with annual passenger turnover more than 5 million and those that are small regional airport with annual passenger turnover below 5 million.

By using those varying terms while referring to regional airport in this study, the authors mean by 'regional airport' non-hub airports that have relatively small traffic of commercial air transportation, that may be located, but need not necessarily be, far from large centres of agglomeration or hub-airports. The authors do not bind the constraints at the choice of airport to its role in the air transport system, whether it is oriented to feeder lines or not, but takes into account the airport's business mission.

Table 1. List of airport's definitions for resulting categorization of regional airport

Concept	**Main characteristics**	**Sources**
Periphery	Located far from large centres of agglomeration, using with "remote"/ the opposite of the core airport/ smaller competitors for nearby hub airports	Tavalaei, M. M., Santalo, J. (2019); Bloice, L. at al. (2017).
Small	By some criteria smaller than others, airports with low volume of traffic	Adler, N., at al (2013); Červinka, M. (2017); Jimenez, E. at al. (2017)
Secondary	Non non-main airport or non-hub airport - the opposite of the main airports, oriented for servicing the own catchment area	Červinka, M. (2017); Dziedzic, M., Warnock-Smith, D. (2016)
Remote	Airport's location isolated from more populated areas by distances or/and lack of transport connections	Donehue, P, Baker, D (2012); Bloice, L. at al. (2017).
Rural	Airports oriented to servicing of general aviation	Donehue, P, Baker, D (2012)
Domestic	US airports which are providing only domestic flights; for the EU old definition which arises from regulated market environment	FAA (2018)
Destination	Airports using the business model as a service centre for the local community, with no or minimal transfer traffic	ACI (2010)
Feeder	Basically the same as *destination* airport, mainly servicing the feeder flights, as a "spoke in hub and spoke system"	Postorino (2010)

Activities by which the regional airports can improve their efficiency indicators and increase aeronautical and non-aeronautical revenues are several. These include focusing on air freight, aircraft Maintenance, Repair & Overhaul (MRO) and manufacturing, training flights and wider cooperation with general aviation sector, servicing of business flights, support of military or search and rescue operations, etc. However, the main parameter for the evaluation of airport ability to cover its operating costs and investments in the airport infrastructure also comprised the number of passengers served.

Though some airports that serve more than 1 million passengers, can cover from their revenue all or large parts of their operating costs, this study focuses on airports with more than 200,000 passengers yet less than one million passengers per year (European Commission, 2014; Pashkevich *et al*., 2017). Combining the two above-mentioned factors, this study focuses on those airports, which are facing difficult financial conditions, but have a significant volume of commercial traffic. In addition, we are taking into account the airports servicing 1-3 million passengers per year while also being oriented to service the low cost airlines (LCC) and, by this, have already increased their catchment area with using "airport leakage" effect (Suzuki *et al*., 2003).

2.2. Comparing aircraft development trends with ICAO recommended practice

The methodology of airport design starts from defining of the mission of the airport including challenges (Medvedev *et al*. 2017). Decision about the aircraft size for which the airport is planned will be made, pursuant to (1) the mission of the airport and (2) the trends in the development of airlines' fleets. In this study, we focus on the tasks for passenger transport and the trends in aircraft design that have an impact on regional airport planning those airports can perform.

From the point of view of servicing the air transport passengers, regional airports have to fulfil the following main tasks:

a) Ensure catchment area accessibility and population's mobility by serving regular flights including taking advantage of the market situation by servicing low cost carrier (LCC) flights.
b) Secure the population's living standards; serve seasonal, regular and charter flights to the leisure destinations;
c) Serve leisure flights if the economy of airport's catchment area is oriented towards servicing incoming tourism.

There are numerous aircraft-related parameters used for airport categorization, one of which is the reference code, which is partly derived from the aircraft wingspan (see Table 2). The reference code is the basis for airport infrastructure planning, e.g., for minimal distance between centre line of runway and taxi ways and for clearance distances between aircraft stands on the apron (ICAO, 2018).

