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Optimization model of staffing for aircraft ground handling in the case of personnel substitutability

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A B S T R A C T

The presented article deals with the mathematical modelling of aircraft ground handling on the service apron to utilize ground personnel more efficiently in the case of existing substitutability of workers. This article proposes a supporting decision-making tool for effective planning of the aircraft ground handling. This tool will be used for a selected type of aircraft and using the minimum number of personnel participating in the aircraft ground handling procedure. The optimization is based on the original mathematical programming model and its solution. Computational experiments verifying the functionality of the proposed model were performed on current data from the Ostrava International Regional Airport in the Czech Republic. The originality of the proposed approach (apart from the original model) comes with introducing the substitutability of workers of individual qualifications and the decomposition of workgroups composed of workers of the same qualification down to the level of individual workers. Above-mentioned decomposition of workgroups enables the flexible and separate transfer of individual workers included in the same groups between activities in the event of downtime of the given group and the existence of an activity that is not covered by the required number of workers. The substitutability of workers and the decomposition of individual groups down to the level of individual workers will make it possible to lower the number of workers or verify that the number of workers is optimal and eliminate potential staff downtime.

1. Introduction

A characteristic feature of air transport is speed when covering medium and longer distances. Therefore, despite the temporary slump caused by the Covid-19 pandemic, air transport is expected to return to pre-pandemic performance in the future. However, the increase in air traffic density also brings with it the fact that important airports are overcrowded with air traffic, often limiting their capacity. At the same time, the demands of air carriers to shorten the aircraft ground handling times are growing (Van Blokland et al., 2008; Kwasiborska, 2010; Strakova & Mrva, 2011).

The whole range of activities within aircraft ground handling is relatively physically demanding and, in many countries, also not significantly financially valued. At airports with heavy traffic, there is always the possibility that a shortage of personnel dealing with aircraft ground handling will emerge. Therefore, it is necessary to address the issue of minimizing the number of employees needed to ensure aircraft ground handling (Evler et al., 2018; Fricke & Schultz, 2008; Al-Bazi et al., 2016).

The article's main goal is to present a possible approach to support personnel planning in aircraft ground handling. The goal is to determine the minimum number of workers needed to perform aircraft ground handling. Optimization results can be used in case of crises, such as increased sickness or quarantine of workers (because of a pandemic) or points of short-term

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increased intensity of the aircraft ground handling when seasonal workers cannot cover this increased intensity (Schmidt, 2017; Malandri et al., 2019; Shen et al., 2019; Okwir et al., 2017; Weigert et al., 2018).

The main contributions of the presented article are three. The first main benefit is the incorporation of substitutability of workers of individual qualifications involved in aircraft ground handling. The second main benefit is the decomposition of individual groups of aircraft ground handling workers down to the level of individual workers, enabling their more flexible use during it. The third main contribution is the extension of the applicability of the methods of mixed integer linear programming (mixed integer linear programming) to other optimization problems of air transport.

1.1 Analysis of the current state

The Covid-19 pandemic had a high impact on aviation causing a 65% drop in air travel worldwide at its start in June 2020 (Arena & Aprea, 2021). This drop was the response of air traffic to the restrictions applied around the world. The entire airline industry had to adjust to shrinking profits and mass layoffs to keep airlines and service companies from going bankrupt. The Covid-19 pandemic also resulted in the modification of the aircraft ground handling process at airports as demonstrated Schultz et al. (2020). A new way of assigning seats to passengers was integrated into the process, and the process of cleaning the aircraft deck was also modified with new, above-standard activities that reduced the risk of passenger infection. The passenger seat allocation process was modified by reducing the aircraft's carrying capacity by 1/3 and leaving every middle seat on the aircraft unoccupied to ensure minimum spacing between passengers. The deck cleaning process was expanded to include deck disinfection, which increased the duration of this activity and the overall duration of aircraft ground handling at the airport. The authors performed an analysis of the given situation and found that the total time of aircraft ground handling is increased by 20% and only by 10% when more workers are used.

The process of checking in an aircraft at the airport, which also includes aircraft ground handling, is a time-consuming, complex process during which the aircraft and passengers are provided with the required services as demonstrated by Kazda and Caves (2010) and Ashford et al. (2015). The total duration of the aircraft ground handling depends on several factors, including:

1. type of aircraft handled (narrow-body, wide-body) and its operational and technical characteristics;
2. the range of services required by the air carrier during aircraft ground handling (the weight of the catering depends on the range of on-board services of the air carrier and the length of the flight, the possibility of a requirement to clean the aircraft);
3. refuelling requirement (mass and volume of fuel);
4. the number of passengers disembarking/boarding from/to the given aircraft;
5. method for the boarding and exit of passengers (use of boarding bridges, transportation of passengers from the terminal to the stand-by bus);
6. amount of checked baggage, goods, and mail;
7. the possibility of a requirement to refill drinking water and empty the onboard septic tank;
8. technical equipment of the airport with handling equipment (quantity and performance parameters of handling equipment);
9. method of placing checked baggage on the plane (free checked baggage, placement of checked baggage in containers);
10. number of ground handling workers;
11. the possibility of substitutability of workers of individual qualifications participating in aircraft ground handling;
12. configuration of stands at the airport and transit times of handling equipment between stands;
13. meteorological conditions (application of anti-icing sprays to the aircraft in winter);
14. the possibility of extraordinary operational circumstances (e.g., Bulky Load, Leg of Loading Equipment, Defueling, Late Documentation, etc.) (Vidosavljevic & Tosic, 2010; Andreatta et al., 2014; Wu & Caves, 2004a; Wu & Caves, 2004b).

The complexity and overall time-consuming nature of the entire aircraft ground handling generate the requirement for the maximum elimination of time reserves occurring during it. Removing reserves can reduce overall handling time and a subsequent increase in airport handling capacity during peak times, as the check-in process can be a bottleneck for airport capacity during peak times (Meredith & Mantel, 2003; Bassett et al., 2000).

Several approaches have been proposed in the past to solve the problem of eliminating time reserves in aircraft ground handling. In many cases, managerial decision-making methods are the key to the entire rationalization process. Most often, CPM (Critical Path Method) is used to identify the time reserves of the sub-activities that make up the project. Even aircraft ground handling can be considered a complete project (Wilson, 2003; Kroese et al., 2011; Popova-Zeugmann, 2013; Mamdouh et al., 2020).

CPM is a primary deterministic project management method. When using it, aircraft ground handling can be represented by an edge-rated acyclic digraph, in which nodes represent the beginnings and ends of individual activities, edges represent the activities themselves, and edge evaluations represent the durations of unique activities. One of the goals of CPM is to identify the so-called critical path, which in the terminology of graph theory, corresponds to the maximal path in the digraph. It is the most extended sequence of related activities starting at the node representing the beginning of the project and ending at the node representing the end of the project. The critical path length represents the shortest possible time for the project to be solved. For the activities forming the critical path (critical activities), their arbitrary extension results in an extension of the total project implementation time (when other organizational measures are not implemented). CPM also allows the calculation of the time reserved for each activity. Critical activities are all activities with zero total time reserve, and other activities are not critical. Detailed information about CPM can be found in several sources, (e.g., Winston, 2003; Maylor, 2010; Lockyer & Gordon, 1991; Field & Keller, 1998). The second most frequently used tool is simulation methods, or approaches referred to as CDM (Collaborative Decision Making) (Kierzkowski & Kisiel, 2017; Kabongo et al., 2016; Endrizalova et al., 2016).

