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SELECTED PROBLEMS TO SUPPORT DECISION MAKING IN A SIMULATION ENVIRONMENT

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Abstract

The article is devoted to the problem of decision support in a simulation environment prepared for the air traffic control service. The limitations resulting from the functionality of the airport have been presented. In addition, the "integration" problems resulting from the movement of aircraft on the apron have been presented. The article outlines optimization problems such as minimizing the total taxiing time, taking into account the waiting time for the start of the runway, minimizing the time elapsed from the first taxiing to the end of taxiing by the last aircraft or multi-faceted functions, including, for example, penalties for deviations from the schedule of take-off / landing operations, failure to keep the CFMU time slots, or for too long taxiing cycles. The article presents restrictions on taxiing of aircraft, integration with other airport operations, decision problems and applied algorithms, groups of restrictions on taxiing of aircraft, scheduled flight table, dependencies between individual operations, positioning of aircraft.

Keywords: *air traffic control, aircraft operations, airport*

1. Introduction

Air traffic control is a fairly complex system consisting of many sets of interconnected and interrelated elements. Small disturbances in the piloting of the aircraft (too large deviations in time or incorrect manoeuvres of the aircraft in different flight conditions, taxiing, etc.), in the short run, lead to economic losses. Today's carrier is focused on minimizing costs related to service and maintenance, which directly translates into market competitiveness. At the same time, any errors on the service side of the airport also generate losses. The solution to these problems is solving decision problems using mathematical models that can then be implemented into virtual reality. Current IT solutions allow for real mapping and solving decision problems in an unambiguous way.

2. Restrictions on taxiing of aircraft

Aircraft taxiing operations on the apron are an element that binds the planning and flight control stage (including arrival and departure sequencing, air traffic planning in the immediate vicinity of the airport Fig. 1) and the issues of passenger service in terminals and ground handling of aircraft.

The main operations deciding on airport capacity are take-off and landing operations (sequencing and scheduling) on the runway [3, 8, 19, 20], the allocation of gates and parking spaces [12] and the movement of aircraft on the apron (taxiing).

Most of the available literature is currently focused on the planning and optimization of only one of these factors, however, from the economic point of view (increasing airport capacity and reducing delays) and from an ecological point of view (noise and environmental pollution reduction) it is necessary to consider all of these operations simultaneously [4].

The problem of aircraft moving on the apron is actually a subset of scheduling and searching for the best route. It is about such running aircraft on ground roads at the airport so that they can achieve their goals in a given time, i.e.: to reduce the total travel time and adapt to time „windows" established for technological reasons and for maintaining the necessary time separations , including the safety of passengers and planes.

These issues may have a significant level of complexity – depending on the size of the airport and its load. In simple cases, where only a few planes simultaneously move in the area there is a small risk of collisions. This is preceded by known algorithms for searching for the shortest paths in the graph, such as the Dijkstra or A * algorithm. More advanced systems require the use of simulation methods.

In the literature on the subject, the following groups of restrictions on taxiing of aircraft are met [4].

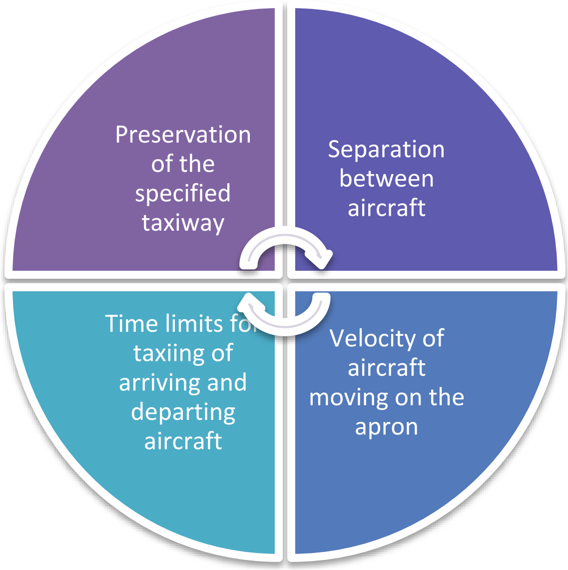

Fig. 1. Groups of restrictions on taxiing of aircraft [source: own development]

Preservation of the specified taxiway. If the taxiway is designated for reasons that are not subject to planning only the scheduling of take-off and landing operations is considered, preceded by taxiing operations [16, 25]. Another approach is presented in [1, 5, 6, 11, 14, 15, 17, 18, 26], in which the problem-solving algorithm selects a taxiway from a set of predefined solutions. In other works, in turn, there are no restrictions on the movement of aircraft on the apron.

