Systemy Logistyczne Wojsk
Zeszyt 58 (2023)
ISSN 1508-5430, s. 97-110
DOI: 10.37055/slw/176017

Instytut Logistyki
Wydział Bezpieczeństwa, Logistyki i Zarządzania
Wojskowa Akademia Techniczna
w Warszawie

Military Logistics Systems
Volume 58 (2023)
ISSN 1508-5430, pp. 97-110
DOI: 10.37055/slw/176017

Institute of Logistics
Faculty of Security, Logistics and Management
Military University of Technology
in Warsaw

Simulation as a tool for calculating the airports' runway capacity

Symulacja jako narzędzie do obliczania przepustowości pasów lotniczych

Krzysztof Jurczyk
krzysztof.jurczyk@flexsim.pl; ORCID: 0000-0001-7569-3161
InterMarium Sp. z o.o., Poland

Agata Kutyba
kutyba@agh.edu.pl; ORCID: 0000-0001-5702-4378
Faculty of Management, AGH University of Science and Technology, Poland

Abstract. The basic parameter for evaluating the efficiency of airport operations is capacity. Investment planning in the aviation industry is a complex process, requiring consideration of many factors and a combination of different aspects. The aim of the study is to present the possibility of using discrete event simulation as a tool for determining the capacity of runways at airports. The main research problem of the article is: How to build a simulation model for determining the capacity of an airport runway using FlexSim software? The research hypothesis is: Discrete Event Simulation can be a useful calculation tool for determining the capacity of runways at airports. The research niche is operations research and systems engineering and in particular simulation modelling using DEVS paradigm. An attempt was made to build simulation model, the purpose of which is to carry out simulation analyzes of airport capacity, and in particular of the runway. Simulation analyzes were performed using the FlexSim 3D Simulation software. The article discusses in detail the operating principle of the model and presents the results of numerical tests carried out to calculate the capacity of runways and taxiways at airports. The constructed simulation model of the airport capacity in the FlexSim environment enables to determine the airport's runway capacity, constituting valuable information to support modernization decisions. The model may contribute to the efficient adjustment of the runway capacity. It should be noted that the creation of an effective system dedicated to a given airport will improve the air traffic control carried out by the system based on calculated maximum hourly runway capacity.
Keywords: air traffic engineering, airport capacity, modeling and simulation, basic capacity, practical capacity

Abstrakt. Podstawowym parametrem oceny efektywności funkcjonowania portów lotniczych jest przepustowość. Planowanie inwestycji w branży lotniczej to złożony proces, wymagający uwzględnienia wielu czynników i połączenia różnych aspektów. Celem opracowania jest przedstawienie możliwości wykorzystania symulacji zdarzeń dyskretnych jako narzędzia do wyznaczania przepustowości dróg startowych na lotniskach. Głównym problemem badawczym artykułu jest: jak zbudować model symulacyjny do wyznaczania przepustowości pasa startowego lotniska za pomocą oprogramowania FlexSim? Hipoteza badawcza, jaką postawiono brzmi: symulacja zdarzeń dyskretnych może być użytecznym narzędziem służącym do obliczania przepustowości dróg startowych na lotniskach. Jako niszę badawczą wskazano badania operacyjne i inżynierię systemów, a w szczególności badania symulacyjne oparte na paradygmacie DEVS. Podjęto próbę zaproponowania modelu symulacyjnego, którego celem jest przeprowadzenie analiz symulacyjnych przepustowości lotniska, a w szczególności pasa startowego. Analizy symulacyjne przeprowadzono za pomocą oprogramowania FlexSim 3D Simulation. W artykule szczegółowo omówiono zasadę działania modelu oraz przedstawiono wyniki badań numerycznych przeprowadzonych w celu obliczenia przepustowości dróg startowych i dróg kołowania na lotniskach. Zbudowany przykładowy referencyjny model symulacyjny przepustowości lotniska umożliwia wyznaczenie przepustowości pasa startowego lotniska, stanowiąc cenne informacje wspierające decyzje modernizacyjne. Model może przyczynić się do sprawnego dostosowania przepustowości drogi startowej. Należy zauważyć, że stworzenie efektywnego systemu dedykowanego danemu portowi lotniczemu usprawni kontrolę ruchu lotniczego realizowaną przez system w oparciu o obliczoną maksymalną godzinową przepustowość pasa startowego.
Słowa kluczowe: inżynieria ruchu lotniczego, przepustowość lotniska, modelowanie i symulacja, przepustowość podstawowa, przepustowość praktyczna