The first work that should be noted in connection with the use of CPM for the process of planning aircraft ground handling is the article (Van Blokland et al., 2008). In it, the authors describe the processes at Amsterdam-Schiphol airport and monitor the possibilities of reducing the turnaround of narrow-body and wide-body aircraft, specifically the B737 and B747. The contribution of their article lies in the proposal to divide the entire process of aircraft turnaround at the airport apron into two sub-processes – processes carried out in the space "above the wing" and the space "under the wing". The processes carried out in the space "above the wing" include the opening and closing of the boarding stairs, boarding, and boarding of passengers, replenishment of catering, cleaning of the cabin, and activities carried out by the flight staff (inspection of the aircraft deck). Processes performed "under the wing" include attaching GPUs, securing undercarriage wheel chocks, unloading and loading baggage, goods, and mail, refilling potable water, draining septic tanks, refueling, setting out a buffer zone, and pushback. The whole process is defined by the time of securing the aircraft's wheels with stops (Block on Time) and the time of removing the stops from the aircraft's wheels (Block off Time). Based on data from the carrier KLM, the authors analyzed the turnaround processes of two types of aircraft using CPM to determine which activities can be reduced in duration to shorten the entire aircraft turnaround process. The authors also analyzed the situation at Arlanda Airport in Sweden, where they investigated the time-consuming process of aircraft turnaround and tried to find activities suitable for reducing the total turnaround time. After implementation, the changes proposed by the authors reduced the turnaround time for the B737 by 42% and for the B747 by 38%.

When evaluating the effectiveness of the aircraft handling process as demonstrated by Kwasiborska (2010), the author uses Gantt charts and works with stochastic operating conditions. The entry of aircraft into the handling system is modeled by a Poisson probability distribution. To solve and evaluate the efficiency of the handling process, it uses a method based on the theory of mass service (Queueing Theory). The connection with the solved problem lies in a different way of modeling the flow of incoming aircraft into the process of aircraft ground handling during their check-in. The results of her research can be followed up in the future in connection with the issue of parallel handling.

Malandri et al. (2019) have recently shown the deal with the efficiency of the processes associated with aircraft check-in at the airport in cases where the efficiency of the process can be impaired by activities that are beyond the control of the carriers. An example of such disruption of processes can be a strike of part of the ground staff. If the number of workers decreases, the time required to check in the aircraft will increase, which can lead to delays in the activities of the aircraft check-in process and therefore the departure. The solution to the problem consists in defining the minimum number of employees at which no delays occur. The solution was created using AnyLogic software. The authors conducted their research on the conditions of the Lisbon Humberto Delgado airport. Here there is a direct link to the research presented in the article because it is precisely in cases of strikes by part of the ground staff that there is a need to ensure aircraft ground handling with a minimum number of employees.

Okwir et al. (2017) have shown the analysis of the check-in process using the Collaborative Decision Making (CDM) method. The data used for the calculation contains 65,000 observations from 2014 at Madrid Airport. The authors monitored the influence of the so-called critical indicators on the total delay time of the check-in process. To control the smoothness of the process of aircraft ground handling, the authors proposed an indicator called "Star Values", the prediction of which can determine the minimum conditions of delay and the total handling time. The article confirms the suitability of using the CDM method for influencing the smoothness of air traffic from their research, the issue of critical indicators with an effect on the total time of aircraft ground handling was taken over for our article. Critical indicators are represented by activities on the critical path.

Approaches published in the past for increasing the efficiency of the process of aircraft ground handling use the entire spectrum of mathematical and informatics disciplines. Most often, modeling is based on network analysis and mathematical programming methods, which combine the mathematical approach in the presented article. In the previous approaches, the possible substitutability of workers with selected qualifications involved in aircraft ground handling was nowhere considered, which the presented article admits. The substitutability of workers with specified qualifications participating in aircraft ground handling is characteristic, especially for smaller airports of regional importance (Tabares et al., 2021; Schultz, 2018 and Shen et al. 2019).

2. Materials and Methods

The mathematical model, as demonstrated by Teichmann & Dorda (2016), was used to create a mathematical model for planning personnel security for service processes taking place during aircraft ground handling with the possibility of mutual substitutability of ground personnel. The functionality of the model was verified in Teichmann & Dorda (2016) only on a simple model example without connection to a real process. For the needs of the solved optimization problem, it was necessary to modify the mathematical model in a form that meets the parameters determined by the operation at the solved airport.

Creating a mathematical model of the solved task is preceded by creating a network graph of the project and obtaining the basic time characteristics of individual activities using CPM.

In the following paragraph, the problem formulation of the solved task will be presented, consisting of a list of input data, expected decisions (required results), and an optimization criterion, according to the value of which the effectiveness of the proposed solution is assessed.

The following are taken from the mathematical model:

N ··· set of activities that make up the process of aircraft ground handling;

P ··· set of qualification needed to implement the aircraft ground handling;

P_i ··· set of qualifications that can perform the activity $i \in N$;

L_p ··· set of workers' qualifications $p \in P$;

$\overline{t_i}$ ··· earliest possible start of activity $i \in N$;

$\overline{\overline{t_i}}$ ··· the latest permissible start of the activity $i \in N$;

t_i … duration of activity $i \in N$.

The formulation of the problem shown in (Teichmann & Dorda, 2016) is supplemented with the following input data types:

C_i ··· the number of employees to be assigned to perform the activity $i \in N$;

c_p ··· number of workers' qualifications $p \in P$;

a_{ip} ··· element of the matrix representing the affiliation of the qualification worker $p \in P$ to perform the activity $i \in N$ – when the worker qualification is $p \in P$ is authorized to perform the activity $i \in N$, then $a_{ip} = 1$, otherwise $a_{ip} = 0$;

b_{ij} ··· matrix element allowing worker transfers between activities – when the worker is transferred to an activity $j \in N$ after task $i \in N \cup \{0\}$, then $b_{ij} = 1$, otherwise $b_{ij} = 0$.

The task is to decide on the assignment of workers of individual qualifications to individual activities so that the total number of workers deployed to implement aircraft ground handling is minimal.

2.1 Solving the optimization problem

Two groups of variables will be introduced into the model to solve the problem. The first group of variables will consist of bivalent variables x_{ijpl}representing the transfer of worker $l \in L_p$ qualification $p \in P$ from activity $i \in N \cup \{0\}$ to activity $j \in N$. Transfers of workers between activities are only permitted if a worker with the same qualifications can perform both activities. If $x_{ijpl} = 1$ after the optimization calculation is completed, then the transfer of the given worker between activities will occur. If, after the optimization calculation, it is true that $x_{ijpl} = 0$, then the transfer of the given worker between activities will not occur. The second group of variables will consist of non-negative variables z_i representing a possible time shift of the start of activity $i \in N$.