Separation between aircraft. The need to maintain adequate time intervals and spacing between aircraft results from the possibility of direct collision between these aircraft [5, 7, 9], or entering the exhaust gas streams or into areas of air swirl caused by the operation of engines [21, 24]. The required distance between aircraft depends on many factors, such as the wind, the type of the first and the next aircraft, and the flight / taxiing phase in which the aircraft is currently located. These are distances ranging from 60 m to 200 m [5, 16].

Velocity of aircraft moving on the apron. Various approaches to the issue of determining the taxiing speed are found in the literature. In general, the speed depends on the type of aircraft [6, 26], and the shape of the road (curves characteristics) on which the airplane moves [5, 17].

Time limits for taxiing of arriving and departing aircraft. In the case of a landing operation, it is assumed that the taxiing time from the runway to the parking space can be fixed or variable to a certain extent. In most cases, it is assumed that the aircraft is taxiing to an empty position and is to reach it in the shortest possible time. In the case of start operations, the matter is more complex, as it is necessary to consider the problem of choosing the best route and additionally the problem of sequencing starts. If the sequencing of take-offs is not considered, the following patterns of behaviour are found in the literature: a) taxiing to the runway in the shortest possible time, b) taxiing to the runway at the set time or as close as possible to that time, c) taxiing to the runway so as to start in a specific time window (e.g. set by the Eurocontrol Central Flow Management Unit (CFMU [18]).

3. Integration with other airport operations

Integration with other airport operations Fig. 2 is another factor influencing the organization of taxiing operations [4]. Taxiing is not a separate part of the process, but is closely related to the take-off, landing, passenger service, and ground handling operations of aircraft. These operations determine the time and place of entry and the exit of aircraft to the taxiway network, so they determine its boundary conditions. The complexity of the system including all of the above operations makes it impossible to optimally control it, but nevertheless it is possible to coordinate between the solutions of these subproblems in the set range given below.

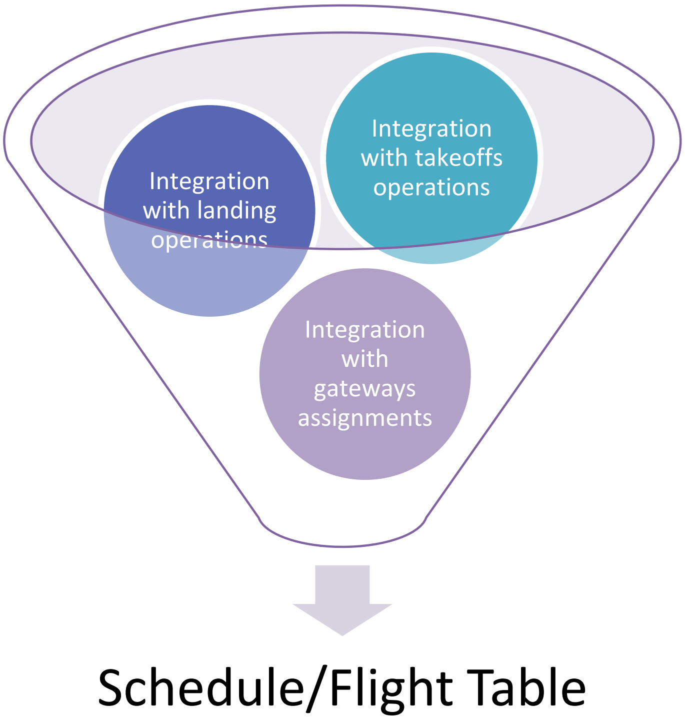

Fig. 2. Scheduled flight table [source: own development]

Integration with take-offs operations Fig. 3. Taxiing affects the sequence of take-offs, and the optimal sequence of take-offs (due to other factors) will be possible to enter only when it can be implemented by the taxiway subsystem [3]. The maximization of runway capacity requires two basic types of separation: swirl separation and road separation. The swirl separation depends on the type of aircraft, the mutual arrangement of taxiways and speed. Sequencing of take-offs is sometimes considered simultaneously with taxiing operations [1, 10, 11 13, 25]. In most cases, taxiing is planned so that the plane reaches the runway at a particular moment, while less importance is given to minimizing the total taxiing time. Swirl separation is often considered, while road separation has a smaller share [10, 13]. The prediction of the exact taxiing time also applies to the planning of the take-off operations, e.g. when interleaving the starting queues [24], or with flexible holding areas [3, 20]. Knowledge of these times facilitates the sequencing of take-offs [2].

