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MATEMATICAL MODEL FOR OPTIMIZING STAFFING OF AIRCRAFT GROUND HANDLING

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Abstract
Presented article deals with optimizing staffing of ground handling process for aircraft at international regional airport´s apron. Solution of optimization problem was conducted in two phases. In the first phase of solution, time reserves were found for each activity of ground handling process. Said reserves provide space for creation of delay of any activity which can lead to decrease of number of workers which are needed for realization of whole process. Critical path method was used for the calculation of time reserves. In the second phase, minimal number of workers which are needed for process of ground handling was calculated. Mathematical programming was used for calculation of solution. In the presented article we used mixed linear mathematical model. Optimizing criterium in the mentioned model was total number of workers needed for realization of all activities of ground handling process. Value of optimizing criterium was minimalized. Calculation experiment was conducted in the conditions of international regional airport Ostrava.

Keywords: *Aviation, Critical Path Method, Ground Handling, Mathematical Programming, Operational Research*

JEL Classification: C6
AMS Classification:

1 MOTIVATION

Technical handling is process which deals with ground handling of aircrafts after their arrival and before theirs departure. Capacity of technical handling is mostly limited by restricted personal resources. This problem appears mainly at regional airports in summer season, when higher capacities for technical handling are needed. Better organization of work allows us to increase the use of staff and trouble-free course of technical handling process even with lower number of staff. This allows us to lower prices at regional airports and increase the competitiveness of said regional airports. This problem which is about increasing of usage of staff can be understand as optimisation task which can be solve with the methods of operation analysis.

2 CURRENT STATE ANALYSIS

The aircraft ground handling process at the airport, which also includes technical ground handling, is a complex and time-consuming process during which both the aircraft and passengers are provided with the required services [3,4]. The total duration of the aircraft ground handling process depends on the airport technical equipment, the type of aircraft operated and the range of services required for the ground handling by the air transport operator. The complexity of the entire ground handling process shows a need to remove time reserves, reduce the overall time required for ground handling, or simply, to make the process more efficient. Numerous approaches can be taken to achieve this. The key to the entire streamlining process involves, in many cases, the methods of managerial decision-making, specifically the methods of network analysis, and namely, CPM.
CPM (Critical Path method) is a basic deterministic method of a network analysis (i.e. project management). Every project (i.e., also the process of technical ground handling of aircraft) can

be represented by an oriented chart, in which the nodes represent the beginnings and ends of individual activities, the edges represent the activities themselves and the evaluation of edges represents the duration of individual activities. One of the goals of CPM is to identify the so-called critical path, which is the longest sequence of consecutive activities starting at the starting node (node representing the beginning of the project) and ending at the end node (node representing the completion of the project), and its length represents the shortest possible duration of the solved project.

The activities that make up a critical path are called critical activities. Any extension of the duration of any of the critical activities will result in an extension of the total project implementation time. CPM allows you to quantify the time reserve for each activity. The critical activities are then all activities with zero time reserve. Detailed information on CPM can be found, for example, in [5,6,7,10].

The authors of the article [2] address the issue of increasing the efficiency of the aircraft handling process by assigning workers to handling equipment. The authors created a heuristic approach, GRAP (Ground - service Resource Allocation Problem). The method assigns workers to the equipment in the shortest possible time intervals. This eliminates staff downtime and possible flight delays. They obtained input data for their experiments at Berlin Tegel Airport, where the INFORM software is used to solve the problem, and the mathematical model created by the authors is only an extension of it. During testing, the authors achieved a reduction in times by an average of 7.5%.

The author of the paper [8] analyzes the overall process of handling by ATR and Embraer type aircrafts. The handling process and the time required by individual activities in her work are represented using a Gantt chart. The article does not reject the hypothesis of the Poisson probability distribution, which models the input flow of aircraft into the system. Further, the author monitored the times of individual phases of handling – boarding and disboarding of passengers, loading and unloading of luggage, goods and mail, refueling, replenishment of catering and cabin cleaning. Based on the analyzed data, the author simulated a ground services model.

The authors of the work [1] investigated the possibilities of improving the aircraft handling process in the conditions of a specific low-cost air carrier Turkish Airline using CPM. The authors focus mainly on the passenger disembarkation and embarkation phases, which they consider critical and the most time-consuming. In the article, the authors define different types of flights and divide them into national, international and their combination according to their nature. Input data were obtained for 3 days by observation at the airport serving the carrier as a hub.