Table 2. Aerodrome reference code (ICAO 2018)

Aerodrome code (number)	**Reference field length (m)**	**Aerodrome code (letter)**	**Wingspan (m)**
1	Less than 800	A	Up to but not including 15
2	800 up to but not including 1 800	B	15 up to but not including 24
3	1 200 up to but not including 1 800	C	24 up to but not including 36
4	1 800 m and over	D	36 up to but not including 52
		E	52 up to but not including 65
		F	65 up to but not including 80

The earlier, letter part of reference code is also influenced by another factor such as aircraft outer main gear wheel span (OMGWS), which since 2018 is a separate parameter for airport infrastructure planning. Nonetheless, an aircraft parameter such as wing span is still playing an important role in aerodrome planning. We have to mention that the type of aircraft plays a greater role in planning the airport infrastructure and operations. For example, the aircraft classification number (ACN) is also important to consider when planning the runway pavement, or the equipment and resources to be implemented, so that they comply with the rescue and firefighting category which conforms to the operating aircraft overall length and maximum fuselage width (ICAO, 2018).

2.3. Regional airports' efficiency

Airports are not decision makers, regards airline operations. The general decisions for opening the routes, timetable, usage aircraft - are traditionally made by airlines or, in the case of charters or Public Service Obligation (PSO) services, by a legal entity ordering flights.

We emphasize that it is not possible to change the infrastructure quickly, as it, in turn, will also requires large resources that the regional airport may not usually have. Pursuant to the aims set for this study, we are focusing on the operating efficiency as it concerns infrastructure planning. Pavlyuk (2012) has highlighted the airport efficiency by using the indicators of airport partial factor productivity (PFP), which are ratios "of a chosen airport output to a given resource used" and divided into the following groups of indexes: labour, infrastructure, financial performance. The same author (Pavlyuk, 2015) presents a list of inputs and outputs used in 96 studies on airports' PFPs. The outputs are mainly representing the air passenger movements (APM) and the number of air traffic movements (ATM). In order to avoid emergence of confusion in the usage of the terms, as ATM is widely used in aviation as an acronym for "air traffic management", the acronym TM (traffic movements) is used in this paper. The inputs most frequently used to measure the airport's infrastructure efficiency, include:

(a) Number of runways, runway length or area.
(b) Aircraft stands (number or area).
(c) Terminal area.

The runway parameters are set according to the aircraft types that will start operating at the given airport, and therefore the specific aircraft types should be considered for operation. According to “Airplane Characteristics for Airport Planning” (Boeing, 2013), the required runway length depends on:

(a) Aerodrome elevation and meteorological conditions of operations.
(b) Aircraft type incl. configuration.
(c) Payload and flight range.

Here it shall be mentioned that the length of the runway has limited possibilities for optimizing for efficiency terms. Attempts to reduce this may result in operating restrictions, thus affecting the attractiveness of the airport as a destination for the aircraft operator, or just make the operation impossible from the point of view of flight safety. However, if one airport is located on higher altitude than the other or is subject to adverse meteorological conditions, the runway dimensions may be even larger to ensure the operation of the same aircraft in the same configuration, regardless of the size of the airport. For the analysis, it is important to include the appropriate TM. In addition to commercial aviation, regional airports can serve general aviation by providing facilities for training flights or state aviation structures’ operations. As an outcome, the number of training flights may account for a higher runway efficiency, even though the operation of light aircraft requires much smaller runway than that of the airport. The maximum runway capacity depends on different circumstances incl. configuration of taxiways and air traffic control procedures. The total capacity of a single runway, depending on the airport and the proportion of take-offs may exceed 40 TM per hour (Janic, 2000).

As general, the aircraft parking stands refer to the airport’s ability to support the traffic of a given airport. But, in that case, the dimensions of the operating aircraft must be taken into account. However, if the airport's secondary activities are airfreight, flight training, MRO or parking for leasing companies, then tying TM and APM is questionable. An inadequate assessment can be made not only of the aircraft stands´ dimensions but also of the intensity of use.

Applied research (Nõmmik and Antov, 2017) shows the possibilities of modelling a regional airport by focusing on the departing passengers’ behavior and the airport terminal bottlenecks capacity. Also, it is possible to optimize apron capacity (Mircovic and Tosic, 2017), once it has been decided, which aircraft types and how are going to use the airport. Individual airport planning needs to be guided by the airport mission, including the information about or from specific consumers.