Introduction

In recent years, there has been a constant development of air transport. In 2018, 4.4 billion passengers were transported worldwide, an increase of 6.9% compared to 2017 (IATA, 2020). An important trend in the evolution of the aviation industry is the rapid development of emerging global mega-carriers (Mascio et al., 2020). Constant and significant increase in air traffic causes the growing problem of ensuring punctuality of air operations. The occurring delays in air operations are related to the capacity of both airspace and airports. The air capacity is defined as the allowable number of aircraft operations that can safely perform take-off and landing operations at a given time, with an average operation delay not greater than the allowable. In the proper functioning of an airport, a key role is played by adjusting the capacity of its individual elements to the existing demand for air transport service, therefore the capacity of the airport is an important criterion for assessing the rationality of design solutions, which, if presented conditionally, give the investor the opportunity to choose the optimal organizational and functional variant of the airport (Horonjeff et al., 2010). Declaration of airport capacity by the airport managing body is a complex decision-making process where many factors must be taken into account, most of which are variable over time and difficult to forecast (Tascón, Díaz Olariaga, 2021).

Increasing airport's capacity is possible thanks to the introduction of organizational and system changes and the liquidation of the so-called bottlenecks, necessitating an estimate of the existing capacity (Di Mascio et al., 2021). Despite the great interest in the problem of increasing airport capacity, there is a noticeable lack of methods for assessing the existing capacity or the capacity that could be obtained after a possible modernization of the airport. Currently there is no user-friendly and free tool for airport lane capacity estimation. Therefore, it is very often necessary to consider extremely costly simulation analyzes in order to obtain reliable data, as confirmed by recent studies (Di Mascio al., 2020). Having an effective and objective method of capacity calculation guarantees that the financial outlays incurred on the modernization of airports will bring the expected effect in increasing the efficiency of airport operation. The large number of elements that must be taken into account, the continuous dynamics of the maintenance processes, and the inability to experiment in real time make the airport an excellent facility for simulation.

The aim of the study is to present the possibility of using discrete event simulation as a tool for determining the capacity of runways at airports. An attempt was made to build simulation model, the purpose of which is to carry out simulation analyzes of airport capacity, and in particular of the runway. The presented model has been developed taking into account various factors and conditions that may affect its performance. Simulation analyzes were performed using the FlexSim 3D Simulation software. The article discusses in detail the operating principle of the model and presents the results of numerical tests carried out to calculate the capacity of runways and taxiways at airports. The constructed simulation model of the airport capacity environment enables to determine the airport's runway capacity, constituting valuable information to support modernization decisions. The model may contribute to the efficient adjustment of the runway capacity. It should be noted that the creation of an effective system dedicated to a given airport will improve the air traffic control carried out by the system based on calculated maximum hourly runway capacity.

Literature review

Calculating airports' runway capacity was a subject of study of many researchers. Stempfel et al. (2021) applied Machine Learning modeling to enhance runway throughput at some big European airport. The authors explain how a Machine Learning analysis can support the development of accurate, yet operational, models for runway occupancy time prediction depending on all impact parameters. Similar study based on Machine Learning in comparison with the approach based on analytical data mining and modelling was prepared by De Visscher et al. (2018). Herrema et al. (2019) also proposed a machine learning model to predict runway exit at analyzed airport.