Integration with landing operations. The ability to accurately predict the landing time affects the quality of taxiing operations organization. In addition, it is possible to choose a runway, which also affects the movement situation on the apron. Furthermore, the situation of intersection of the runway with taxiways is also considered, as well as the use of runways both for landing and take-off [18, 21].

Integration with gateways assignments Fig. 4. Gateways (and parking spaces on the apron) are entrances and exits to and from the taxiway system. Gateways allocation is important in the case of minimizing the distance travelled by passengers on foot [12]. Another criterion is the minimization of taxiway length (saving fuel and reducing congestion).

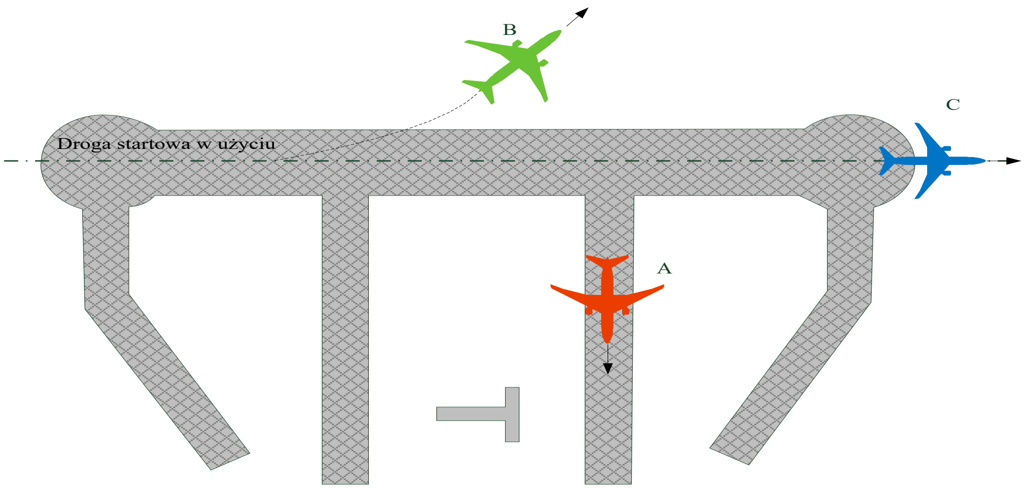

Fig. 3. Dependencies between individual operations [source: own development]

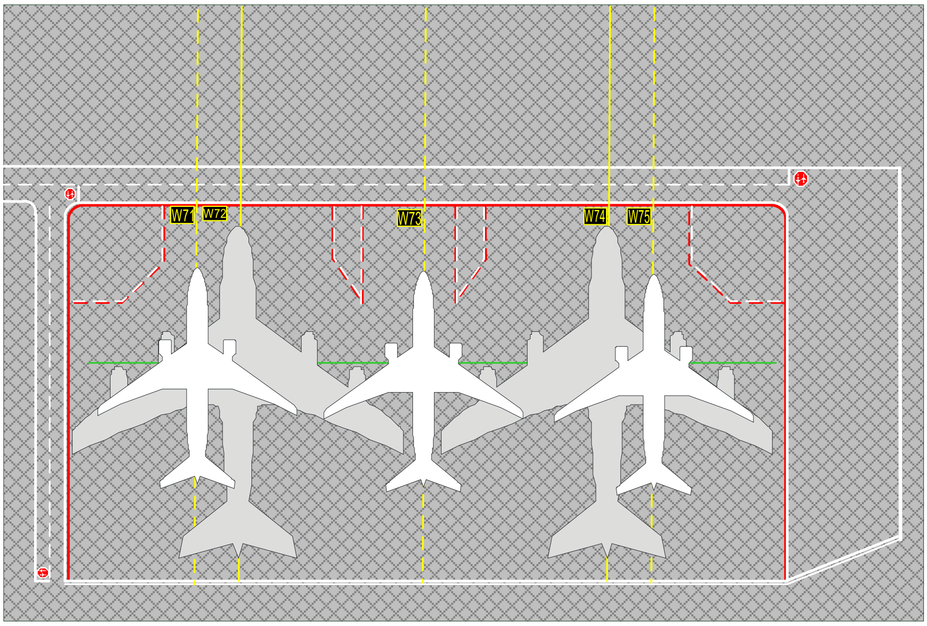

Fig. 4. Positioning of aircraft [source: own development]