Furthermore, the variables x_{0jpl} are included in the model. If after completion of the optimization calculation, $x_{0jpl} = 1$, then this means that a worker $l \in L_p$ with qualification $p \in P$, who has not yet performed any activity in aircraft ground handling, will be deployed to perform activity $j \in N$.

If, after the optimization calculation, it is true that $x_{0jpl} = 0$, then the transfer of the given worker will not occur.

The mathematical model of the solved problem has the form:

$$min\, f(x\ z) = \sum_{j \in N} \sum_{p \in P} \sum_{l \in L_p} x_{0jpl} \qquad (1)$$

Under conditions:

$$\sum_{i \in N \cup \{0\}} \sum_{p \in P_j} \sum_{l \in L_p} a_{jp} x_{ijpl} = C_j \qquad \text{for } j \in N \qquad (2)$$

$$\sum_{j \in N} \sum_{l \in L_p} x_{0jpl} \le c_p \qquad \text{for } p \in P \qquad (3)$$

$$x_{ijpl} \le a_{jp} \qquad \text{for } i \in N \cup \{0\};\ j \in N;\ p \in P;\ l \in L_p \qquad (4)$$

$$x_{ijpl} \le b_{ij} \qquad \text{for } i \in N \cup \{0\};\ j \in N;\ p \in P;\ l \in L_p \qquad (5)$$

$$\sum_{j \in N} x_{ijpl} \le 1 \qquad \text{for } i \in N;\ p \in P;\ l \in L_p \qquad (6)$$

$$\sum_{i \in N \cup \{0\}} x_{ijpl} = \sum_{i \in N \cup \{0\}} x_{jipl} \qquad \text{for } j \in N;\ p \in P;\ l \in L_p \qquad (7)$$

$$\overline{t_i} + z_i + t_i \le \overline{t_j} + z_j + M \cdot \left(1 - x_{ijpl}\right) \qquad \text{for } i \in N;\ j \in N;\ p \in P;\ l \in L_p \qquad (8)$$

$$z_i \le \overline{\overline{t_i}} - \overline{t_i} \qquad \text{for } i \in N \qquad (9)$$

$$x_{ijpl} \in \{0\ 1\} \qquad \text{for } i \in N \cup \{0\};\ j \in N;\ p \in P;\ l \in L_p \qquad (10)$$

$$z_i \in R_0^+ \qquad \text{for } i \in N \qquad (11)$$

Function (1) represents the total number of workers deployed to perform aircraft ground handling. The set of constraint conditions (2) ensures that each activity $j \in N$ is assigned the required number of workers. The group of limiting conditions (3) ensures that no more workers than are available are used in each qualification group $p \in P$ within the task solution. The group of limiting conditions (4) ensures that if a worker with the qualification $p \in P$ cannot perform activity $j \in N$, then the worker of the given profession will not be employed to perform the given activity. A group of limiting conditions (5) of observing a logical sequence of activities according to the constructed network graph with a critical path identified by the CPM. The group of limiting conditions according to relation (6) ensures that every worker $l \in L_p$ who can perform activities $i \in N$ and $j \in N$ will switch to at most one activity $j \in N$ after completing activity $i \in N$. The group of limiting conditions according to relation (7) will ensure the continuity of the worker $l \in L_p$ qualification $p \in P_i \cap P_j$.

It means that when a worker $l \in L_p$ of qualification $p \in P_i \cap P_j$ is assigned to activity $j \in N$, he must also be removed from this activity after its completion. A group of restrictive conditions according to relation (8) will prevent temporally inadmissible time shifts of workers. It means that if a worker $l \in L_p$ of qualification $p \in P_i \cap P_j$ assigned to activity $i \in N$ does not reach the start time of activity $j \in N$, then his transfer between activities $i \in N$ and $j \in N$ will not occur (the symbol M represents a prohibitive constant). The group of limiting conditions according to relation (9) ensures that the time shift of the activity $i \in N$ can take place only in the interval bounded by the earliest possible time of the activity and the latest permissible start of the activity. The groups of limiting conditions (10) and (11) define the definition domains of the variables used in the model.

Since the objective function only minimizes the number of workers deployed, there is a possibility that an undesirable deviation from the technical procedures used in practice occurs. This undesirable deviation consists in the fact that a worker with a qualification that is designated for the performance of this activity as second or third in order will be deployed to perform a certain activity, while a worker with a qualification that is intended to perform the given activity is first in order is free. To prevent this undesirable technological deviation (even if it was caused by the reduction of the total number of workers deployed for aircraft ground handling, it is advisable to perform one more phase of the optimization calculation consisting in solving a model containing a system of limiting conditions (2) – (11) supplemented by a purpose function (12),

$$\min f(x\ \ z) = \sum_{j\in N}\sum_{p\in P}\sum_{l\in L_p} r_{jp} x_{0jpl} \tag{12}$$

in which the constants r_{jp} are the elements of the penalty matrix. The penalty matrix is created based on the following considerations. Since the objective function (12) is of the minimization type, the element r_{jp} representing the deployment of the qualification $p \in P$ intended to perform the activity $j \in N$ as the first in the sequence will be assigned the lowest penalty value – e.g. 1, the element r_{jp} representing the deployment of the qualification $p \in P$ determined to the performance of activity $j \in N$ as the second in order, will be assigned a higher penalty value - e.g. 100, and the element r_{jp}representing the qualification $p \in P$ intended to perform activity $j \in N$ as the third in order will be assigned the highest penalty value - e.g. 1000.

However, in the second phase of the optimization calculation, the result of the first phase of the optimization calculation must be respected, that is, a greater number of workers than was calculated in the previous phase must not be used for the aircraft ground handling. Let this minimum number be denoted by Q. The condition ensuring the fulfillment of the stated requirement will have the form Eq. (13). This condition will ensure that the number of employees calculated in the 1st phase of the optimization calculation will not be exceeded during the implementation of aircraft ground handling.

$$\sum_{j\in N}\sum_{p\in P}\sum_{l\in L_p} x_{0jpl} \le Q \tag{13}$$

3. Computational experiments with proposed model

Computational experiments with the designed tool will be conducted in the regional Leoš Janáček International Airport in Ostrava in the Czech Republic. At Leoš Janáček Airport in Ostrava, aircraft ground handling is performed by only one handling company, which the airport operates. It is a legal monopoly that complies with Council Directive 96/67/EC of 15 October 1996. Seven groups of workers with different numbers of defined qualifications work at the above-mentioned airport. Four groups are made up of airport staff, and the other three are hired externally to carry out specific activities such as refuelling or cleaning the aircraft deck. The division of groups into individual workers is introduced for process modelling to be able to transfer workers between representative activities individually. Converting the entire group with more employees may not benefit personnel, economy, and capacity.

