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Evaluation of efficiency and reliability of airport processes using simulation tools

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Highlights

- The genetic algorithm to evaluate the effectiveness of take-offs and landings is shown.
- The model for assessing the implementation of airport processes is developed.
- The proposed simulation tool reduces the landing time of aircraft.
- The optimization of taxi routes affects the reliability of airport processes.

Abstract

The purpose of this paper is to evaluate the efficiency of airport processes using simulation tools. A critical review of selected scientific studies relating to the performance of airport processes with respect to reliability, particularly within the apron, has been undertaken. The developed decision-making model evaluates the efficiency of airport processes in terms of minimizing penalties associated with aircraft landing before or after the scheduled landing time. The model takes into account, among other things, aircraft take-offs and landings and separation times between successive aircraft. In order to be able to verify the correctness of the decision-making model, a simulation tool was developed to support decision making in the implementation of airport operations based on a genetic algorithm. A novel development of the structure of a genetic algorithm as well as crossover and mutation operators adapted to the determination of aircraft movement routes on the apron is presented. The developed simulation tool was verified on real input data.

Keywords

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efficiency, airport processes, simulation tools, safety of airport operations, genetic algorithm, reliability of airport processes.

1. Introduction

The concept of transport or logistics process efficiency is widely discussed in the literature and is interpreted differently depending on the analysed research problem, e.g., efficiency of supply chains [20], production processes [8], intermodal transport [25], railway transport [46], international transport [22], or efficiency of means of transport studied in the context of minimizing exhaust emissions [6].

Processes implemented by airport systems are mainly the so-called airside operations, i.e. operations performed near the airport and on its manoeuvring area. These include aircraft take-off, landing and taxiing operations [30], and ground handling [49]. Airport processes are logistics processes that focus on the operations associated with the flow of a passenger stream at a given airport. The efficiency of any logistic, transport process is based on its reliability in carrying out given logistic operations [48]. Reliability of airport processes implementation is considered in the context of efficient functioning of the airport and its ability to serve passengers [42].

The procedures for take-off and landing are an important aspect in the implementation of airport operations. These procedures include several stages (Fig. 1):

- stage 1 – during which the aircraft captain requests permission to taxi for take-off. He receives information about the runway in use and permission to taxi;
- stage 2 – the aircraft taxis along the taxiways to a designated place in front of the runway (if the air traffic situation requires so, the departing aircraft will be stopped at a place safe for the performance of other airport operations);
- stage 3 – in the absence of contraindications to the take-off operation, a take-off permission is issued, if the situation did not allow the issue of such permission in Stage 2;
- stage 4 – a landing permission is issued if there are no factors preventing the landing operation;
- stage 5 – at this stage permission for the aircraft to taxi on the apron is issued;
- stage 6 – information is given on the location of the aircraft's parking on the apron.

At larger airports, the aircraft, after taxiing to a parking area designated by the air traffic coordinator, is connected to the passenger terminal by a mobile jetway. Many researchers [32] identify aircraft taxiing operations on the airport apron as the most important element affecting airport safety, reliability and capacity. In most cases, the

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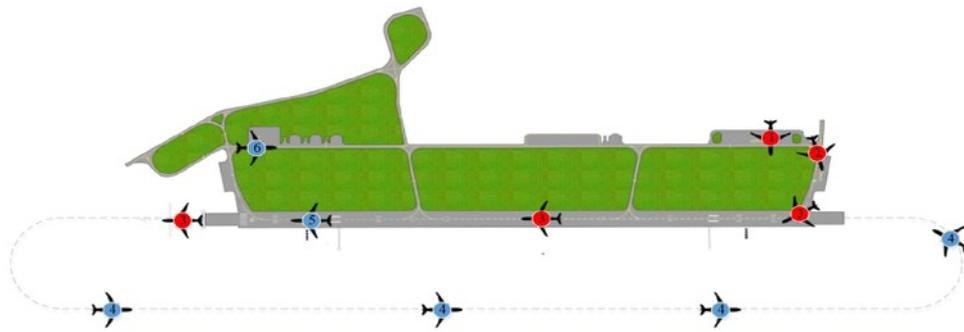


Fig. 1. Specific aircraft positions as seen from the aerodrome control tower

Source: own elaboration based on the developed application for simulation and management of aircraft traffic within the airport.

problem of determining a taxiway is solved solely by taking into account the shortest taxiway distance, disregarding the number of stops and accelerations or the necessity to wait for a free parking space.