Different publication based on Operations Research Approach was prepared by Wang et al. (2022). The objective of cited paper was to assess the efficiency of various airport runway configurations based on input factors such as number of runways, dimension of runways, airport area, and output factors such as annual number of flights and annual number of passengers. The authors used DEA approach for calculating runway utilization of some set of European airports. On the other hand, Cheung et al. (2021) use mixed integer programming to determine dynamic capacity and variable runway configurations in airport slot allocation. The proposed model provides a dynamic capacity estimation over the planning horizon based on a varying flight mix. Presented approach also allows for exploration of possible runway configurations, arrival/departure priority, and operational modes (segregated/mixed) to ensure that the higher levels of demand during the strategic planning phase does not lead to excessive delays on the day of operations. Similar studies were performed by Ng et al. (2021), Farhadi et al. (2014) and Lieder and Stolletz (2016).

The important group of articles which should be pointed out relates to the usage of stochastic methods and models for calculating airports' runway capacity. A simulation study to investigate runway capacity using TAAM Software was presented by Bazargan et al. (2002). Similar work with the usage of different software was proposed by Chao et al. (2008). Simulation modelling of runway capacity was also analyzed by Cetek and **Çetek** (2014), Zou et al. (2014), Peng et al. (2013) and Kuzminski (2013). Simulation approach is also used in this article, but before we go into analyzed case study some theory regarding to airport capacity should be explained.

Airport capacity

The airport plays a significant role in the understanding of air traffic engineering. This function consists in associating traffic participants, i.e., servicing the aircraft traffic stream and the passenger traffic stream. The primary goal of an airport's operation is safe, fast and cheap handling of both these streams. In order to ensure the safety and regularity of transport, air traffic control services are faced with the need to determine airport capacity. (Malarski, Skorupski, 1997). Airport capacity is the primary measure of the operational efficiency of an airport. In the literature there are many definitions treated as synonyms of the terms of airport capacity or capacity. (Aerodrome Design 1991; Malarski, 2006; Annex 2005; Stelmach, Malarski, 2006).

There are two types of airport capacity (Nita, 2014):

-basic airport capacity (theoretical) – i.e., the maximum number of take-off and landing operations of the contractual aircraft per time unit, carried out under set air traffic conditions and continuous handling of passengers and cargo (goods and mail).

-practical airport capacity – i.e., the number of take-off and landing operations of the contractual aircraft per unit of time (conducted under set air traffic conditions and continuous handling of passengers, cargo, cargo, and mail) for which the average delay time will correspond to the acceptable average delay time.

An important difference between the above definitions is that the basic bandwidth does not take into account the delay. On the other hand, the second type of capacity assumes the existence of a static relationship between the volume of air traffic and the average delay time. The delay should be treated as a sum of airplane delays in individual subsystems of the airport area. There are many factors that cause delays. Some factors can be precisely calculated, others are very difficult to estimate and change rapidly. When planning traffic handling, one should take into account not only the occurrence of disturbances, but also the probability of their occurrence and the level of risk for the entire maintenance process (Nita, 2014).

Understanding the principles by which an airport operates requires building models that reflect the actual processes taking place in it. The model must reflect both the physical environment and the logical aspects of the system that guide the activities in the modeled environment. One of such models are simulation models.