Computational experiments with the model (1) – (13) were conducted in the conditions of aircraft turnaround of charter flights operated by the Boeing 737 aircraft. In the case of the aircraft ground handling, the presence of transit passengers on board was not considered. As the calculation relates to aircraft ground handling, it does not matter whether the flight was performed inside or outside the Schengen area. The data used for the computational experiment was obtained from a real process of aircraft ground handling at the airport. This course of aircraft ground handling is typical for the airport and corresponds to most flights in the summer season. In this way, approximately 250-300 aircraft are handled at the airport during the 3-month summer season. It was about the aircraft ground handling of flights carrying passengers. A handling agent manages the aircraft ground handling at the above-mentioned airport. Two mobile stairs are used at Ostrava airport for boarding and disembarking passengers on Boeing 737 aircraft, and two belt conveyors are used for unloading and loading luggage. Only checked baggage was loaded in the cargo area of the aircraft. Loading of checked baggage and mail-in containers was not considered. Baggage is loaded both in the front and in the rear cargo area of the fuselage. Refuelling of the aircraft takes place from the vehicle when there are no passengers on board the aircraft (there is, therefore, no need for the assistance of airport firefighters in the airport area during aircraft ground handling. Consequently, the approach and removal of fire engines are also not part of aircraft ground handling).

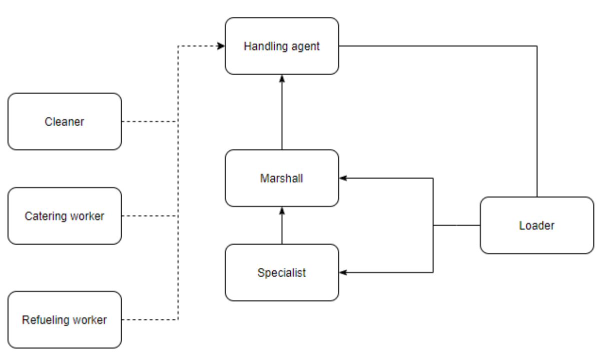

Fig. 1. Hierarchy of workers in aircraft ground handling at Ostrava airport

The following technological specifications are defined for aircraft ground handling in the conditions of the above-mentioned airport. At Ostrava Airport, departing and boarding passengers cross the route from the plane to the gate and back on foot. Boarding of passengers begins after the aircraft is refuelled, and aircraft are not pushed out of the stand using pushback. Fig. 1 shows individual groups of workers involved in aircraft ground handling at the airport. Their hierarchy is also shown. It also implies the substitutability of individual qualifications. The solid lines in Figure 1 show the relationship between direct superior/subordinate workers. As already mentioned, the highest-ranking worker in aircraft check-in is the handling agent. Dashed lines indicate indirect relationships. Indirect management relationships mean the indirect subordination of workers providing the given activity (workers of external companies). The list of activities and the authorization of workers with individual qualifications to perform them are shown in Table 1. Table 1 also shows the order in which another can represent a given work group. For example, the activity of approaching belt conveyors is primarily performed by workers of qualification 4 (aircraft loading workers). Secondarily it can be carried out by workers of qualification 3 (specialist) and tertiary by a worker with qualification 2 (marshalling worker). The last row of Table 1 shows the number of workers of individual qualifications participating in aircraft ground handling in the current state.

The highest-ranking worker in aircraft check-in, as already mentioned, is the handling agent. Indirect relationships are indicated by dashed lines. Indirect management relationships mean the indirect subordination of workers providing the given activity (these are workers of external companies). The list of activities and the authorization of workers of individual qualifications to perform them are shown in Table 1.

Table 1
Tasks and number of workers needed

	Task/Qualification	**Handling agent**	**Marshaling worker**	**Specialist**	**AC loading worker**	**Cleaning worker**	**Catering worker**	**AC refueling worker**
1	Guide the aircraft to the stand		1					
2	The wedge of the aircraft		1					
3	Setting up and connecting a GPU		2	1				
4	Creation of a safe zone		1	2	3			
5	Visual inspection of the aircraft		1					
6	Apposition of stairs		3	2	1			
7	Opening cargo spaces		3	2	1			
8	Delivery of a belt conveyor and a tractor with trolleys for checked baggage		3	2	1			
9	Unloading baggage				1			
10	Exit of passengers	1						
11	Refuelling							1
12	Loading catering						1	
13	Loading drinking water		2	1				
14	Emptying lavatory system		2	1				
15	Cleaning the interior of the aircraft					1		
16	Baggage loading				1			
17	Parking of a belt conveyor and a special baggage vehicle		3	2	1			
18	Closing cargo spaces		3	2	1			
19	Boarding of passengers	1						
20	Preparation of departure documentation	1						
21	Parking of stairs		3	2	1			
22	Disconnection and parking of the GPU		2	1				
23	Closure of safe zone		1	2	3			
24	Visual inspection of the aircraft		1					
25	Clearance of the aircraft		1					
26	Marshalling		1					
	Number of employees	1	1	1	6	5	1	1

To implement the computing experiment, it was necessary to create an overview of the activities taking place during aircraft ground handling and to assign groups of workers who can perform them, including their substitutability, to individual activities. This is done in Table 1. The first column represents the number of aircraft ground handling activities for the B737 aircraft at the airport. The second column contains the name of the aircraft ground handling activity for the B737 aircraft at the airport. Columns marked 1 – 7 correspond to the individual workgroups involved in handling. The last row of Table 1 shows the number of workers with the given qualification who currently provide aircraft ground handling at the airport. Numbers 1 - 3 in the rows of the table corresponding to individual activities represent priorities in assigning individual groups to individual activities. The table field corresponds to row 8 and the column labelled 2 shows the number 3. This means that it is recommended that worker group 2 (the marshalling worker) participate only third to ensure activity 8. The table field corresponding to row 8 and the column marked as 3 shows the number 2. This means that it is recommended that the group of workers 3 (specialists) participate second to ensure activity 8. The table field corresponding to row 8 and the column marked 4 shows the number 2. This means, that it is recommended that worker group 4 (aircraft loading worker) participates first to ensure activity 8. When an aircraft loading worker is not available, a specialist can replace him in activity 8. When an aircraft loading officer or specialist is not available, a marshalling officer may fill in for them.

Names of the qualifications listed in Table 1: 1 - handling agent, 2 - marshalling worker, 3 - specialist, 4 - aircraft loading worker, 5 - aircraft cleaning worker, 6 - catering worker, 7 - aircraft refuelling worker.

To find a solution to the abovementioned problem, it was necessary to create a network graph. The network diagram of the aircraft ground handling of a B 737 aircraft serving a charter flight handled at the above-mentioned airport was made in compliance with all the above entry conditions and is shown in Figure 2. Vertices are numbered according to the principles of the critical path method. The established numbering is helpful for the needs of the solved task. Marking the edges is key. Edge evaluation is composed of two parts. The number before the parenthesis represents the activity number. This number corresponds to the number in the first column of Table 1. The number in parentheses represents the duration of the activity.