Scheduling of take-off and landing operations has received quite a bit of attention in the literature. For example, in the study [45], the authors present a stochastic approach to scheduling take-off operations by describing delays, taxi time, or deviation from the desired arrival time as random variables. The authors emphasize that the aircraft taxiing system is a key factor generating delays in the landing and take-off phases during peak hours. However, scheduling of take-off operations in terms of minimizing potential delays and maximizing airport capacity is also the subject of the paper [35]. The authors propose a dynamic programming based, real-time method to generate a set of potential flight sequences given criteria related to airport delays and capacity. The constraints considered are distance separation, potential taxiway intersections, and separation due to aircraft induced air and exhaust turbulence.

Importantly, many researchers point to the need for a new approach to scheduling and routing of taxiing operations due to the need to maintain adequate safe take-off intervals [40]. In the work presented, the authors proposed an approach using a combinatorial integer optimization task that takes into account the time windows of aircraft entry into an airport's network of ground roads, taxiing speeds, and aircraft stopping characteristics on the apron. On the other hand, in the paper [34], the authors propose an airport taxiway network condition monitoring algorithm using advanced stochastic hybrid linear algorithms.

The main processes determining the reliability and capacity of airports and thus their efficiency are operations of take-off and landing on the runway [4] allocation of gates and parking places [9] and movement of aircraft on the apron [47].

Taking into account the fact that airport processes taking place on the apron affect the reliable and efficient functioning of the airport and determine the safety of passengers, it is advisable to develop modern methods and algorithms to improve safety and minimize the risk of accidents. The authors of this paper presented an original approach to evaluate the efficiency of airport processes by the application of a simulation tool based on a genetic algorithm.

In the first part, a critical analysis of the literature in the described research area is made. Then the author's decision-making model is presented, which includes all the important elements of the process of aircraft management on the airport apron. The model takes into account, among other things, aircraft take-offs and landings and separation times between successive aircraft. The developed decision-making model evaluates the efficiency of airport processes in terms of minimizing penalties associated with aircraft landing before or after the scheduled landing time. The factor that determines the amount of penalties associated with landing an aircraft outside of the designated time windows is the aircraft's taxiing time on the apron. This time will be optimized by the developed simulation tool.

An important element of the article is the verification of the decision-making model and the evaluation of the efficiency of the implementation of airport processes using a simulation tool. The optimization processes in the simulation tool used are implemented by a genetic algorithm. Genetic algorithms are algorithms often used in complex optimization issues, e.g. vehicle routing issue [24] in supply chain design [23] in airspace traffic management [12].

2. Research problems of airport process management - analysis of the literature

2.1. Decision-making problems in air traffic management on the airport apron

The movement of aircraft on the apron is actually a set of scheduling problems and finding the most advantageous route. It is about transit of the aircraft on the ground routes at the airport in such a way that they can achieve their objectives within a given time, i.e.: to reduce the overall travel time and to match the arrival and departure time windows of other aircraft using the airport, bearing in mind the reliability and safety of all operations.

The issues of finding the most advantageous route show a significant level of complexity, depending on the size of the airport and its traffic load. In simple cases where only a few aircraft are simultaneously moving through an area, there is little risk of collisions occurring. In such cases, well-known algorithms for finding shortest paths in a graph, such as Dijkstra's or A* algorithm, are used. More advanced systems require the use of simulation methods and complex optimization algorithms e.g. ant colony optimization (ACO) algorithms [13].

The aircraft taxiing problem is a complex decision-making issue. The following groups of aircraft taxiing restrictions are encountered in reference literature [43]:

- Maintaining an established taxiway. If a taxiway is designated for non-planning reasons, only the issue of take-off and landing scheduling operations that are preceded by taxiing operations is considered [40]. Another approach is presented in [12] in which the problem solving algorithm selects a taxiway from a set of predefined solutions.
- Separation between aircraft [14]. For the sake of reliability and safety of all airport operations, the need for adequate time and distance intervals between aircraft results from the possibility of a direct collision between them.
- The speed at which aircraft move on the apron. In literature there are various approaches to the problem of determining the taxiing speed. Generally speaking, speed depends on the type of aircraft and the shape of the taxiway (curve characteristics) on which the aircraft is moving.
- Taxiing time restrictions for arriving and departing aircraft. For landing operations, it is assumed that the taxiing time from the

runway to the parking area may be constant or variable within a certain range. In most cases it is assumed that the aircraft taxis to a vacant parking area and is expected to reach it in the shortest possible time. In the case of take-off operations, the matter is more complex as it is necessary to consider the problem of selecting the optimal route and, in addition, the problem of take-off sequencing [30].