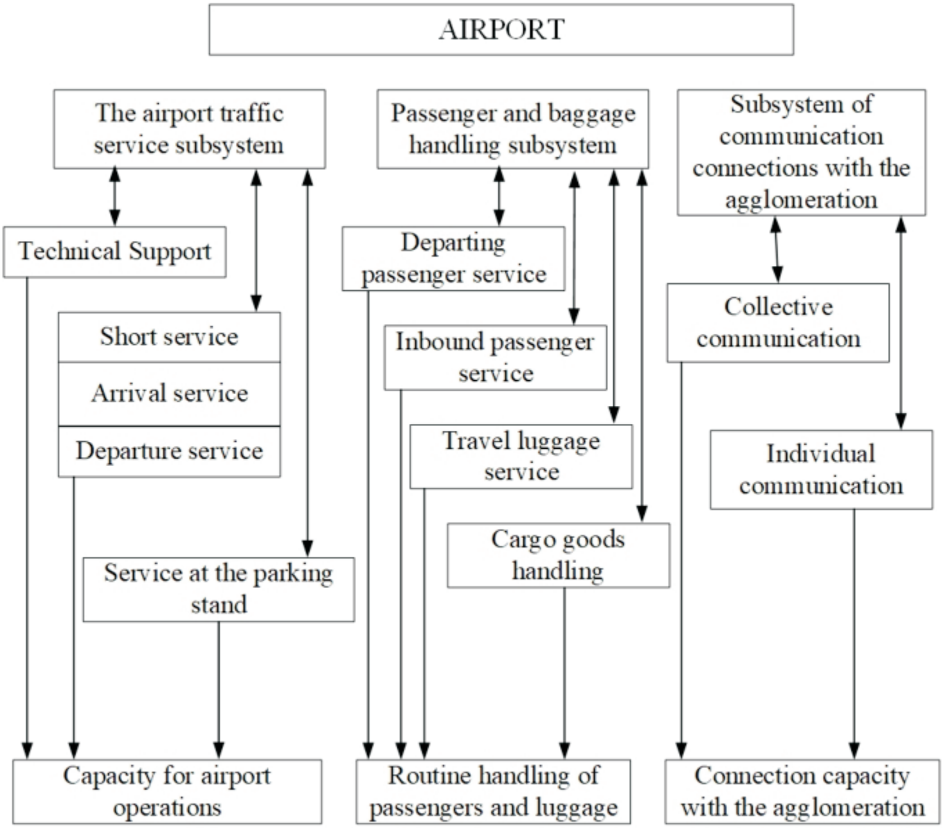

Fig. 1. Airport subsystem capacity

Source: Own elaboration based on (Malarski, Manerowski, 2007)

On the Figure 1 shows the airport as a system. The following subsystems can be distinguished (Malarski, Manerowski, 2007):

- airport capacity for aircraft operations,
- airport capacity for passenger and baggage handling,
- capacity of the transport subsystem between the airport and the urban agglomeration.

Simulation

Computer simulation is an excellent tool for analyzing complex processes. Simulation methods, in comparison with analytical methods, are characterized by considerable complexity and the necessity to identify many modeled areas, but they generate more accurate results. They make it possible to easily change model parameters and verify the design before its implementation. The basic element of simulation research is the construction of a model reflecting the entire system or its individual processes in accordance with the adopted research objective. The model is created graphically or by entering codes. The consequence of constructing the simulation model is conducting computer experiments. The model is subjected to changing conditions in order to assess the functioning of the tested system.

The airport is an excellent area for simulation, as the processes of airport traffic handling change dynamically. The general algorithm for solving the problem of determining the airport's capacity consists of the following stages (Malarski, Manerowski, 2007):

- precise identification of phenomena in the tested system,
- save the model using a specialized simulation language,
- carrying out a series of simulation experiments,
- analysis of the obtained statistical sample and determination of the capacity.

The analysis and testing of such a complex system as an airport create not only methodological but also computational problems, especially when the purpose of the research is to determine its capacity.

Material and research methods

To determine the value of the runway capacity, it is necessary to know the following parameters:

- separation distance between aircraft, for both departing and arriving aircraft,
- the expected increase in the volume of traffic and the parameters of the landing area (number, directions and dimensions of runways, high-speed exit routes),
- layout of the maneuvering area (number and layout of taxiways).

It is also necessary to know the level of navigation equipment and the procedures of the airport Air Traffic Control Services.

Using the FlexSim 3D Simulation software, an exemplary reference simulation model was built, which, after further modifications and adaptation to the needs of a given airport, can find practical application.