3 FORMULATION OF TASK AND PROPOSED MATHEMATICAL MODEL

3.1 Formulation of optimization task

In the presented paper, we follow up on the article [9], in which a linear mathematical model was proposed to solve the general problem of allocating staff to activities. However, the mentioned linear mathematical model was significantly modified for the needs of the solved problem.

The creation of a mathematical model is preceded by the creation of a network graph of the project and the acquisition of basic time characteristics of individual activities using CPM.

The objective function remains the same as in the previous model; the weights of the decision variables do not change either. In addition to the previous model, a constant C_j is introduced for each activity $j \in N$, modeling the number of employees to be assigned to perform the given activities. Furthermore, a set of qualifications P is introduced into the model, deviating from

the previous model, and a constant c_p, representing the number of employees of the given qualification, is defined for each qualification $p \in P$. The competence of a qualification $p \in P$ to perform an activity $j \in N$ is modeled by means of an incidence matrix, $\boldsymbol{A}$, while if the activity $j \in N$ can be performed by an employee with a $p \in P$ qualification, then $a_{jp} = 1$, and in the opposite case, $a_{jp} = 0$.
To solve the problem, two groups of variables will be introduced into the model:
x_{ijpl}…bivalent variable representing the transfer of the worker l with qualification p from activity i to activity j (this, of course, occurs when both activities can be performed by a qualified worker p). When x_{ijpl} = 1, the transfer of the given worker between activities will take place, when x_{ijpl}= 0, the transfer of the given worker between activities will not take place.
z_i…a non-negative variable representing the possible shift in the start time of activity $i \in N$.

3.2 Mathematical model

Mathematical model has the following form:

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

Under the conditions:

$\sum_{i \in N} \sum_{p \in P_j} \sum_{l \in L_p} a_{jp} x_{ijpl} = C_j$	$pro\ j \in N$	(2)
$\sum_{j \in N} \sum_{l \in L_p} x_{0jpl} \leq c_p$	$pro\ p \in P$	(3)
$x_{ijpl} \leq a_{jp}$	$pro\ i \in N \cup \{0\}; j \in N;\ p \in P;\ l \in L_p$	(4)
$b_{ij} \geq x_{ijpl}$	$pro\ i \in N \cup \{0\}; j \in N;\ p \in P;\ l \in L_p$	(5)
$\sum_{j \in N} x_{ijpl} \leq 1$	$pro\ i \in N;\ p \in P; l \in L_p$	(6)
$\sum_{i \in N \cup \{0\}} x_{ijpl} = \sum_{i \in N} x_{jipl}$	$pro\ j \in N;\ p \in P; l \in L_p$	(7)
$\overline{t_i} + z_i + T_i \leq \overline{t_j} + z_j + M \cdot (1 - x_{ijpl})$	$pro\ i \in N; j \in N;\ p \in P; l \in L_p$	(8)
$z_i \leq \overline{\overline{t_i}} - \overline{t_i}$	$pro\ i \in N$	(9)
$x_{ijpl} \in \{0,1\}$	$pro\ i \in N; j \in N;\ p \in P; l \in L_p$	(10)
$z_i \geq 0$	$pro\ i \in N$	(11)