The achievable number of aircraft landings and take-offs under certain infrastructure conditions is essential information for planning the expansion of airports with new taxiways, runways and aircraft parking areas. Accurate information can significantly affect financial planning for airport expansion. In addition, accurate information on taxiing times is essential for planning airport operations and thus ensuring their reliability and safety. Air traffic controllers instruct pilots on departures and approaches to parking areas and designated take-off routes [29]. Reliable and predictable taxiing time information takes some of the air traffic coordination burden off the air traffic controller.

The airport ground traffic problem involves planning aircraft movements between airport facilities so as to eliminate traffic conflicts in the most technically, economically, environmentally, and safety efficient manner possible [14]. Thus, it affects the reliability of airport operations.

Each arriving aircraft is directed off the runway to a parking area on the apron, or service area. The departing aircraft must be diverted from its current parking position to the runway. Taxiways for departing aircraft moving from established gates and parking areas to runways are predetermined and if there is a conflict with another aircraft, one aircraft must stop and wait. This situation results in delayed departures and potential delays in reaching the destination or increased travel cost due to the need to increase speed [1].

2.2. Issues of aircraft taxiing on the apron in terms of congestion consequences of aircraft traffic

The limited capacity of the airport associated with the organization of ground traffic results in long waiting times for aircraft to take off. The airport ground traffic problem involves planning aircraft movements between airport facilities so as to eliminate traffic conflicts in the most technically, economically, environmentally, and safety efficient manner possible.

One of the primary indicators for evaluating the quality of work in aircraft handling systems is the punctuality of flight completion. The European Organization for the Safety of Air Navigation points out that the main factors determining flight punctuality are delays due to airport operations, including limited runway access. Minimizing take-off times improves runway safety, ensures good utilization of its capacity and ensures reliability of all operations. Minimizing parking waiting times reduces passenger waiting times, which increases the quality of service.

Taxiing time is the time when the aircraft uses its engines while remaining on the ground. For departures, it is the time between leaving the parking position and take-off; for arrivals, it is the time between landing and reaching the parking position. This includes any waiting time, as well as queuing time, not just time in motion. The primary objective of the research work in this area is to minimize average departure and arrival delay times and average taxi waiting times and the associated safety and environmental impact criteria. Minimization of taxiing time implies reduction of pollutant emissions. The taxiing issue may be broken down into the following elements [2]:

- decisions concerning the aircraft movement path on the apron, to and from the parking position (if not already taken),
- allocation of gates and aircraft parking areas,
- landing (and take-off) sequence decisions where ground routes are already established.

Decision support is most often carried out by developing optimization and simulation models. The importance of the ground traffic

optimization problem is highlighted in [4]. Most of the proposed approaches to solving taxiway determination problems are based on simplified decision-making models based on basic ground traffic information [7].

Most of the available research work is devoted to the analysis of runway access planning using heuristic techniques: genetic and ant colony algorithms [28], or cellular automata [36].

An issue related to taxiing is congestion and its impact on the efficiency of airport operations. This paper [29] presents a model of aircraft taxiing on the apron and two strategies for solving it: varying aircraft departure and arrival times and varying departure times only, which greatly facilitates the use of the model.

In airport processes, the flight controller managing aircraft traffic has access to information on all aircraft and their location in the airspace. In this respect, ground air traffic control is similar to the systems used in Automated Guided Vehicles (AGVs) [10], which are computer controlled.

The problem of aircraft taxiing is widely described in publications [39]. These publications offer some detailed solutions, but do not present a coherent model or methodology for studying and making decisions about the processes of taxiing and handling aircraft at airports and their impact on the efficiency of airport operations.

The literature review has highlighted that it is reasonable to develop new tools to support decision-making in the implementation of airport operations to eliminate conflict situations while minimizing the duration of airport operations [15], which consequently affects the efficiency of all operations.

3. Model of airport process implementation

3.1. Take-off and landing model parameters

The data necessary for the development of a mathematical model for scheduling aircraft take-offs and landings, taking into account the separation times between successive aircraft, the possibility of landing on different runways/landing fields, and the costs of penalties for landing outside the time set are presented below in Table 1.