In the construction of the model, it was assumed that the runway is 2,500 m long. In addition, there are two taxiways that can be used to reach the runway – each 200 m long, located at both ends of the runway. At a distance of 1,800 m from the beginning of the runway in direction 18, there is a fast exit road. Figure 2 shows the layout of the simulation model objects.

Fig. 2. Arrangement of simulation model objects
Source: Own elaboration

A mock-up of the Airbus A319, which maximum speed is 871 km/h, was used as the reference (computational) aircraft. Figure 3 shows the view of the apron used in the model, where the aircraft are located.

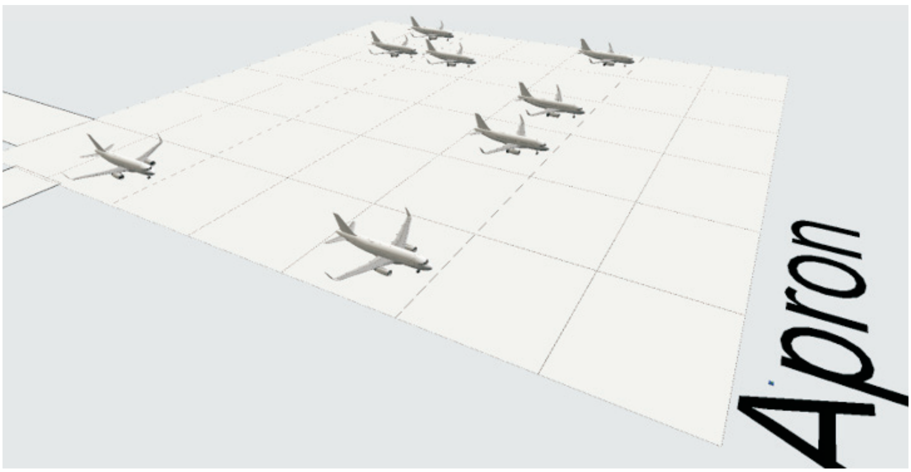

Fig. 3. View of the parking plane of airplanes with Airbus A319 aircraft parked on it
Source: Own elaboration

The following assumptions were made for the research:

- Length of separation between two successively arriving aircraft – 7 NM,
- Length of separation between two successively departing aircraft – 2 minutes,
- Increasing the separation between two incoming aircraft separated by a take-off operation – 3 NM,
- Aircraft speed at touchdown – 220 km/h,
- Aircraft speed at the beginning of taxiing to the fast exit route – 90 km/h,
- Aircraft speed at the end of the runway – 25 km/h,
- Speed of the aircraft leaving the apron – 20 km/h.

Discussion

The constructed simulation model was used to test the capacity of the system presented at the beginning. The research began with an analysis of the situation in which the occurrence of take-off and landing operations alternated. An assumption was also made regarding the number of aircraft using the expressway. The summary of the results is presented in Table 1.

Table 1. Runway capacity when take-off and landing operations alternate

Percentage of aircraft using the expressway – RET	Average number of operations in one hour
0	23.9
25	24.5
50	25.4
75	26.3
100	27.2

Source: Own study

The greater the number of arriving aircraft using the expressway, the greater the average number of operations that can be completed in one hour. It should be noted that in the analyzed case the most likely scenario is the one in which 75% of aircraft use the fast exit route – of course, this may change dependently of weather conditions.

The second analyzed case is a situation in which three landing operations occur, followed by two take-off operations. There are two take-off operations for every three landing operations. The results are summarized in Table 2.

As before, with the increase in the number of aircraft using the fast exit route, the average hourly number of operations that can be performed within one-hour increases. Moreover, it should be noted that in this case the average number of operations is lower in relation to the previously analyzed uniform flight distribution.

The next step was to analyze the opposite case to the one previously discussed, i.e., the situation in which the departure to arrival ratio is 3:2. The results are summarized in Table 3.