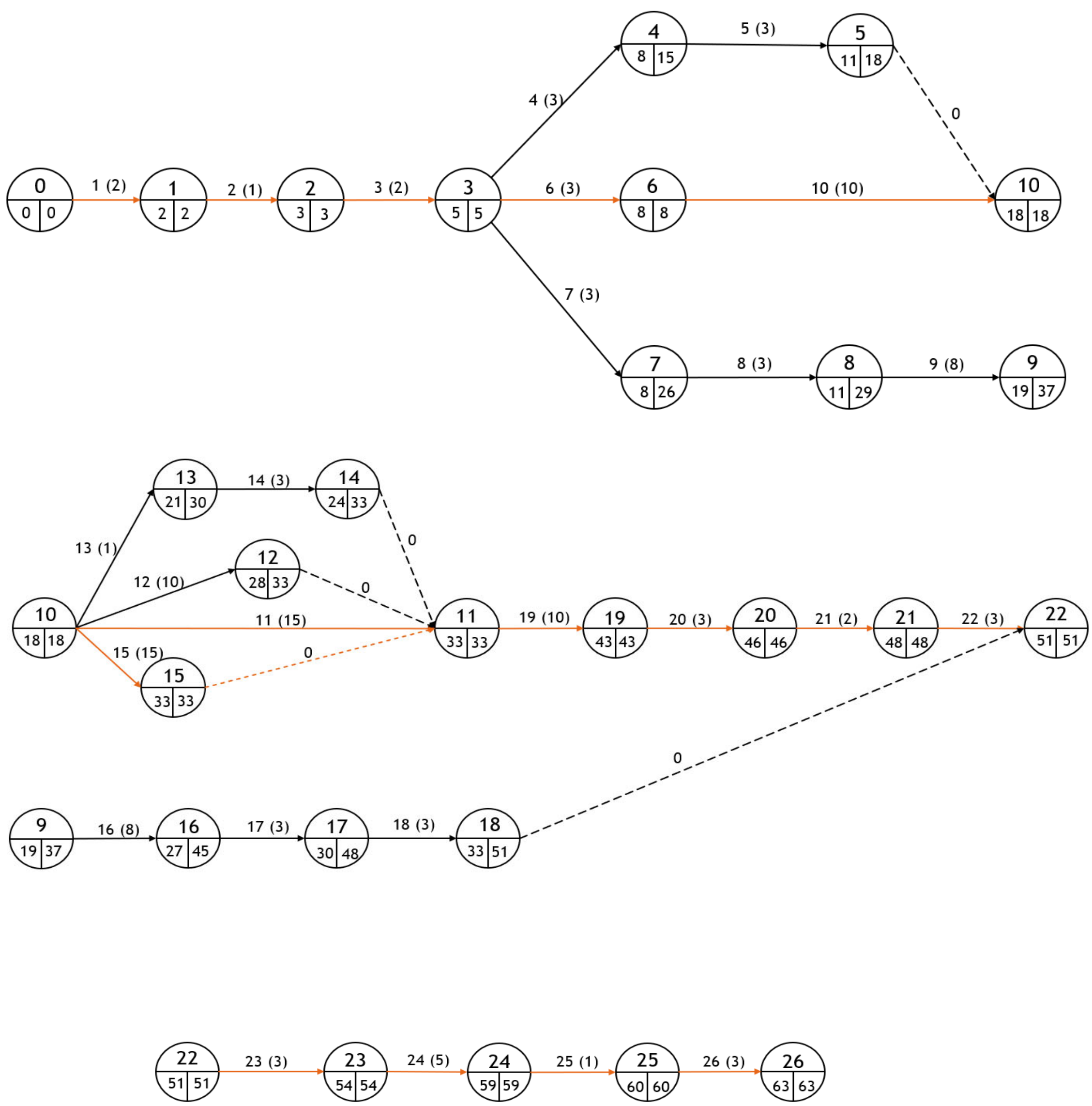

Fig. 2. CPM of aircraft ground handling

A detailed calculation of the individual values shown in Fig. 2 is evident from Table 2. Table 2 shows a list of all activities planned for aircraft ground handling in the above-mentioned airport conditions. Each edge in the graph (representing an activity during aircraft ground handling) intersects with two vertices v_i and v_j, where the vertex v_i represents the start of the activity and the vertex v_j represents the end of the activity. The activities listed in the table are arranged in a logical sequence.

Table 2 also contains the time requirement of individual activities (duration t_k) and the calculated earliest possible start times of individual activities ($\bar{t}_k$), the latest permissible start times of activities ($\bar{\bar{t}}_\kappa$), and calculated reserve time values of individual activities.

Table 2
Input information for creating a network graph

Task k	i	j	t_k (min)	$\bar{t}_k$ (min)	$\bar{\bar{t}}_k$ (min)	CR	VR	ZR	NR
1	0	1	2	0	0	0	0	0	0
2	1	2	1	2	2	0	0	0	0
3	2	3	2	3	3	0	0	0	0
4	3	4	3	5	5	7	0	0	0
5	4	5	3	8	15	7	0	0	0
6	3	6	3	5	5	0	0	0	0
7	3	7	3	5	5	18	0	18	0
8	7	8	3	8	26	18	0	0	0
9	8	9	8	11	29	18	0	0	0
10	6	10	10	8	8	0	0	0	0
11	10	11	15	18	18	0	0	0	0
12	10	12	10	18	18	5	0	5	0
13	10	13	3	18	18	9	0	9	0
14	13	14	3	21	30	9	0	0	0
15	10	15	15	18	18	0	0	0	0
16	9	16	8	19	37	18	0	0	0
17	16	17	3	27	45	18	0	0	0
18	17	18	3	30	48	18	0	0	0
19	11	19	10	33	33	0	0	0	0
20	19	20	3	43	43	0	0	0	0
21	20	21	2	46	46	0	0	0	0
22	21	22	3	48	48	0	0	0	0
23	22	23	3	51	51	0	0	0	0
24	23	24	5	54	54	0	0	0	0
25	24	25	1	59	59	0	0	0	0
26	25	26	3	60	60	0	0	0	0

As seen in Fig. 2 and the calculations shown in Table 2, the critical path has a length of 63 minutes. The values in the column labeled CR represent the total reserves of individual activities. The values in the column labelled VR represent individual activities' free reserves. The values in the column labelled ZR represent the dependent reserves of individual activities, and the values in the column labeled NR represents the independent reserves of individual activities.

CR - represents the total reserves of individual activities. VR – the maximum time by which its earliest possible start can be delayed so that the earliest possible starts of activities immediately following this activity are not affected. ZR – the maximum time by which its latest permissible start can be delayed so that the latest permissible starts of activities directly connected to this activity are not affected.

NR – the maximum time by which the latest permissible start of the activity can be delayed so that the earliest possible start of activities directly connected to this activity is not affected.

In the next step, it is necessary to create matrices A, B, and R. Table 3 contains the basis for the creation of matrix A. Table 3 has bivalent values for combinations of individual activities and qualifications of airport personnel. If a worker of qualification $p \in P$ can perform activity $j \in N$, then the value one is given at the intersection of the row and the column. Otherwise, the value 0 is given at the intersection of the row and the column. The existence of substitutability of workers is marked in colour. Primarily, the activities are carried out by the working group with a red field colour, secondarily with a yellow field colour, and tertiary with a green field colour. For example, if an aircraft loading worker cannot open the cargo hold, a specialist worker can replace him. If a specialist worker performs another activity, a marshalling worker can replace him. This table contains data on the number of workers needed for each activity and the number of workers with individual qualifications.

