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SELECTED DECISION PROBLEMS IN THE IMPLEMENTATION OF AIRPORT OPERATIONS

Summary. The article presents the key processes taking place in the area of the airport's plate. The need to look for effective methods and tools supporting decision-making in the area of improving the efficiency and effectiveness of airport operations is pointed out. In addition to efficiency, reliability and the level of costs generated, work safety is an important aspect in the organization of airport operations. Work safety during the implementation of airport operations is one of the basic factors affecting the design and organization of airport systems. A graph of the airport panel structure is proposed and the decision problems regarding the taxiing of the aircraft on the apron and handling of the ship after landing are indicated.
Keywords: air traffic management; model; simulation; air traffic control

1. INTRODUCTION

Most airports are extremely busy environments, which operate at the peak of their capabilities. Congestion at airports and in airspace causes frequent delays, which additionally burden already tight schedules. Nevertheless, as the medium- and long-term predictions by the International Civil Aviation Organization (ICAO) show, aircraft traffic will increase significantly.

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The demand in societies for material goods multiplies the number of flights between countries and companies. Significant companies in the world market often have their own aircraft, and the use of aircraft as a means of transport is as common as using a bus or rail. All these elements mean that maintaining the high efficiency of airport processes is a necessary condition for the proper and competitive functioning of airports.

Constant advances in technology give these changes speed; as a result, airports must implement newer methods and tools to improve their efficiency and effectiveness. Nevertheless, among the ubiquitous efforts to reduce operating and exploitation costs, while increasing the efficiency of airports, one cannot forget the safety of the working environment, employees and, most importantly, passengers. An important area of transport system research is transport ecology and the construction of appropriate models in this regard. [9].

The design of airports and the organization of their work requires the identification of the basic components of the airport process, such as:

- The “air” side, including the approaching landing phase and the landing operation itself, as well as the take-off
- The “ground” side, including the taxiing of aircraft on the apron and ground handling tasks
- The “terminal” side, including passenger service tasks

These elements create a causal sequence, or a series-parallel structure, which determines the quality of services provided by the airport, their efficiency, reliability and price. As seen the data in Figure 1, the average delay value of aircraft during one taxi operation based on the 34 largest airports in Europe is as long as 4.8 min.

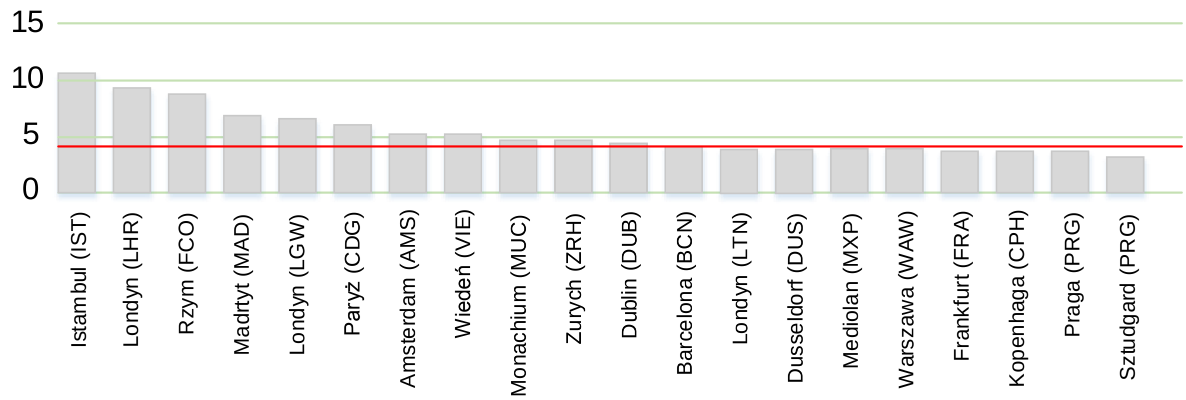

Fig. 1. The average delay value of aircraft during one taxi operation for the top 20 airports in Europe.
Source: own work based on [2]

Aircraft taxiing operations on the apron integrate the flight phase (including its components and its problems, such as arrival and departure sequencing) and the phase of the ground handling of aircraft and passengers in terminals [1]. For this reason, the design of the taxiway system and organization of the taxiing process on these roads is a two-sided problem, which is clearly visible in the literature on the subject [1,4,5,10,12,14,16].