Table 1. Decision-making model parameters

Parameter	Description
I	the set of flight/aircraft numbers, where i, j are elements of the set
SL	the set of runways/landing fields, where sl, sl' are elements of the set
A_i	the earliest possible time for landing by i -th flight/aircraft
B_i	the latest possible time for landing by i -th flight/plane
ML_i	planned time of landing by the i -th flight/aircraft
kA_i	unit amount of penalty for landing the aircraft before its scheduled time of arrival
kB_i	the unit amount of the penalty for landing the aircraft after its scheduled time of arrival
TS_{ij}	separation time between the landing of aircraft no. i and aircraft no. j
ts_{ij}	separation time between landing of aircraft no. i and aircraft no. j on different runways/landing fields

3.2. Quantities sought

The decision variables sought in the model relate to the values of aircraft landing times, landing sequence and runways/landing fields. Therefore, the aircraft landing sequence in the model was written in the form of a binary variable (taking the values 1 and 0). On the other

hand, the aircraft landing times were recorded in the form of variables taking values from the set of positive real numbers. The defined decision variables are shown in Tab. 2.

Table 2. The variables sought in the decision model

Variable	Description
f_{ij}	$f_{ij}=1$ if the i -th aircraft lands before the j -th aircraft; otherwise it takes the value 0;
g_{ij}	$g_{ij}=1$ if the i -th aircraft lands on the same runway/landing field as the aircraft no. j ; otherwise it takes the value 0
u_i^{sl}	$u_i^{sl}=1$ if the i -th aircraft lands on sl -th runway/landing field; otherwise it takes the value 0
lm_i	landing time of the i -th aircraft

3.3. Criterion function and constraints

The criterion function has the interpretation of minimizing penalties associated with landing the aircraft before or after the scheduled landing time:

$$\sum_{i=1} (kA_i (ML_i - lm_i) + kB_i (lm_i - ML_i)) \rightarrow \min \quad (1)$$

The constraints imposed on the values of the decision variables are as follows:

- Each landing must be made within the time interval determined by the earliest and latest landing times:

$$\forall i \in I \quad A_i \leq lm_i \leq B_i \quad (2)$$

$$lm_i = A_i + g_{ij} (B_i - A_i) \quad (3)$$

- Constraint of the sequence in which aircraft land:

$$\forall i, j \in I \quad \wedge \quad j > i \quad f_{ij} + f_{ji} = 1 \quad (4)$$

$$\forall i, j \in I \quad g_{ij} = g_{ji} \quad (5)$$

- Constraint of the separation time between successive landing aircraft:

$$\forall i, j \in I \quad lm_j \geq x_i + TS_{ij} g_{ij} + ts_{ij} (1 - g_{ij}) - M \cdot f_{ij} \quad (6)$$

where: M – is a large number ensuring that this constraint is redundant when aircraft number j lands before aircraft number i .

- Each aircraft is assigned to only one runway/landing field:

$$\forall i \in I \quad \sum_{sl=1} u_i^{sl} = 1 \quad (7)$$

$$\forall i, j \in I \quad \forall sl \in SL \quad g_{ij} \geq u_i^{sl} + u_j^{sl} - 1 \quad (8)$$

4. Application of genetic algorithm in the organization of aircraft traffic on the apron

4.1. General assumptions

The simulation tool developed in this paper to evaluate the efficiency of airport processes is based on the genetic algorithm. The

task of the algorithm is to determine the transit routes of aircraft when they take off and land, taking into account the sequence of their take-offs and landings. These routes will generate apron occupancy times and thus determine the amount of penalties associated with aircraft landing before or after the scheduled landing or take-off time. In addition, the landing times for individual aircraft at the airport are determined based on the apron occupancy times.