Table 3
The basis for the creation of matrix A

Task/Qualification	1	2	3	4	5	6	7	Employees needed
1	0	1	0	0	0	0	0	1
2	0	1	0	0	0	0	0	1
3	0	1	1	0	0	0	0	1
4	0	1	1	1	0	0	0	1
5	0	1	0	0	0	0	0	1
6	0	1	1	1	0	0	0	2
7	0	1	1	1	0	0	0	2
8	0	1	1	1	0	0	0	2
9	0	0	0	1	0	0	0	6
10	1	0	0	0	0	0	0	1
11	0	0	0	0	0	0	1	1
12	0	0	0	0	0	1	0	1
13	0	1	1	0	0	0	0	1
14	0	1	1	0	0	0	0	1
15	0	0	0	0	1	0	0	5
16	0	0	0	1	0	0	0	6
17	0	1	1	1	0	0	0	2
18	0	1	1	1	0	0	0	2
19	1	0	0	0	0	0	0	1
20	1	0	0	0	0	0	0	1
21	0	1	1	1	0	0	0	2
22	0	1	1	0	0	0	0	1
23	0	1	1	1	0	0	0	1
24	0	1	0	0	0	0	0	1
25	0	1	0	0	0	0	0	1
26	0	1	0	0	0	0	0	1
The sum of the workers	1	1	1	6	5	1	1	

Other input data for the optimization calculation are the elements of matrix B. The number of rows and columns corresponding to the number of activities implemented within the process of aircraft ground handling increased by 1 (a point introduced for modelling purposes representing a fictitious entry and exit point of the process). In the model process at the Ostrava airport, matrix B consists of 27 rows and columns, which indicate all activities from 0 to 27. The values in the matrix are binary. When the transfer of workers from activity $i \in N$ to activity $j \in N$ is not permissible in the network graph, the value in the matrix is 0. When the transfer of workers from activity $i \in N$ to activity $j \in N$ is permitted in the network graph, the value in the matrix is 1. The matrix is constructed so that there are 0s on and below the main diagonal. These transitions are disabled and 1s above the main diagonal. Transitions between these activities are allowed. Implementing this incidence matrix in the model ensures that the logical sequence of activities is followed according to the constructed network graph.

The penalty matrix R is based on the incidence matrix A. Beyond the scope of this description, it should be noted that if the qualification $p \in P$ is not intended primarily, secondarily, or tertiary for the performance of activity $j \in N$. Then due to the minimization of the objective function (12), it is in the position of the relevant prohibitive constant assigned to the element.

4. Results

As mentioned above, the mathematical approach (1) – (13) applies in two stages. First, model (1) – (11) is solved. In this phase of the optimization calculation, the total number of employees required for aircraft ground handling is minimized. After solving the model (1) – (11), the results shown in Table 4 were achieved. The value of the objective function in the first stage was 15, which means saving one worker compared to the current state. Table 4 also contains the results after the end of phase 2 of the optimization calculation (minimization of the total value of the penalty). Table 4 contains a list of the assigned qualifications and their workers for the sub-activities of aircraft ground handling. It subsequently shows them in each phase of the optimization calculation and the time shift of the beginnings of the sub-activities.

However, the optimization calculation results in the finding that workers whose qualifications correspond to the second or third in the preferred order of qualifications were used in the process of aircraft ground handling. Table 5 shows a comparison between the assumed and deployed qualifications that were used for the aircraft ground handling. After performing the first phase of the optimization calculation, qualification 3 – Specialist was replaced entirely/removed. In four cases, she was represented by qualification 2 – a marshalling worker and in one case by qualification 4 – an aircraft loading worker. Before starting the calculation of the second stage, an R matrix was implemented in the model. It penalized the deployment of qualifications other than the primary one. After the end of the second phase of the calculation, qualification 3 – Specialist was eliminated again, and qualification 2 – marshaling workers were assigned to perform their activities. To perform activity 23, to which qualification 4 - aircraft loading worker was appointed in the first phase, its assumed qualification, which is also primary, was assigned in the second phase.

Table 4
Results of optimization calculations

Phase 1				**Phase 2**			
Task	Qualification	Employee	Time shift	Task	Qualification	Employee	Time shift
1	2	1	0	1	2	1	0
2	2	1	0	2	2	1	0
3	2	1	0	3	2	1	0
4	2	1	0	4	2	1	0
5	2	1	0	5	2	1	0
6	4	1,3	0	6	4	2,6	0
7	4	6	0	7	4	5	0
8	4	1,4	7	8	4	5,6	7
9	4	1,2,3,4,5,6	13	9	4	1,2,3,4,5,6	13
10	1	1	0	10	1	1	0
11	7	1	0	11	7	1	0
12	6	1	0	12	6	1	0
13	2	1	0	13	2	1	0
14	2	1	8	14	2	1	8
15	5	1,2,3,4,5	0	15	5	1,2,3,4,5	0
16	4	1,2,3,4,5,6	13	16	4	1,2,3,4,5,6	13
17	4	2,4	13	17	4	4,6	13
18	4	3,5	13	18	4	2,5	13
19	1	1	0	19	1	1	0
20	1	1	0	20	1	1	0
21	4	2,3	0	21	4	1,3	0
22	2	1	0	22	2	1	0
23	4	6	0	23	2	1	0
24	2	1	0	24	2	1	0
25	2	1	0	25	2	1	0
26	2	1	0	26	2	1	0

Table 5 compares the results from both phases of the calculation. In the first part of the calculation, no activity was assigned to workgroup 3. The activities that were to be performed by work group 3 were assigned to work group 2 and group 4.

Table 5
Comparison of the results of both calculation phases

Phase 1				Phase 2			
Task	Presumed Qualifications	Deployed qualification	Employee	Task	Presumed Qualifications	Deployed qualification	Employee
1	2	2	1	1	2	2	1
2	2	2	1	2	2	2	1
3	3	2	1	3	3	2	1
4	2	2	1	4	2	2	1
5	2	2	1	5	2	2	1
6	4	4	1,3	6	4	4	2,6
7	4	4	6	7	4	4	5
8	4	4	1,4	8	4	4	5,6
9	4	4	1,2,3,4,5,6	9	4	4	1,2,3,4,5,6
10	1	1	1	10	1	1	1
11	7	7	1	11	7	7	1
12	6	6	1	12	6	6	1
13	3	2	1	13	3	2	1
14	3	2	1	14	3	2	1
15	5	5	1,2,3,4,5	15	5	5	1,2,3,4,5
16	4	4	1,2,3,4,5,6	16	4	4	1,2,3,4,5,6
17	4	4	2,4	17	4	4	4,6
18	4	4	3,5	18	4	4	2,5
19	1	1	1	19	1	1	1
20	1	1	1	20	1	1	1
21	4	4	2,3	21	4	4	1,3
22	3	2	1	22	3	2	1
23	2	4	6	23	2	2	1
24	2	2	1	24	2	2	1
25	2	2	1	25	2	2	1
26	2	2	1	26	2	2	1

After the second stage of the calculation, workgroup 2 takes over the activities to which workgroup 3 was assigned. Each representation is penalized according to the matrix R. The objective function was increased to the value of 441 - for activities 3, 13, 14, and 22, workers from other than the primary were deployed qualification. Therefore, there was an increase in the purpose function.