The article presents decision problems related to the organization of taxiways for aircraft after landing and the assignment of positions for passenger service, followed by preparing the aircraft for the next flight.

2. ANALYSIS OF PROCESSES REALIZED ON THE APRON: A LITERATURE REVIEW

Work safety, along with efficiency, reliability and the level of generated costs, is one of the basic factors affecting the design and organization of airport systems. This particularly applies to processes taking place in the area of the apron, where, in a small space, with a high density of resources and significantly reduced visibility, transport processes are carried out and generally significantly intensified. Working conditions in the area of the manoeuvring area are conducive to hazards related to collisions or accidents to which not only individuals, but also loads and infrastructure are exposed.

Despite interdependences related to security, capacity, weather constraints and the individual goals of stakeholders, today's air traffic management (ATM) system is already highly optimized. We are constantly looking for tools that will support decision-making in this area. The development of an appropriate tool requires, however, the ability to recognize and effectively analyse issues concerning, among others:

- increasing the capacity of the airport
- planning the positioning of aircraft on the apron
- taxiway lengths
- selection of the number of runways
- optimization of taxiing routes of aircraft on the apron
- take-off and landing sequences, including analysis of rapid exit routes
- maintaining high security stocks
- efficiency and effectiveness of airport processes in the aspect of airport operations safety

In many works, the problem of analysis and evaluation of ground operations at airports in various aspects is being raised. For example, the authors Atkin, Burke and Ravizza in [1] present research on the organization of the taxiing process of aircraft on the apron. The basic problems in the organization of the taxiing process of aircraft on the apron include, among others: minimization of delays caused by congestion on manoeuvring areas, shortening the time of landing and take-off operations by appropriate planning of aircraft and displacement routes, increasing performance at the airport and minimizing the negative impact of air transport on the environment.

On the other hand, Nikoleris, Gupta and Kistler in [14] present a detailed analysis of the level of emissions of harmful exhaust components during subsequent phases of taxiing operations. They show that aircraft stop and start operations, resulting from congestion on taxiways, are responsible for about 18% of the total fuel used for taxiing. In turn, the operation of engines in the minimum range and rolling of the plane at a constant speed and braking are the operations responsible for the emission of a large part (about 35%) of the exhaust gas. To conduct the tests, data on ground operations are used and broken down into the following phases: stopping, turning back, accelerating, braking and moving at a constant speed. The results obtained in this and in other similar studies can be used to construct the objective function of the task of organizing the process of aircraft taxiing on the apron, taking into account environmental aspects and, at the same time, translating them into increased traffic flow and shortening taxi time, which are associated with reducing emissions [3,13].

Gotteland, Durand, Alliot and Page [5] deal with the issue of ground traffic optimization using the example of Paris Charles de Gaulle Airport, noting that ground operations at such a loaded airport are an essential factor in port performance. The authors have presented the formulation of the optimization task, whereby the time in which aircraft travel the route between the gates and the runway is minimized. The proposed optimization model includes time and distance separation, as well as the maximum number of take-off and landing operations that can be carried out on runways. It has been proposed to map the uncertainty of aircraft speed on the apron and the time separation model. The structure of the airport was represented by a graph. The task is solved using the genetic algorithm and A*: 1-to-n strategy for a fixed aircraft flight plan. The correctness of the solution algorithms' operation is verified with the use of simulations with real data. The authors emphasize the high computational complexity of the problem.

The above-mentioned tests and computational experiments indicate that it is possible to construct a tool supporting the management of taxiing operations for a major airport. An important aspect in this respect is the selection of appropriate algorithms [6,7,8,11]. The analysis in many studies shows that methods based on evolutionary algorithms have a large application in this field.