Table 2. The runway capacity when the ratio of landing operations to take-off operations is 3:2

Percentage of aircraft using the expressway – RET	Average number of operations in one hour
0	20.8
25	21.4
50	22.2
75	22.9
100	23.7

Source: Own elaboration

Table 3. The capacity of the runway when the ratio of landing operations to take-off operations is 2:3

Percentage of aircraft using the expressway – RET	Average number of operations in one hour
0	23.6
25	24.1
50	24.7
75	25.7
100	26.1

Source: Own elaboration

In a situation where a larger number of departure operations are handled capacity increases again. Figure 4 shows the comparison results of mentioned cases.

In addition, it was decided to analyze the impact on the hourly capacity of the extension or shortening of the separation between successive arriving aircraft. The results are summarized in Table 4.

Table 4. Analysis of the runway capacity depending on the assumed separation length between successive arriving aircraft

Analyzed sequence [A – arrival; D – departure]	Length of separation between arrivals [NM]					
	5	6	7	8	9	10
AD	34.9	31.2	28.9	26.3	25.1	23.5
AAADD	30.3	26.9	24.9	22.9	21.6	20.1
DDDAA	31.3	28.8	27.2	25.7	24.3	23.1

Source: Own elaboration

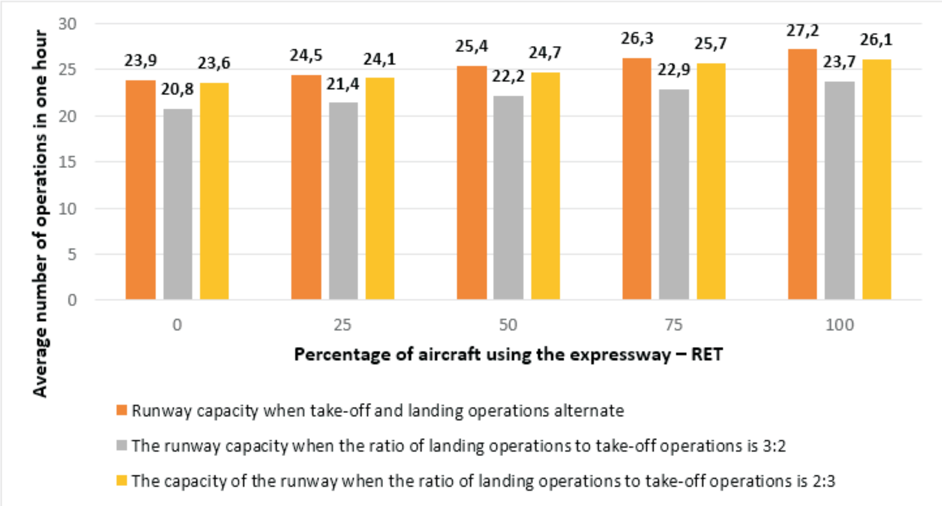

Fig. 4. Simulation results of analyzed cases
Source: Own elaboration

For each variant, it was assumed that 75% of aircraft use the expressway. Most operations are possible when the arrivals and departures operations alternate, and the separation length between successive arrivals is 8 NM. It should be noted that the analyzed sequences should be defined based on the previously implemented schedules of arrivals and departures at the given airports.

Conclusions

The basic parameter for assessing the efficiency of the operation of an airport is capacity. Increase airport capacity affects to environmental sustainability, air transport accounts around 10% of all transport energy consumption in the EU and is responsible for approximately 15% of all CO2 emissions (Stanners, Bourdeau, 1995; Ivkovic, Cokorilo, Kaplanović, 2018; Di Mascio, Rappoli, Moretti, 2020). The methods for calculating airport capacity they vary in labor input, data requirements and cost (Di Mascio et al., 2020). The use of simulation models allows for the flexibility of analyzing multiple objects with different runway configurations and separation rules. This can save time, money, or also could potentially help decision makers optimize their operating systems.