2.4. Regional airport traffic variability

Each development plan designed, drawing on the results of forecasts. Forecasts are generally prepared on the annual basis. However, on the other side, the demand has its own characteristics. For a single airport, taking into account the annual numbers only are not sufficient for airport infrastructure and operation planning. It is necessary, with regard to regional airports or airports of limited capacity that the changes in traffic demand during the year are taken into account. It is possible to find a solution, e.g. a regional airport with limited traffic, based on the cost/benefit analysis. There are several options available for an individual airport, for optimising the labour or financial productivity but this should always reflect solely the results of extensive research. These options include:

(a) Various airport services may be at the expense of airport staff, but the services may be also outsourced.
(b) Technological solutions that correspond to the status of the airport, including passenger traffic, the level of wages in the country, and other factors that influence the decisions on the implementation of technological solutions. It is also important to consider the local legislation, for example, whether it is possible passenger boarding without their identification at the gate.
(c) Where several regional airports are managed by a single organization, movements of equipment and personnel between airports may be possible, as appropriate.

In order to predict the variability of traffic, it is useful to use benchmarking by taking into account the airports that perform a similar mission. For the investigated airports, this indicator may be vague due to the variability of air traffic resulting from a significant change in demand during the year. Tsekeris (2011) in own research found the significance of seasonality in demand on the airports’ performance. This is especially important because some previous studies contain a result as airports that serve more APM and TM are more effective (Psaraki-Kalouptsidi and Kalakou, 2011) or a statement that “seasonal concentration is higher at smaller versus larger airports” (Halpern, 2011). Proceeding from this, yet taking into account the objectives of the research, we are interested in the finding the maximum of seasonality index for airports capacity and operation planning.

3. Analysis

Based on the objectives of this research and the synthesis of the methodological material offered, the following features have been identified for the regional airport, as they play a critical role in terms of infrastructure and operational planning:

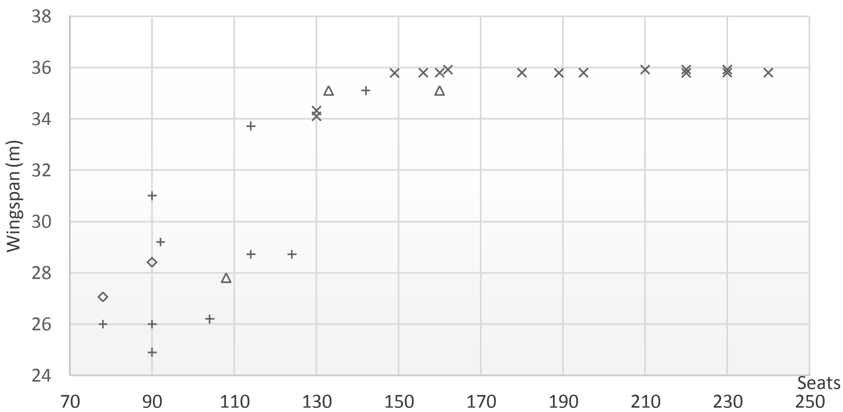
(a) The runway size or size of aircraft stands cannot be always optimized by taking into account the needs of efficiency. That is why the runway efficiency measures indicator TM per runway, which could be replaced for one runway airport with TM, has also limited value for benchmark. It can be considered as an indicator that provides input for planning taxiway(s) configuration in order to minimize construction and operational costs. It can also serve as an indicator of the need to find secondary activities for the airport.

(b) When selecting data for benchmarking, the mission of the airport, which is close to the type of the planned airport, should be precisely defined. Analyzing a particular airport, it is necessary to consider its specific users.

(c) Based on the goals of our research, we are interested in the seasonality of air traffic, as well as in other possible reasons for the low efficiency of regional airports.

3.1. Narrow body aircraft development trend

Considering the importance of aircraft wing span for planning the airport infrastructure, we took into account all the narrow-body aircrafts that have been produced or entered into production during the last decade.



× - 6 abreast seating aircraft; Δ - 5 abreast seating aircraft; + - 4 abreast seating jet aircraft; ◊ - 4 abreast seating turboprop aircraft

Figure 1. Aircraft wingspan by maximum number of seats

Figure 1 shows the data of the narrow-body aircraft with the maximum seating capacity exceeding 70. The figure reflects current decade in production aircraft or planned for the next few years as follows: 6-abreast seating Airbus 320 series, Boeing 737 including NG and MAX series; 5-abreast seating A220 family and SSJ100; 4-abreast seating Bombardier CRJ 700/900/1000; Embraer E and E2 series; MRJ70/90 family aircraft. It also includes the data of Dash-400 and ATR-72 4-abreast seating turboprop aircraft. The data used is issued by the aircraft manufacturers. It is obvious that 36m is an important limit for airplane design, which allows airplanes to use the airport reference code for planning according to the C reference number (see the Table 2). This conclusion can be drawn from 5-abreast and 6-abreast aircraft data with a maximum seat numbers from 135 to 240.