3. MAPPING THE STRUCTURE OF THE APRON

3.1. General assumptions

The airport structure is distinguished by the air side of the airport, aerial ground equipment and centralized airport infrastructure. The air side of the airport is an area permanently designed for aircraft take-offs and landings together with devices used to service this traffic, for which access is controlled. On the other hand, aerial ground equipment comprises devices installed for the purpose of safe aircraft navigation. These are: radiocommunication devices, radiolocation devices, radio navigational devices, visual navigational aids, and automatic measurement systems for meteorological parameters, e.g., RVR visibility, cloud bases. Centralized airport infrastructure includes devices and objects used for the ground handling of aircraft.

The airport apron is a paved element at the airport where aircraft are placed after landing and taxiing (Figure 2).

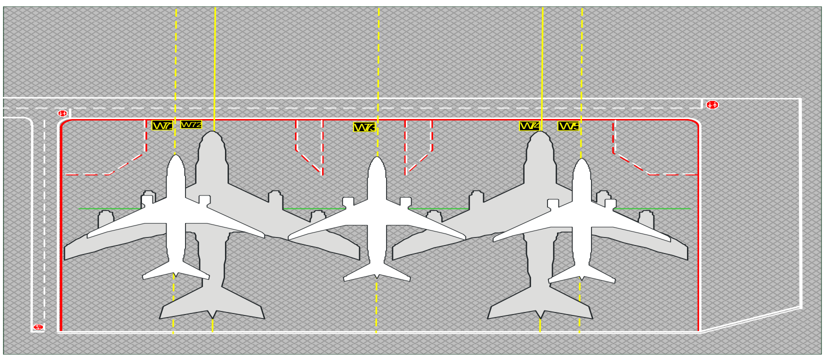

Fig. 2. Positioning points of aircraft after landing and taxiing
Source: own work based on [15]

3.2. Graph of the apron structure

For the purposes of the research, it is assumed that the structure of the apron, on which operations related to the take-off, landing and taxiing of aircraft on the apron are performed, can be presented in the form of a graph, understood as a set of elements and a set of relations between these elements. It is assumed that the connections between all distinguished points of the apron structure will be taxiing routes for aircraft.

It is assumed that the structure is defined as follows:

$$\boldsymbol{GPL}=<\boldsymbol{K},\boldsymbol{L}> \tag{3.1}$$

where:

GPL - the structure of the apron on which the aircraft is moved,

K - a set of points distinguished in the airport structure for defining taxiways for aircraft on the apron,

L - a set of taxiway sections between the highlighted points of the apron structure.

For the purposes of developing the model structure, it is assumed that the structure elements will be numbered with the index *k*. Thus, ***K*** will be a set in the form:

$$\boldsymbol{K}=\{1, 2, ..., k, k', ..., \overline{K}\} \tag{3.2}$$

where $\overline{K}$ is the cardinality of the set ***K***.

Among the elements of the ***K*** set, three types of nodes can be distinguished, namely: touchdown points, parking points and intermediate points of taxiways of aircraft in which planes change the direction of movement or have a temporary stop resulting from the traffic situation on the apron (e.g., due to a touchdown point taking place).

Thus, if:

- $\alpha(k)=0$, then the element with the number *k* ($k\in\boldsymbol{K}$) is the touchdown node in the aircraft traffic system on the apron
- $\alpha(k)=1$, then the element with the number *k* ($k\in\boldsymbol{K}$) is the intermediate node in the aircraft traffic system on the apron
- $\alpha(k)=2$, then the element with the number *k* ($k\in\boldsymbol{K}$) is the parking node in the aircraft traffic system on the apron

Taking into account the above, it was assumed that:

– $\boldsymbol{PP} = \{k: \alpha(k)=0, k\in\boldsymbol{K}\}$ will be a set of touchdown point numbers