In this article a simulation model was built to analyze the capacity of a single airport runway serving flights in various operational scenarios. The obtained results relate to the specific tested system, the results are reliable, and the proposed approach can be applied at various airports. Three scenarios were considered in which the sequence of arrivals and departures of passenger aircraft was adjusted. Moreover, each scenario was analyzed due to the use of the high-speed exit road – RET. In the first scenario, a situation with an equal distribution of take-off and landing operations was analyzed. In this case, the average number of operations that could be performed ranged from 23.9 to 27.2 depending on the degree of RET usage. In the second scenario, the share of landing operations was increased (60% of landing operations, 40% of take-off operations). In this case, the average number of operations that could be carried out ranged from 20.8 to 23.7. In the third scenario, the share of take-off operations was increased (60% of take-off operations, 40% of landing operations). In this case, the average number of operations that could be performed ranged from 23.6 to 26.1. It can therefore be concluded that the runway capacity is mainly influenced by the definition of the appropriate sequence between take-off and landing operations.

The constructed simulation model of the airport capacity in the FlexSim environment enables to determine the airport's runway capacity, constituting valuable information to support modernization decisions. The model may contribute to the efficient adjustment of the runway capacity. It should be noted that the creation of an effective system dedicated to a given airport will improve the air traffic control carried out by the system.

BIBLIOGRAPHY

[1] Aerodrome Design Manual, 1991, ICAO Doc 9157, Third Edition.

[2] Annex 9 ICAO of the Convention on International Civil Aviation – Facilitation Twelfth Edition, 2005.

[3] Bazargan, M., Fleming, K., Subramanian, P., 2002. A simulation study to investigate runway capacity using TAAM. In Proceedings of the winter simulation conference, 2, 1235–1243. IEEE. DOI: 10.1109/WSC.2002.1166383.

[4] Beaverstock, M., Greenwood, A., Nordgren, W., 2018. Applied Simulation: Modeling and Analysis using FlexSim. Orem, Utah, USA.

[5] Cetek, F. A., Çetek, C., 2014. Simulation modelling of runway capacity for flight training airports. The Aeronautical Journal, 118(1200), 143–154. DOI: 10.1017/S0001924000009039.

[6] Chao, W., Xinyue, Z., Xiaohao, X., 2008. Simulation study on airfield system capacity analysis using SIMMOD. In 2008 International Symposium on Computational Intelligence and Design, 1, 87–90. DOI: 10.1109/ISCID.2008.70

[7] Cheung, W. L., Piplani, R., Alam, S., Bernard-Peyre, L., 2021. Dynamic capacity and variable runway configurations in airport slot allocation. Computers & Industrial Engineering, 159, 107480. DOI: 10.1016/j.cie.2021.107480

[8] De Visscher, I., Stempfel, G., Rooseleer, F., Treve, V., 2018. Data mining and Machine Learning techniques supporting Time-Based Separation concept deployment. In 2018 IEEE/AIAA 37th Digital Avionics Systems Conference, 1–10. DOI: 10.1109/DASC.2018.8569325

[9] Di Mascio P., Rappoli G., Moretti L., 2020. Analytical Method for Calculating Sustainable Airport Capacity. Sustainability. 12(21):9239. DOI: 10.3390/su12219239

[10] Di Mascio, P., Cervelli, D., Correra, A. C., Frasacco, L., Luciano, E., Moretti, L., 2021. Effects of departure manager and arrival manager systems on airport capacity. Journal of Airport Management, 15(2), 204–218.

[11] Di Mascio, P., Cervelli, D., Correra, A. C., Frasacco, L., Luciano, E., Moretti, L., Nichele, S., 2020. A critical comparison of airport capacity studies. Journal of Airport Management, 14(3), 307–321.