4. Decision problems and applied algorithms

Optimization tasks for the taxiing problem described in the literature are formulated around various objective functions, depending on the approach [4]:

- minimization of the total taxiing time taking into account the waiting time for take-off on the runway [5, 23, 25, 26],
- minimization of the time elapsed since the first plane starts taxiing until the last aircraft has finished taxiing in the trial [14, 15],
- multifaceted functions, including e.g. penalties for deviations from the schedule of take-off / landing operations [1, 6, 11, 16], for not keeping CFMU time slots [18], or for too long taxiing cycles [10, 13, 27],
- other factors, such as the number of motion controller interventions [22].

Related issues whose are solutions can be used in the organization of airport taxiing operations: Automated Guided Vehicles (internal transport), production scheduling, routing of trains and scheduling, forecasting and detection of route conflicts.

Optimization tasks formulated on the basis of the above mentioned partial problems are in most cases saved using the Mixed Integer Linear Programming (MILP) and solved using available solvers or (if this is not possible) using heuristic methods, mainly time-effective methods Genetic Algorithms (AG) [4].

In the literature, the following approaches to the issue of organization of taxiing with the use of MILP are met:

- fixed position. Assignment of transition time to individual aircraft is on certain parts of taxiways at a fixed time: [6, 22, 23, 26]. The approach consists in constructing a spatio temporal network representing the physical structure of the road system and time dependencies of the passage along its arcs,
- the ordering approach. First, a decision is made regarding the sequence of passage of aircraft and on this basis is allocated the moments of entry into individual arcs and vertices of the network: [10, 13, 16, 25]. In most cases, binary variables are used to represent the arc and apex transition sequences. Time in this approach can be modelled continuously,
- direct predecessor / successor. Indicating only successive predecessors and successors for each aircraft on each arc / vertex instead of full sequencing: [16].

Search methods using genetic algorithms (GA) are an alternative to solutions to exact MILP problems. Solutions using the GA are time-effective and therefore suitable for practical use. The greatest difficulty in their implementation is to reflect the decision-making structure of the chromosome task. Next, it is difficult to determine the mechanisms of crossing, mutation and selection.

As in the case of MILP, the genetic algorithms implemented to solve the task of organization of taxiing of aircraft operate on the process time data and on ship sequence data. Most implementations of genetic algorithms [1, 5, 6, 8, 11, 14, 15, 18, 19, 26], determine the allocation of a specific route to a particular aircraft, and additionally can include:

- initial, depending on the type of aircraft, the delay time (i.e. stopping) of the taxi start. The genetic algorithm is to determine the time of initial delay for each aircraft and to give it a taxiway [14, 15],
- the occurrence of a delay at any time during the taxiway, including before it starts. Such a delay can be determined by defining the moments of its beginning and ending [5, 17], or by specifying its duration and the point in the space in which it happened (or is supposed to happen) [11]. The genetic algorithm is to determine where (when) the delay should take place and how long it should last and to give it a taxiway,
- the priority of the aircraft moving ahead of others in the event of a conflict on taxiways, [1, 17, 18]. The genetic algorithm, in this case, sets the priorities and allocates the taxiway to the aircraft.

4. Summary

All the above-mentioned approaches and methods should always be formulated using real quality data. Depending on the size of the state space, different approaches have their advantages. Relatively small examples can be solved optimally using "accurate" methods; however, the solution for complex cases may no longer be possible. For this reason, simulation approaches and genetic algorithms are used that offer rational solutions in an acceptable time.

Another problem is the quality of formulated MILP models, especially the discretization of the state space, which may lead to the loss of optimal solutions obtained with a smaller time grain. Similarly, the way in which the model deals with the application of separation rules can affect the quality of the solution. There are no studies in the literature regarding the determination of optimal separation intervals in real conditions or the study of the influence of the size of time grain in the discretization of time on the quality of the results and the method of their practical application.

Due to the possibility of practical application of the results, the methods are preferred short-term solutions, such as genetic algorithms. There are no (or very few) items describing the use of other heuristic methods (e.g. simulated annealing, taboo search) in the subject in the literature.

One of the most important aspects of the organization of the taxiing process is its dynamic character resulting from the stochastic conditions of this process and the inability to accurately predict the time and position in the traffic tasks. The need for continuous data update significantly extends the calculation process.

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