– $\boldsymbol{PS} = \{k: \alpha(k) = 1 \wedge k\in\boldsymbol{K}\}$ will be a set of intermediate point numbers

– $\boldsymbol{PO} = \{k: \alpha(k) = 2 \wedge k\in\boldsymbol{K}\}$ will be a set of parking point numbers

Sets ***PP, PS*** and ***PO*** are, by definition, sets of disjointed pairs, i.e.:

$$\boldsymbol{PP} \cap \boldsymbol{PS} = \emptyset; \boldsymbol{PP} \cap \boldsymbol{PO} = \emptyset, \boldsymbol{PS} \cap \boldsymbol{PO} = \emptyset$$

and

$$\boldsymbol{PP} = \boldsymbol{K}\backslash(\boldsymbol{PS}\cup\boldsymbol{PO}); \quad \boldsymbol{PS} = \boldsymbol{K}\backslash(\boldsymbol{PP}\cup\boldsymbol{PO}); \ \boldsymbol{PO} = \boldsymbol{K}\backslash(\boldsymbol{PP}\cup\boldsymbol{PS});$$

It is also necessary to identify connections between the highlighted points of the apron structure. It has been assumed that, for the purpose of building the model, direct connections between individual elements of the apron structure are used, i.e., connections occurring between:

- touchdown points (nodes) and intermediate points (nodes)
- various indirect points (nodes) of taxiways
- taxiing intermediate points (nodes) and parking points (nodes)

The symbol ***L*** is the set of sections between the points of the airport plate structure.

$$\boldsymbol{L} = \{(k,k'):\ \gamma(k,k') = 1,\ \ k \neq k' \wedge\ \ k,k' \in \boldsymbol{K}\} \qquad (3.3)$$

Thus, ***L*** = ***LPPS*** ∪ ***LPSP*** ∪ ***LPSS***∪ ***LPSO*** ∪ ***LPOS***

where:

- $\boldsymbol{LPPS} = \{(k,k'):\ \gamma(k,k') = 1,\ \ k \neq k'\ \wedge\ \ k \in \boldsymbol{PP},\ k' \in \boldsymbol{PS}\}$ a set of taxiway sections connecting touchdown points from a ***PP*** set and intermediate points from a ***PS*** set
- $\boldsymbol{LPSP} = \{(k,k'):\ \gamma 2(k,k') = 1,\ \ k \neq k'\ \wedge\ \ k \in \boldsymbol{PS},\ k' \in \boldsymbol{PP}\}$ a set of taxiway sections connecting intermediate points from the ***PS*** set and touchdown points from the ***PP*** set
- $\boldsymbol{LPSS} = \{(k,k'):\ \gamma 3(k,k') = 1,\ k \neq k' \wedge\ \ k,k' \in \boldsymbol{PS}\}$ a set of taxiway sections directly connecting the highlighted intermediate points from the ***PS*** set
- $\boldsymbol{LPSO} = \{(k,k'):\ \gamma 4(k,k') = 1,\ \ k \neq k'\ \wedge\ \ k \in \boldsymbol{PS},\ k' \in \boldsymbol{PO}\}$ a set of taxiway sections connecting intermediate nodes from the ***PS*** set and nodes from the ***PO*** set
- $\boldsymbol{LPOS} = \{(k,k'):\ \gamma 5(k,k') = 1,\ \ k \neq k'\ \wedge\ \ k \in \boldsymbol{PO},\ k' \in \boldsymbol{PS}\}$ a set of taxiway sections connecting parking nodes from the ***PO*** set and intermediate nodes from the ***PS*** set

For the purposes of research, it is assumed that the defined taxiway sections are bidirectional and that, between two nodes, according to the previous assumption, at most one connection is identified.

4. DECISION PROBLEMS FOR COMPLETING AIRPORT OPERATIONS

4.1. Decisions regarding the taxiing operation of an aircraft on the apron

Aircraft taxiing operations on the apron are an important element in the aircraft's handling process on the apron. As part of taxi operations, aircraft move within the airport using a network of roads for various purposes. The times of these operations have an impact on the time of succession and the time of take-off and landing. Therefore, they may limit the capacity of the airport.