The principle of the genetic algorithm can be presented in the following steps:

- Step 1.** Input data introduction: average transit time between point elements of the apron structure, times for additional aircraft handling, estimated landing and take-off times for aircraft, delays in aircraft landings and take-offs, take-off and arrival separations, etc.
- Step 2.** Generating an initial population. Chromosomes (matrix structures) set the routes of aircraft movement on the apron, both take-off and landing routes.
- Step 3.** Setting the input parameters of the genetic algorithm i.e. number of iterations, population size, crossover and mutation parameters. The setting of the input parameters determines the correctness of the result generation.
- Step 4.** Each individual in the population is assessed according to its adaptation function. In the case under consideration, the evaluation function is the time of airport apron occupancy by aircraft, measured from landing to take-off (taxiing time).
- Step 5.** Using the roulette method, individuals with the best adaptation function are selected for the next generation (iteration of the algorithm).
- Step 6.** The process of the algorithm rapidly aiming at undesirable local minima blocked by the introduction of a scaling process.
- Step 7.** The purpose of the crossover process is to trigger genetic changes in a population of individuals to introduce new chromosomes into the population.
- Step 8.** The purpose of the mutation process is to trigger genetic changes in a population of individuals to introduce new chromosomes into the population.
- Step 9.** The repair algorithm is triggered in the case of an erroneous structure generated after the crossover and mutation process.
- Step 10.** Generating a final population about the interpretation of aircraft routing.

Steps 3-9 of the algorithm are repeated a specified number of iterations until a stop condition is obtained. The stop condition is a certain number of iterations. The matrix structure determines the routes of the aircraft movement on the apron. The matrix structure of the chromosome was randomly generated according to developed algorithms. The matrix structure has an interpretation of the decision variables developed in the mathematical model. The initial population consists of a certain number of matrix structures determined at the beginning of the algorithm.

The algorithm for selecting chromosomes for crossover takes into account the whole process of selecting chromosomes for crossover, in the case of chromosome oddity it randomly selects the chromosome to pair, randomly pairs the two chromosomes, randomly selects the cutting points of the chromosomes and activates the crossover algorithm adequate to the proposed matrix structure. The crossover algorithm is supported by an individual repair algorithm. The mutation algorithm draws the chromosome for the mutation process and swaps the values of randomly selected genes. The crossover and mutation algorithms occur with a certain probability defined as input data. The end result of the genetic algorithm is a generated population that determines a comprehensive set of aircraft movement routes on the apron. The parameters of the genetic algorithm i.e. crossover and mutation probabilities, number of iterations and population size were chosen experimentally. The process of verifying the genetic algorithm was carried out on the basis of comparison of the genetic algorithm solutions with those