3.2. Regional airport traffic variability

For a regional airport benchmarking, it is important to select suitable objects. In practice, sometimes one carefully selected example is enough for comparison. To ensure the diversity of this study we analyzed five airports' business profiles and 25 regional airports, with five airports per each airport group (see Table 3). For comparison, we included the sixth group with five large airports into the analysis.

Table 3. Airports according to their profile in 2016

Airport type	Airport (Country of location)	APM	TM	Av. TM per day
Remote	Bornholm (Denmark)	268 481	5411	15
	Kirkenes Høybuktmoen (Norway)	306 031	6337	17
	Visby (Sweden)	463 972	9057	25
	Skellefteå (Sweden)	281 187	3024	8
	Kuopio (Finland)	226 872	4013	11
Tourism	Zadar (Croatia)	501 816	5303	15
	Kittilä (Finland)	257 213	2456	7
	Almería (Spain)	908 929	9214	25
	Toulon–Hyères (France)	497 948	7803	21
	Preveza/Aktion (Greece)	482 116	4406	12
Without LCC	Vaasa (Finland)	288 384	5668	16
	Linz (Austria)	431 649	6045	17
	Ronneby (Sweden)	231 860	4204	12
	Kristiansund/Kvernberget (Norway)	250 328	5597	15
	Saarbruecken (Germany)	398 860	6429	18
With LCC	Limoges-Bellegarde (France)	290 308	4208	12
	Kaunas (Lithuania)	740 499	4600	13
	Szczecin (Poland)	459 142	4262	12
	Ostrava (Czech Republic)	236 794	6596	18
	Percara Abruzzo (Italy)	569 315	5084	14
AL with LCC	Skavsta (Sweden)	2 025 019	13102	36
	Girona (Spain)	1 646 736	10314	28
	Niederrhein/Weeze (Germany)	1 853 346	11453	31
	Bratislava (Slovakia)	1 745 967	14816	41
	Frankfurt-Hahn (Germany)	2 514 919	16718	46
Large airports	Stockholm Arlanda (Sweden)	24 696 871	220168	603
	Barcelona (Spain)	43 749 730	290639	796
	Amsterdam (Netherlands)	63 549 632	466845	1279
	Vienna (Austria)	23 318 172	219550	602
	Frankfurt/Main (Germany)	60 668 733	434810	1191

The groups are derived based on the airport activity profile as follows:

Group 1 ‘Remote’: operations in the remote areas. The airports with location far from more highly populated areas have been included in this research.

Group 2 ‘Tourism’: operation with strong tourism orientation.

Group 3 ‘Without LCC’: operation without LCCs. The airports are operating without LCC carriers while servicing schedule and charter flights.

Group 4 ‘With LCC’: operation with LCCs. These airports servicing traditional and low cost carriers.

Group 5 ‘AL with LCC’: specialization for low cost carriers with increasing the catchment area at the expense of a larger airport in the neighborhoods. Owing to the growth of the catchment area with using “airport leakage” effect, the fifth group includes airports with an exceptional passenger turnover of more than 1 million but less than 3 million passengers per year in the category.

Group 6 ‘Large airports’: is a control group of the busiest airports in Europe with different volumes of annual traffic. An additional selection criterion was the presence of a potential competitor in the 5th group.

Proceeding from the objective of the study, we are interested in the maximum values of variability. The data is retrieved from Eurostat (Statistical Office of the European Community) database, under the category "Air passenger transport by main airports in each reporting country” (avia_paoa). For the analysis we used statistics of the operational years 2012-2017. The characteristics of the airports include “passengers carried” as APM indicator and “commercial passenger air flights” as a TM indicator. For each selected airport, in each observed year, the months with the highest traffic variability were selected. Next, the maximum value relative to the annual average were calculated to find the index of variability. Thereafter, for every airport the average MAX values for six years were found and the standard deviations (σ) were calculated. The results are presented in Table 4. Note the higher seasonality at regional airports compared with the 6th group – the large airports. Nor did we find a significant role of LCC in reducing seasonality at regional airports.

Explanation of the reasons of the relatively high standard deviations at regional airports may be an object of further research if it is needed for benchmarking. For example, the high scores of the standard deviation at Kaunas airport can be explained by extraordinary traffic numbers during the closure for reconstruction of the Vilnius Airport in its neighbourhood in the summer of 2017 (Lithuanian Airports, 2018).