Important aspects in the implementation of airport operations are the take-off and landing procedures. These procedures include several stages, of which the most prominent are (Figure 3):

- Stage 1 – This is when the captain of the aircraft asks for permission to taxi in order to take off and receives information about the runway in use and permission to taxi.
- Stage 2 - The aircraft is taxing on taxiways up to the designated place in front of the runway (if the traffic situation so requires, the departing aircraft will be stopped in a safe place for other airport operations). At the place of stopping and waiting for a start, an engine test may be performed.
- Stage 3 - In the absence of contraindications concerning the execution of the take-off operation, the permit to take off is issued, if the situation did not allow for the issue of such a permit in Stage 2.
- Stage 4 - A landing permit is issued, if there are no factors preventing the landing operation
- Stage 5 - At this stage, a permit is issued to taxi the aircraft on the apron.
- Stage 6 - Information about the aircraft parking place on the apron is provided.

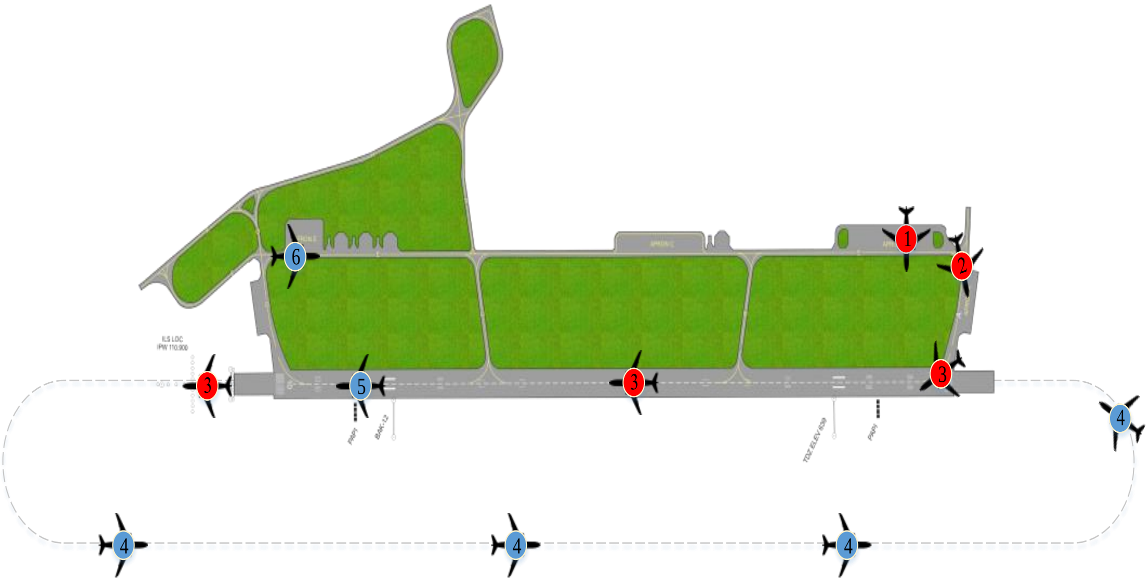

Fig. 3. Important stages during airport operations
Source: own work based on [15]

Among the decision problems in the area of taxiing operations of an aircraft on the apron, the following should be mentioned:

- the runway during arrivals and departures
- length, maximum permissible wingspan and maximum permissible total weight of the aircraft for each taxiway
- location of the intersection between the two taxiways
- specific rules for the use of taxiways in special conditions, such as wet surfaces, poor visibility and daytime limitations

4.2. Decisions regarding the operation of the aircraft

In larger airports, the aircraft, after taxiing to a parking place designated by the air traffic coordinator for its service, is connected to the passenger terminal by means of a mobile sleeve. After taxiing to the parking place, the aircraft is serviced. All vehicles and aircraft that use and move on the apron must have an air traffic control permit. In addition, vehicles are required to follow the ICAO regulations and applicable rules at the airport.