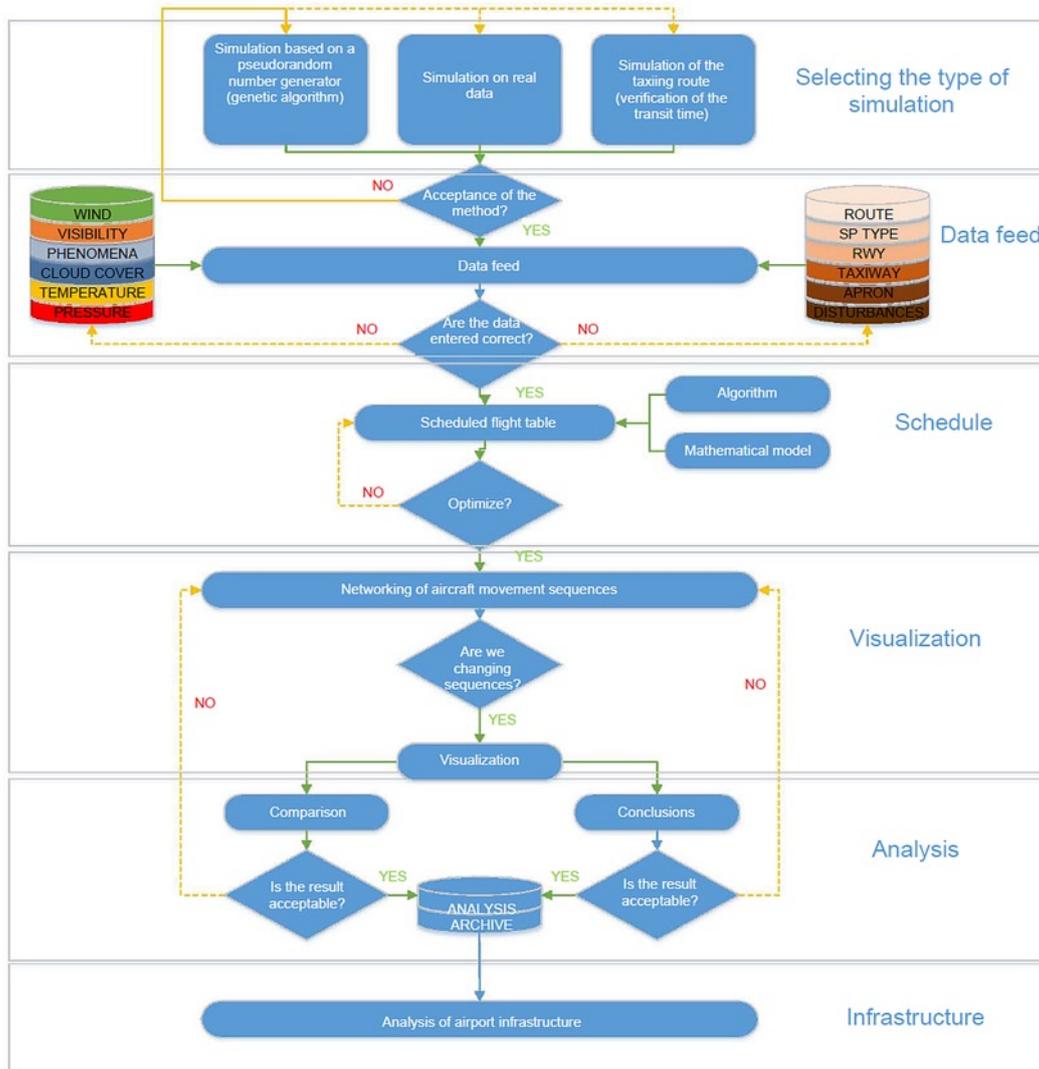


Fig. 6. Functional modules of the simulator

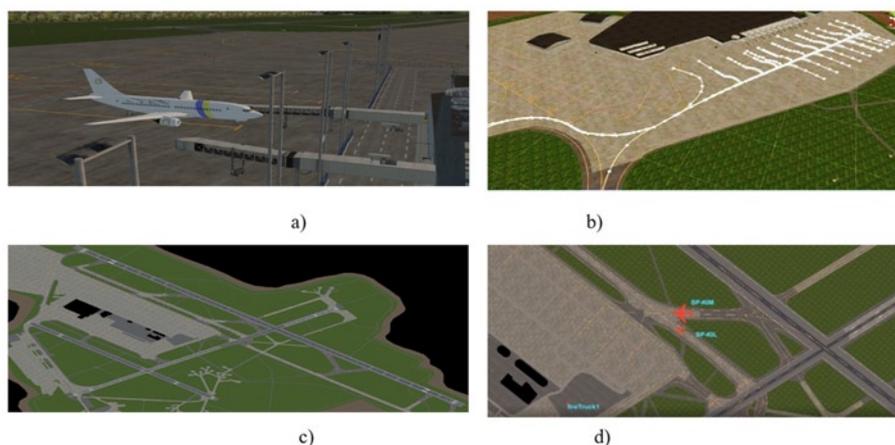


Fig. 7. Graphic representation of the simulation visualization module
Source: printout of the simulation using the simulation tool (own elaboration)

initial population (initial aircraft transit routes) for the genetic algorithm. This simulation is determined based on optimization processes so it is an effective tool for assessing the quality of airport processes.

The data feed module is used to enter various types of data such as service time of a given carrier and types of aircraft operated at a given airport. This data may also include the number of runways (RWY) or apron parking areas.

The scheduled flight table is an element that shows the arrival and departure times of aircraft from a given airport based on the data entered. This module is a kind of a schedule of the simulation set, thanks to which it is certain that given operations are planned and introduced correctly with simulation assumptions created on the basis of real data or random number generator.

The visualization module depicts the complete airport environment, including: depiction of aircraft (Fig. 7a), configuration of runways and taxiways (Fig. 7b), airport apron (Fig. 7c), natural terrain surrounding the airport, man-made objects or runway conditions.

The result analysis module verifies the correctness of the simulation based on the genetic algorithm. In case of an erroneous verification, the algorithm is calibrated by changing the initial settings of the algorithm parameters. Additionally, the performance analysis module evaluates the efficiency of a given airport in terms of existing airport infrastructure.

6. Practical example of using a simulation tool to evaluate the efficiency of traffic management processes on the apron

6.1. Simulation assumptions

To analyse and evaluate the organization of aircraft traffic on the apron, simulation studies were conducted on real data obtained from the operation of a real airport. The simulation assumed that different “S” and “D” taxiways would be used, and assumed that aircraft have different technical parameters (e.g., ground speed, acceleration time, braking time, taxiing time, and handling time).