Table 4. Variability of traffic in the selected airports

Airport type	Airport (Country of location)	MAX (APM)	σ	MAX (TM)	σ
Remote	Bornholm (Denmark)	1,35	0,12	1,21	0,09
	Kirkenes Høybuktmoen (Norway)	1,22	0,02	1,07	0,01
	Visby (Sweden)	1,93	0,12	1,52	0,25
	Skellefteå (Sweden)	1,22	0,05	1,21	0,03
	Kuopio (Finland)	1,26	0,05	1,24	0,08
Tourism	Zadar (Croatia)	2,44	0,07	2,46	0,21
	Kittilä (Finland)	3,24	0,31	2,02	0,10
	Almería (Spain)	1,60	0,07	1,36	0,09
	Toulon–Hyères (France)	1,55	0,08	1,83	0,06
	Preveza/Aktion (Greece)	2,86	0,12	2,89	0,19
Without LCC	Vaasa (Finland)	1,27	0,03	1,21	0,05
	Linz (Austria)	1,49	0,11	1,28	0,03
	Ronneby (Sweden)	1,23	0,02	1,22	0,03
	Kristiansund/Kvernberget (Norway)	1,16	0,03	1,10	0,06
	Saarbruecken (Germany)	1,47	0,19	1,27	0,07
With LCC	Limoges-Bellegarde (France)	1,30	0.05	1,17	0,05
	Kaunas (Lithuania)	1,48	0,45	1,40	0,68
	Szczecin (Poland)	1,44	0,21	1,31	0,29
	Ostrava (Czech Republic)	2,27	0,13	1,94	0,08
	Percara Abruzzo (Italy)	1,31	0,06	1,33	0,07
AL with LCC	Skavsta (Sweden)	1,41	0,02	1,24	0,03
	Girona (Spain)	1,79	0,06	1,68	0,12
	Niederrhein/Weeze (Germany)	1,39	0,06	1,29	0,05
	Bratislava (Slovakia)	1,95	0,13	1,63	0,08
	Frankfurt-Hahn (Germany)	1,33	0,08	1,22	0,04
Large airports	Stockholm Arlanda (Sweden)	1,15	0,02	1,13	0,03
	Barcelona (Spain)	1,31	0,03	1,21	0,02
	Amsterdam (Netherlands)	1,22	0,02	1,14	0,01
	Vienna (Austria)	1,22	0,03	1,13	0,02
	Frankfurt/Main (Germany)	1,22	0,02	1,10	0.01

3.3. Regional airport efficiency and traffic characteristics

As mentioned above, we found out that aircraft stands can be considered standard, designed for aircraft that meet the reference code C. The capacity of even one runway significantly exceeds the number of commercial flights at regional airports. Let us consider how the size of the airport, or rather the number of aircraft parking stands, can affect the efficiency from the point of view of the returns to scale in regional airport. The aircraft turnaround time or time while the stand is occupied by aircraft has been suggested by us as t = 40 minutes, which can be considered significantly longer than the time it takes for the aircraft to occupy the runway for landing or take off. In our model, the "arrival times of aircraft" does not depend on the airport and can, thus, be considered a random value. In keeping with the above mentioned, we adduce the apron as Erlang multi-channel queuing system where n is the number of channels by which we mean aircraft stands. Based on the underload of the runway as an ineffectively used resource on the one hand, as well as the small opportunity to influence the arrival time of the aircraft on the other, the regional airport apron should correspond to the maximum probability of aircraft reception. In order to ensure uninterrupted reception of aircraft, we do not take into account the possibility of a queue and are guided only by the probability of aircraft serving p which should be maximized as $p \geq 0.995$. The goal is to find out with the condition described in equation (1), how many flights TM_f, (TM_f = TM/2) an airport can serve, dependent on the number of aircraft stands, under the conditions necessary to ensure minimal probability of blocking. In this model, the airport's operating time T is 18 hours (from 6 a.m. to 24 p.m.).

$$p \geq 1 - \frac{\rho^n}{n!} p_0 \quad (1)$$

for what:

$p_0 = \frac{1}{\sum \frac{\rho^n}{n!}}$, where: p_0 – the probability that the channel is free, or a fraction of the idle time of the channels, utilization factor $\rho = \frac{\lambda}{\mu}$, arrival rate $\lambda = \frac{TM_f}{T}$, μ – service rate (μ = 1,5). To measure the efficiency, we used the formula (2) for calculating the potential channel utilization rate by service (K).

$$K = \frac{\rho p}{n}. \quad (2)$$

The result of calculations is shown in Table 5. Based on the results it can be argued, that airport systems with a higher number of aircraft stands and more flights have obvious prerequisites for a higher apron efficiency.