Aircraft service is carried out according to a specific sequence of activities (Figure 4).

Among the decision-making problems in the area of servicing the aircraft after taxiing to the parking place are:

- assignment of a parking place
- handling (low cost)
- type of service

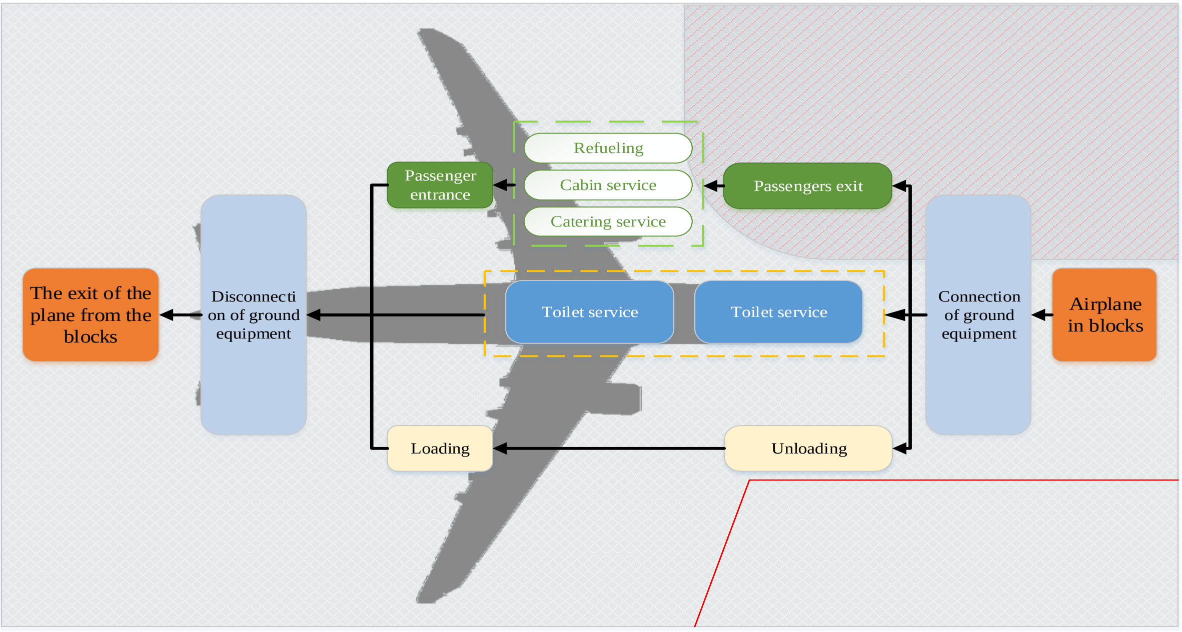

Fig. 4. Aircraft service diagram
Source: own work based on [2]

5. CONCLUSIONS

Congestion at airports and in airspace causes frequent delays, which additionally burden already tight schedules. Nevertheless, as the medium- and long-term ICAO predictions show, aircraft traffic will increase significantly. Currently used tools supporting the management of safety, throughput and organization of air traffic are beginning to encounter many problems. These are determined by many constraints, including weather constraints and individual goals of stakeholders. That is why today's ATM system requires constant analysis and the search for more effective methods to solve these problems.

It is therefore necessary to conduct research into and analysis of issues including:

- identification of types and tasks of airport facilities in real systems
- identification of tasks at airports
- identification of types of processes and activities carried out at airports
- identification of security threats
- identification of methods, principles and tools for measuring and assessing airport performance

Discussing the methods for building targeted models of real airport processes, including the development of mathematical models of aerodrome objects and processes enabling the assessment of airport performance, requires the identification of effective algorithms for solving them. An important area of research involves methods based on the simulation tests of airport processes, taking into account safety and efficiency.

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