The chosen procedure is known from multicriteria decision-making when the order of importance of the criteria is known, but the specific values of the weights of the individual criteria are not known. The number of deployed workers is of the highest importance. This criterion was applied as a priority because the number of workers (pandemic, increased intensity of requirements for aircraft ground handling) is the most important in crises. After the first phase was carried out, it was found that substitutability preferences were not followed. Therefore, the second phase was carried out.

5. Discussion

Traffic in regional Ostrava is mainly seasonal; in the winter months, it reaches its minimum (flights per week), and the summer months are characterized by increased traffic intensity. Increased traffic intensity also means an increase in demand for service personnel. However, it is not always possible to staff all work groups involved in aircraft ground handling. Therefore, it is important to deal with the identification of the minimum number of employees needed to ensure aircraft ground handling and to make full use of staff downtime to transfer it to other activities that take place during aircraft ground handling. First, all the activities that must be carried out as part of aircraft ground handling were identified.

The basis of the mathematical modelling of the process of aircraft ground handling of the aircraft in the operational area is the schedule of aircraft ground handling, which is the result of the CPM application. The CPM results (especially the obtained information on time reserves) are the primary inputs to the subsequent phases of the solution.

The originality of the presented approach to aircraft ground handling lies primarily in designing a mathematical model for assigning workers to activities based on their job qualifications, which the original critical path method does not consider. The basis of the transfer of individual workers between activities is the substitutability matrix, in which three levels of preference in staffing are also included. The first level of preference considers staffing of a regular nature, i.e., when unreduced numbers of workers are available in individual groups. The second level of preference considers the normal replacement regime of substitutability, and the third level of preference corresponds to the crisis variant of the solution.

The originality of the proposed approach also lies in the decomposition of work groups down to the level of individual workers. Decomposition enables the transfer of individual workers between individual activities based on their qualifications to perform these activities and possible substitutability.

The result of the presented procedure is obtaining information on the minimum number of workers needed to ensure the aircraft ground handling in a defined time interval, which does not disrupt the flight schedule and does not create unnecessary delays. Since an approach was used to model the solving process, the result of obtaining an optimal solution, it is not necessary to replicate the optimization experiments.

Malandri et al. (2019) have recently shown the effect of reducing the number of workers on the duration time of aircraft turnaround is determined. In the presented article the number of workers used during aircraft turnaround is determined in such a way that the duration time for the turnaround is not negatively affected.

Since a specific approach was used to model the solving process, the result of which is obtaining an optimal solution, it is not necessary to replicate the optimization experiments. The proposed approach will enable not only the determination of the minimum time of aircraft ground handling but also the verification of whether the airport can comply with the limits arising from the requirements of air carriers for the maximum duration of aircraft ground handling.

To solve the problem of minimizing the number of personnel providing aircraft ground handling, a mathematical model of mixed integer linear programming (mixed integer linear programming) was used, which was solved on a regular personal computer in the Xpress-IVE optimization software. The calculation time in the case of both calculation phases did not exceed 1s.

In real tasks at airports, there may be other optimization criteria. Such an optimization criterion can be, for example, personnel costs for aircraft ground handling. The optimization criterion is appropriate to use in cases where the differences between the financial evaluation of aircraft ground handling workers working with different qualifications are more significant. However, this is not currently the case in the Czech Republic. If there are significant differences between the costs of aircraft ground handling workers and the solver chooses personnel costs as an optimization criterion, the mathematical model (1) – (11) is adjusted. The modification of the mathematical model (1) – (11) consists of expanding the set of input data to the model by coefficients representing the labour costs of personnel working with individual qualifications, and these coefficients are subsequently incorporated into the optimization criterion.

The result of the optimization calculations is a possible reduction in the number of workers involved in ensuring aircraft ground handling while maintaining the maximum prescribed priorities in the substitutability of workers of various qualifications. Any reduction in the total number of workers does not affect the increase in the time needed to perform individual activities. This also means that there will be no reduction in time reserves for individual activities because the number of workers who provide individual activities does not change. Maintaining the requirement for the prescribed number of workers is treated by condition (2) in the mathematical model. Only the qualifications of the workers who perform individual activities can change. The substitutability of workers with individual qualifications is known in advance and it is assumed that workers with substitute qualifications are trained to perform individual activities. This implies that the assignment of a worker who does not normally perform the activity to another activity does not have a fundamental effect on extending the duration of individual activities. Operators of handling services at airports can therefore be recommended to regularly rotate aircraft ground handling staff when performing various qualifications. In this way, their problem-free replaceability is preserved in the long term. Both phases of the computational experiments were carried out for the case where an aircraft occupancy of 75% is considered. An increase in aircraft occupancy means an increase in the time required for boarding and disembarking passengers and loading and unloading luggage.

In the future, it is possible to research how the critical path in the network graph will change and thus also the time reserves depending on changes in the occupancy of the aircraft or incorporate indeterminacy into the times of individual activities. In the future, it is also possible to implement an experimental setting of the weights of individual members of the optimization criterion so that the optimization calculation can be implemented in one phase. Another research potential is offered by parallel handling when the simultaneous check-in of several aircraft is considered.

6. Conclusion

Aircraft ground handling is a time-consuming technological process that includes various activities that follow each other materially and temporally. The primary goal is for the subject process to run efficiently. Efficiency means that all activities will not only run smoothly but also with the use of the minimum resources necessary to secure them. Resources can be different; we deal with personnel resources in the presented article. The article's main goal was to present a mathematical model for planning the staffing of service processes related to aircraft ground handling. Service workers of various professions participate in aircraft ground handling, while some are interchangeable. The abovementioned facts lead to the basic consideration of whether reducing the number of service workers using substitutability is possible. In the case of aircraft ground handling, there are activities where the operator(s) can be replaced by workers from another profession. However, there may also be activities where the operator(s) may be replaced by workers of several professions. In such a case, the order (preference) in which it is appropriate to replace workers of the profession is usually determined.

Mathematical programming methods were used to solve the problem. Two original mathematical models are presented in the article. The first model is designed to minimize the total number of workers needed for aircraft ground handling. After determining the minimum number of workers needed to carry out the aircraft ground handling, a second mathematical model is solved, which will consider preferences in the eventual deployment of the original profession or representation of workers of one profession by workers of other professions. The solution of the models is, therefore, two-phase. If there is no need to consider preferences in the substitutability of professions, the optimization process can be terminated already after the first phase. The isolated solution of both phases does not affect the solution's optimality after the second phase.

The results achieved during the computational experiments corresponded to the real conditions in which aircraft ground handling takes place at the airport, thus proving the full functionality of the proposed approach.