Table 5. The impact of number of aircraft stands on the airport apron capacity and utilization

Number of aircraft stands (n)	**2**	**3**	**4**	**5**	**6**	**7**
System capacity (TM_f)	2	9	19	31	44	59
Utilization rate (K)	0,04	0,11	0,18	0,23	0,27	0,31

In the case of the apron, we took into account the infrastructure only i.e. a place to stop the aircraft, which affects the indicators of congestion of aircraft stands and airport ground handling services. The infrastructure as well as the operation of the passenger terminal should be coordinated with the flow of aircraft arriving at the airport. However, the throughput capacity of critical service points such as check-in and security check, also provide space for passengers at different stages of servicing, directly depends on the number of passengers on the flight.

Table 6. European LCCs fleet development 2008 vs 2018 years

Airline	**As of 2008 year fleet, aircraft type (number of seats)**	**As of 2018 new aircraft orders, aircraft type (number of seats)**
RyanAir	Boeing B 737-800 (189)	Boeing B737 MAX-10 (up to 200)
Easyjet	Airbus A319 (156)	Airbus A320NEO (186); A321NEO (235)
Wizzair	Airbus A320 (180)	Airbus A321NEO (239)

With a decrease in the number of aircraft with fewer than 100 seats in Europe (Nõmmik, 2019), regional airports are faced with a situation where it is necessary to provide services to larger aircraft. Taking into account the fact that most regional airports have to be ready to serve LCC flights, we analyzed the changes in the fleets of these airlines in recent years. The results are presented in Table 6. The data is obtained from the websites of Europe's largest LCC airlines.

4. Discussion and conclusions

Modelling regional airports is generally simpler than that of large airports, but it requires consideration of their own specificities. It has been found that the wing span of nowadays narrow body aircraft in operation is close to the maximum value of the ICAO's reference code C. On one hand, it could be seen as flexibility. However, at the same time, it is a challenge and part of choices for the airport infrastructure, including terminal capacity planning. If the single regional airport is oriented, according to its business mission, to the activities, such as LCC services or holiday charters, it is reasonable to target at the longest versions of B737 or A320 aircraft families for infrastructure planning. Predictably, aviation standards and recommended practices, such as the reference code, will also be a constraint for aircraft designers, but this topic is beyond the scope of this research.

In the case of regional airports, when the size of the runway is often impossible to optimize in terms of increasing efficiency, one can just accept TM as a parameter for measuring the efficiency of using the runway. Based on the above-mentioned, we see a clear underload of runways at regional airports.

From the point of view of the efficiency of using the apron, a simplified model based on the theory of multichannel queuing, with no queue and minimal probability of failure, was presented. A relationship was shown between the number of aircraft stands and possible efficiency. However, this model shows only a predisposition to efficiency, which in practice needs to be realized. In the simplified model of the apron considered, the possible specific patterns of the distribution of arrivals of flights during the day, which may vary among airports, were not taken into account. However, it should be noted that the number of aircraft stands planned for servicing commercial flights should ensure the reception of aircraft arriving at night stop regardless of TM per day at the airport. With a small number of aircraft parked for night stop and their early departure, the ability of the apron to service flights under given condition can increase. A large number of aircraft at a night stop, whereby their number essentially determines the quantity of aircraft stands, will, besides the possible overload of the terminal due to tightly scheduled departures, also lead to apron inefficiency for a small number of flights during the day.

Planning an airport solely on the basis of average values of traffic indicators cannot be considered substantial. This research confirmed also that regional airports expect relatively high traffic variability, which are dependent on the season. We have also noted that servicing LCC operators have not significantly reduced the variability in the chosen airport group, that is consistent with other research (Fernández *et al.*, 2018). It can be explained by the fact that in this case LLC airlines often operate from regional airports as competitors for the seasonal charter market. The selection of regional airports for mission based groups can sometimes be considered rather conditional since the airports often perform several missions and the situation changes over time. Due to the wide representation of low cost carriers in regional airports we have also note that it has been difficulty to find suitable airports for building up a group "without LCC". It should also be noted that careful airport selection is essential for benchmarking, as it has been found that even at regional airports with the same profile, the variability of traffic is somewhat different.

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