[12] Farhadi, F., Ghoniem, A., Al-Salem, M. (2014). Runway capacity management–an empirical study with application to Doha International Airport. Transportation Research Part E: Logistics and Transportation Review, 68, 53–63. DOI: 10.1016/j.tre.2014.05.004

[13] Herrema, F., Curran, R., Hartjes, S., Ellejmi, M., Bancroft, S., Schultz, M., 2019. A machine learning model to predict runway exit at Vienna airport. Transportation Research Part E: Logistics and Transportation Review, 131, 329–342. DOI: 10.1016/j.tre.2019.10.002

[14] Horonjeff, R., McKelvey, F., Sproule, W.J., Young, S.B., 2010. Planning & Design of Airports, 5th ed., McGraw Hill, New York, NY, USA.

[15] IATA (2020), Word Air Transport Statistics.

[16] Ivkovic, I., Cokorilo, O., Kaplanović, S., 2018. The estimation of GHG emission costs in road and air transportsector: Case study of Serbia. Transport, 33, 260–267. DOI: 10.3846/16484142.2016.1169557

[17] Kuzminski, P.C., 2013. An improved runway Simulator – Simulation for runway system capacity estimation. In 2013 Integrated Communications, Navigation and Surveillance Conference (ICNS), 1–11. DOI: 10.1109/ICNSurv.2013.6548575

[18] Lieder, A., Stolletz, R., 2016. Scheduling aircraft take-offs and landings on interdependent and heterogeneous runways. Transportation research part E: logistics and transportation review, 88, 167–188. DOI: 10.1016/j.tre.2016.01.015

[19] Malarski M., 2006. Inżynieria ruchu lotniczego. Warszawa, Oficyna Wydawnicza PW.

[20] Malarski M., Manerowski J., 2007. Przepustowość portu lotniczego. Journal of Aeronautica Integra 1/2007 (2), 51–58.

[21] Malarski M., Skorupski J., 1994. Modelowanie przestrzeni lotniska dla wyznaczenia jego pojemności dla różnych systemów organizacji ruchu lotniczego. Zeszyty Naukowe Politechniki Śląskiej, Automatyka, z. 115.

[22] Ng, K.K., Chen, C.H., Lee, C.K., 2021. Mathematical programming formulations for robust airside terminal traffic flow optimisation problem. Computers & Industrial Engineering, 154, 107–119. DOI: 10.1016/j.cie.2021.107119

[23] Nita P., 2014. Projektowanie lotnisk i portów lotniczych, Wydawnictwa Komunikacji i Łączności WKŁ, Warszawa.

[24] Peng, Y., Wei, G., Jun-Qing, S., 2013. Capacity analysis for parallel runway through agent-based simulation. Mathematical Problems in Engineering. DOI: 10.1155/2013/505794

[25] Stanners, D., Bourdeau, P., 1995. Europe's Environment: The Dobris Assessment; Office for Official Publications of the European Communities: Luxembourg. European Environment Agency: Copenhagen, Denmark.

[26] Stelmach A., Malarski M., 2006. Model procesu obsługi ruchu lotniczego w rejonie portu lotniczego. Prace naukowe Politechniki Warszawskiej – Transport z. 56, 41–60.

[27] Stempfel, G., De Visscher, I., Ellejmi, M., Brossard, V., Bonnefoy, A., Treve, V., 2021. Applying machine learning modeling to enhance runway throughput at a big European airport. In IOP Conference Series: Materials Science and Engineering, 012106. IOP Publishing. DOI: 10.1088/1757-899X/1024/1/012106

[28] Tascón, D. C., & Olariaga, O. D., 2021. Air traffic forecast and its impact on runway capacity. A System Dynamics approach. Journal of Air Transport Management, 90, 101946. DOI: 10.1016/j.jairtraman.2020.101946

[29] Wang, C.N., Imperial, K.N.C., Huang, C.C., Dang, T.T., 2022. Output targeting and runway utilization of major international airports: A comparative analysis using DEA. Mathematics, 10(4), 551. DOI: 10.3390/math10040551

[30] Zou, X., Cheng, P., Cheng, N., 2014. A simulation model for airport runway capacity estimation. In 17th International IEEE Conference on Intelligent Transportation Systems (ITSC), 2669–2674. DOI: 10.1109/ITSC.2014.6958117