Table 3. Aircraft taxiing times on the ways

Measurement No.	Aircraft type	Taxiway marking	Taxiing time (min)	Measurement No.	Aircraft type	Taxiway marking	Taxiing time (min)
1	ATR72	SOMZA32	2.06	37	ATR72	DAW76	1.56
2	ATR72	SOMZA32	1.59	38	ATR72	DAW76	1.35
3	ATR72	SOMZA32	1.35	39	ATR72	DAW76	1.29
4	B737	SA51	5	40	ER145	DA33	2.54
5	B737	SA51	4.58	41	ER145	DA33	2.35
6	B737	SA51	4.21	42	ER145	DA33	2.59
7	MD87	SOM24	2.55	43	AVRO	DA36P	3
8	MD87	SOM24	2	44	AVRO	DA36P	2.59
9	MD87	SOM24	2.22	45	AVRO	DA36P	3.19
10	MD82	SOM70	2.26	46	B737	DAZM12	3.38
11	MD82	SOM70	2.15	47	B737	DAZM12	3.29
12	MD82	SOM70	2.18	48	B737	DAZM12	3.41
13	JS32	SAW87	4.13	49	B767	DAZ10L	2.28
14	JS32	SAW87	4.25	50	B767	DAZ10L	2.25
15	JS32	SAW87	4.33	51	B767	DAZ10L	3
16	A320	SOM11	8	52	ER190	DAZM32	2.3
17	A320	SOM11	8.36	53	ER190	DAZM32	2.1
18	A320	SOM11	9.05	54	ER190	DAZM32	2.45
19	A321	SOMZ10	2.38	55	ATR72	DAZM31	7
20	A321	SOMZ10	2.24	56	ATR72	DAZM31	6.54
21	A321	SOMZ10	2.17	57	ATR72	DAZM31	6
22	CRJ	SOM35	1.15	58	FOCKER	DAZM35	3.15
23	CRJ	SOM35	1.21	59	FOCKER	DAZM35	3.28
24	CRJ	SOM35	1.36	60	FOCKER	DAZM35	3.18
25	ER180	SOM14P	2.21	61	CRJ	DA34	3.1
26	ER180	SOM14P	2.47	62	CRJ	DA34	3.12
27	ER180	SOM14P	2.14	63	CRJ	DA34	3.06
28	A319	SOM13L	2.45	64	ER170	DAZM21	4.3
29	A319	SOM13L	2.15	65	ER170	DAZM21	4.28
30	A319	SOM13L	3	66	ER170	DAZM21	4.56
31	A319	SOM19	3.56	67	B737	DAE48	6.29
32	A319	SOM19	3.48	68	B737	DAE48	6.45
33	A319	SOM19	3.23	69	B737	DAE48	6.18
34	B737	SOMZU5	5.42	70	ER145	DA33	2.54
35	B737	SOMZU5	5.3	71	ER145	DA33	2.59
36	B737	SOMZU5	6.01	72	ER145	DA33	2.38

Source: own study

Table 4. Taxiing times for aircraft on the "S" fast exit roads

Type of Aircraft	Taxiway	Taxiing time [min]	Taxiing time according to simulation [min]	Difference
ATR72	SOMZA32	2.06	1.35	-34%
ATR72	SOMZA32	1.59	1.35	-15%
ATR72	SOMZA32	1.35	1.35	0%
B737	SA51	5	4.15	-17%
B737	SA51	4.58	4.15	-9%
B737	SA51	4.21	4.15	-1%
MD87	SOM24	2.55	2.1	-18%
MD87	SOM24	2	2.1	5%
MD87	SOM24	2.22	2.1	-5%
MD82	SOM70	2.26	2.1	-7%
MD82	SOM70	2.15	2.1	-2%
MD82	SOM70	2.18	2.1	-4%
JS32	SAW87	4.13	4.2	2%
JS32	SAW87	4.25	4.2	-1%
JS32	SAW87	4.33	4.2	-3%
A320	SOM11	8	7.3	-9%
A320	SOM11	8.36	7.3	-13%
A320	SOM11	9.05	7.3	-19%
A321	SOMZ10	2.38	2.15	-10%
A321	SOMZ10	2.24	2.15	-4%
A321	SOMZ10	2.17	2.15	-1%
CRJ	SOM35	1.15	1.1	-4%
CRJ	SOM35	1.21	1.1	-9%
CRJ	SOM35	1.36	1.1	-19%
ER180	SOM14P	2.21	2.12	-4%
ER180	SOM14P	2.47	2.12	-14%
ER180	SOM14P	2.14	2.12	-1%
A319	SOM13L	2.45	2.2	-10%
A319	SOM13L	2.15	2.2	2%
A319	SOM13L	3	2.2	-27%
A319	SOM19	3.56	3.12	-12%
A319	SOM19	3.48	3.12	-10%
A319	SOM19	3.23	3.12	-3%
B737	SOMZU5	5.42	5.29	-2%
B737	SOMZU5	5.3	5.29	0%
B737	SOMZU5	6.01	5.29	-12%