Author Contributions

Conceptualization, J.C., D.T., and S.S.; data curation, J.C., and D.T.; methodology, S.S. and D.T.; formal analysis, J.C; validation D.T. and S.S.; supervision, S.S.; resources, J.C.; writing—original draft preparation, D.T. and S.S.; writing—review and editing, J.C., D.T. and S.S.. All authors have read and agreed to the published version of the manuscript.

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References

Al-Bazi, A., Gok, Y. S., Ozturk, C., & Guimarans, D. (2016). Developing a mathematical model for scheduling of turnaround operations (low cost airline as a case study). In *International Aviation Management Conference (IAMC 2016)*.

Andreatta, G., De Giovanni, L., & Monaci, M. (2014). A fast heuristic for airport ground-service equipment–and–staff allocation. *Procedia-Social and Behavioral Sciences*, *108*, 26-36.

Arena, M., & Aprea, C. (2021). Impact of COVID-19 pandemic on air transport: Overview and implications. *Advances in Environmental and Engineering Research*, *2*(1), 1-14.

Ashford, N. J., Stanton, H. M., Moore, C. A., Coutu, P., & Beasley, J. R. (2015). *Operações Aeroportuárias*. Bookman Editora.

Bassett, E. E., et al. (2000). Statistics: problems and solutions, Second edition, *Singapore: World Scientific*, ISBN 981-02-4321-9.

Endrizalová, E., Němec, V., Szabo, S., & Radovan, S. (2016). Dynamic mathematical model of ground support equipment utilization in aircraft technical handling. In *Proceedings of 20th International Conference Transport Means* (pp. 759-762).

Evler, J., Asadi, E., Preis, H., & Fricke, H. (2018). Stochastic control of turnarounds at HUB-airports. *Proceedings of the Eighth SESAR Innovation Days, Salzburg, Austria*, 3-7.

Field, M., S. Keller, L.S. (1998), Project management, London: International Thomson Business Press, ISBN 1-86152-274-6.

Fricke, H., & Schultz, M. (2008, June). Improving aircraft turn around reliability. In *Third International Conference on Research in Air Transportation* (pp. 335-343).

Kabongo, P. C., Ramos, T. M. F., Leite, A. F., Ralha, C. G., & Weigang, L. (2016, November). A multi-agent planning model for airport ground handling management. In *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)* (pp. 2354-2359). IEEE.

Kazda, A., & Caves, R. E. (Eds.). (2010). *Airport design and operation*. Emerald Group Publishing Limited.

Kierzkowski, A., & Kisiel, T. (2017). A simulation model of aircraft ground handling: case study of the Wroclaw airport terminal. In *Information Systems Architecture and Technology: Proceedings of 37th International Conference on Information Systems Architecture and Technology–ISAT 2016–Part III* (pp. 109-125). Springer International Publishing.

Kroese, D. P., Taimre, T., & Botev, Z. I. (2011). Handbook of Monte Carlo Methods. John Willey & Sons. *Inc., Hoboken, New Jersey*.

Kwasiborska, A. (2010). Modelling of ground handling operations at airport. *Journal of KONES*, *17*(3), 253-261.

Lockyer, K. G., & Gordon, J. (1991). *Critical path analysis and other project network techniques*. Financial Times/Prentice Hall.

Malandri, C., Mantecchini, L., & Reis, V. (2019). Aircraft turnaround and industrial actions: How ground handlers' strikes affect airport airside operational efficiency. *Journal of Air Transport Management*, *78*, 23-32.

Mamdouh, M., Ezzat, M., & Hefny, H. A. (2020). Airport resource allocation using machine learning techniques. *Inteligencia Artificial*, *23*(65), 19-32.

Maylor, H. (2010). Project management, *Harlow: Financial Times Prentice Hall*, 4th ed., ISBN 978-0-273-70432-4.

Meredith, J.R., & Mantel S.J. (2003). *Project management: a managerial approach*, 5th ed., New York: Wiley, ISBN 0-471-07323-7.

Okwir, S., Ulfvengren, P., Angelis, J., Ruiz, F., & Guerrero, Y. M. N. (2017). Managing turnaround performance through collaborative decision making. *Journal of Air Transport Management*, *58*, 183-196.

Popova-Zeugmann, L. (2013). Time and Petri net, *Heidelberg: Springer*, ISBN 978-3-642-41114-4.

Shen, C. W., Peng, Y. T., & Tu, C. S. (2019). Multi-criteria decision-making techniques for solving the airport ground handling service equipment vendor selection problem. *Sustainability*, *11*(12), 3466.

Schmidt, M. (2017). A review of aircraft turnaround operations and simulations. *Progress in Aerospace Sciences*, *92*, 25-38.

Schultz, M. (2018). Fast aircraft turnaround enabled by reliable passenger boarding. *Aerospace*, *5*(1), 8.

Schultz, M., Evler, J., Asadi, E., Preis, H., Fricke, H., & Wu, C. L. (2020). Future aircraft turnaround operations considering post-pandemic requirements. *Journal of Air Transport Management*, *89*, 101886.

Strakova, E., & Mrva, P. (2011). Analysis the Utilization of Ground Support Equipment in Aircraft Ground Handling, *New trends in civil aviation 2011*, CTU in Prague, Publisher CTU in Prague, pp. 113-116, ISBN 978-80-01-04893-1

Tabares, D. A., Mora-Camino, F., & Drouin, A. (2021). A multi-time scale management structure for airport ground handling automation. *Journal of Air Transport Management*, *90*, 101959.

Teichmann, D., & Dorda, M. (2016). About an Unconventional Application of Assignment Problem, SSOV proceedings, available online: http://www.fhi.sk/files/katedry/kove/ssov/proceedings/Zbornik2016.pdf

Van Blokland, W. B., Santema, S. C., Huijzer, R., & Stals, R. (2008). Future airport turnaround ground handling processes. How to reduce the turn around time of aircraft at the airport. In *10th TRAIL Congress; TRAIL in perspective* (pp. 1-25). TRAIL Research school.

Vidosavljevic, A., & Tosic, V. (2010, July). Modelling of turnaround process using petri nets. In *Air Transport Research Society (ATRS) World Conference*.

Weigert, D., Rettmann, A., Alomar, I., & Tolujew, J. (2018, April). Shortening the turnaround times of aircraft by improving ground handling processes through a simulation study. In *2018 4th International Conference on Logistics Operations Management (GOL)* (pp. 1-8). IEEE.

Wilson, M. A. (2003, September). Collaborative decision making: Building consensus group decisions for project success. In *Proceedings of the Project Management Institute Global Congress, North America, Baltimore, MD, USA* (pp. 1-7).

Winston, W. L. (2003), Operation Research, 4, ISBN 9780534380588

Wu, C. L., & Caves, R. E. (2004a). Modelling and optimization of aircraft turnaround time at an airport. *Transportation Planning and Technology*, *27*(1), 47-66.

Wu, C. L., & Caves, R. E. (2004b). Modelling and simulation of aircraft turnaround operations at airports. *Transportation Planning and Technology*, *27*(1), 25-46.