Source: own report based on data from the airport

The purpose of conducting the simulation is to compare the actual aircraft taxiing times with the taxiing times in the simulation environment using the optimization algorithm proposed in this paper. Tab. 3 shows actual aircraft taxiing times at the airport selected for the study.

6.2. Comparison of results

Aircraft movement studies using the simulation tool provided a percentage representation of the differences between actual taxiing times and times generated by the simulation process. The time gains when applying the simulation method in several cases reach or exceed 20%, which proves the high efficiency of the tool used and the cor-

rect verification of the optimization algorithm. The results of the percentage summary are presented sequentially in Tab. 4 for the taxiway starting from the "S" fast exit road (sierra) and Tab. 5 for the taxiway starting from the "D" fast exit road (delta).

7. Conclusions

The movement of aircraft on the apron must be based on well-considered decisions, taking into account many aspects of scheduling and finding the best route, in order to reduce overall travel times and to match the take-off and landing windows of individual aircraft to minimise the risk of potential collisions.

Table 5. Taxiing times for aircraft on "D" fast exit roads

Type Aircraft	Taxiway	Taxiing time [min]	Taxiing time according to simulation [min]	Difference
ATR72	DAW76	1.56	1.2	-23%
ATR72	DAW76	1.35	1.2	-11%
ATR72	DAW76	1.29	1.2	-7%
ER145	DA33	2.54	2.1	-17%
ER145	DA33	2.35	2.1	-11%
ER145	DA33	2.59	2.1	-19%
AVRO	DA36P	3	3	0%
AVRO	DA36P	2.59	3	16%
AVRO	DA36P	3.19	3	-6%
B737	DAZM12	3.38	3.15	-7%
B737	DAZM12	3.29	3.15	-4%
B737	DAZM12	3.41	3.15	-8%
B767	DAZ10L	2.28	2.12	-7%
B767	DAZ10L	2.25	2.12	-6%
B767	DAZ10L	3	2.12	-29%
ER190	DAZM32	2.3	2.11	-8%
ER190	DAZM32	2.1	2.11	0%
ER190	DAZM32	2.45	2.11	-14%
ATR72	DAZM31	7	-	-100%
ATR72	DAZM31	6.54	-	-100%
ATR72	DAZM31	6	-	-100%
FOCKER	DAZM35	3.15	3.18	1%
FOCKER	DAZM35	3.28	3.18	-3%
FOCKER	DAZM35	3.18	3.18	0%
CRJ	DA34	3.1	2.59	-16%
CRJ	DA34	3.12	2.59	-17%
CRJ	DA34	3.06	2.59	-15%
ER170	DAZM21	4.3	4.11	-4%
ER170	DAZM21	4.28	4.11	-4%
ER170	DAZM21	4.56	4.11	-10%
B737	DAE48	6.29	6	-5%
B737	DAE48	6.45	6	-7%
B737	DAE48	6.18	6	-3%
ER145	DA33	2.54	2.3	-9%
ER145	DA33	2.59	2.3	-11%
ER145	DA33	2.38	2.3	-3%

Source: own report based on data from the airport

The research presented in this paper has confirmed the efficiency of a simulation tool based on a genetic algorithm used to evaluate airport processes.

The proposed simulation tool allows the analysis and evaluation of airport processes in the context of, among others: increasing airport capacity, planning the positioning of aircraft on the apron, extending taxiways, selecting the number of runways, optimizing aircraft taxiways on the apron, determining the order of take-offs and landings,

increasing the efficiency and effectiveness of airport processes in the context of safety of airport operations.

The application in the form of a simulation tool allows for the verification of the operation of a given airport in a given time interval.

The developed proprietary tool additionally enables the analysis and evaluation of operations related to take-off, landing, taxiing and handling of aircraft in real traffic conditions.

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