Function (1) represents the number of employees deployed. The group of restrictive conditions (2) will ensure that the required number of staff is allocated to each activity $j \in N$. The group of restrictive conditions (3) will ensure that no more staff are used in each qualification group $p \in P$ to solve the task being addressed than is currently available. The group of restrictive conditions (4) ensures that if the activity $j \in N$ cannot be performed by a $p \in P$ qualified worker, then the worker of the given profession will not be deployed to perform the given activity. The group of restrictive conditions (5) will ensure that no $p \in P$ qualified worker $l \in L$ can return to an activity $i \in N$ after performing the activity $j \in N$; this condition is ensured by means of an incidence matrix $\boldsymbol{B}$. The group of restrictive conditions according to relation (6) will ensure that each worker $l \in L_p$ who can perform activities $i \in N$ and $j \in N$ will, upon completion of the activity $i \in N$, switch, at most, to one activity $i \in N$. The group of restrictive conditions according to relation (7) ensures the continuity of the worker $l \in L_p$, with qualification $p \in P_i \cap P_j$. This means that when a worker $l \in L_p$ with qualification $p \in P_i \cap P_j$ is engaged in an activity, he or she must also be removed from this activity after its completion. The group of restrictive conditions according to relation (8) prevents temporally inadmissible time transfers of workers. This means that if a qualification $p \in P_i \cap P_j$ worker $l \in L_p$ assigned to the activity $i \in N$ does not make start time of the activity $j \in N$, then the worker's transition between activities $i \in N$ and $j \in N$ will not occur (the symbol M represents a prohibitive constant). The group of restrictive conditions according to relation (9) ensures that the time shift of the activity $i \in N$ can take place only in the interval delimited by the earliest possible time of the activity and no later than the permissible start of the activity. The groups of constraints (10) and (11) determine the domain of variables used in the model.

4 COMPUTIONAL EXPERIMENTS

Computational experiments with the proposed model were carried out during handling of charter flights operated with Boeing 737 aircraft at Leoš Janáček International Airport in Ostrava, Czech Republic (Ostrava Airport). The charter flights under consideration were handled without a stopover, so that no transit passengers remained on board during ground handling during their stay at Ostrava Airport. As the calculation relates to technical ground handling , it does not matter whether the flight took place inside or outside the Schengen area.
In the conditions of Ostrava Airport, one handling agent is assigned to the aircraft. Two exit steps were used to disembark passengers, two belt conveyors were used for unloading luggage, and only luggage, no cargo or mail, was loaded in the cargo area of the aircraft, and luggage was not loaded in containers. The luggage was loaded in the front and rear cargo area. Refueling of the aircraft was performed from a vehicle after departing of all passengers, so there was no need for assistance from firefighters during handling.
The following technological specifics for performing technical handling are defined in the conditions of Ostrava Airport:

1. Departing and boarding passengers cross the route from the plane to the gate and back on foot under the supervision of a handling agent,
2. Boarding of passengers begins immediately after the completion of refueling of the aircraft,
3. Aircrafts are not pushed back from the apron by push-back vehicle.

Table 1 shows the activities that can be performed by a given group of occupations. This table serves as the base for creation of matrix $\boldsymbol{A}$. **Table 1** also shows how many members each workgroup has.

Table 1 ***Authorization to perform component activities***

	Activity/Qualification	1	2	3	4	5	6	7
1	Guiding to the apron		1					
2	Securing the landing gear		1					
3	GPU connection		1	1				
4	Safety zone		1	1	1			
5	Visual check of aircraft		1					
6	Delivery of stairs		1	1	1			
7	Opening of cargo space		1	1	1			
8	Delivery of belt conveyors		1	1	1			
9	Baggage unloading				1			

10	Passenger exiting	1						
11	Refueling							1
12	Refilling catering						1	
13	Refilling drinking water		1	1				
14	Draining of toilets		1	1				
15	Cabin cleaning					1		
16	Baggage loading				1			
17	Removal of conveyors		1	1	1			
18	Closing of cargo space		1	1	1			
19	Passenger boarding	1						
20	Delivery of documents	1						
21	Removal of stairs		1	1	1			
22	GPU disconnection		1	1				
23	Cancellation of the safety zone		1	1	1			
24	Visual check of aircraft		1					
25	Removal of chocks		1					
26	Marshalling		1					
	Number of workers	1	1	1	6	5	1	1

Group job titles from Table 1:
1 – Handling agent, 2 – Marshall, 3 – Specialist, 4 – Loader, 5 – Cleaner, 6 – Catering worker,
7 – Aircraft refueling worker.

The solution process started with the creation of a network chart. The network chart was created in compliance with all the above input conditions. Table 2 lists all the activities that were performed during the technical ground handling, their time intensity (duration) and the edge that represents the activity in the network chart. This table lists the values of the earliest possible starts of activities ($\bar{\bar{t}}$), the latest allowable starts of activities (t), the time requirements of each activity (t) and the calculated time values of reserves. The activities are arranged in a logical sequence.

After completing the optimization calculation it was found, that in process of technical handling, one qualification group can be saved. This qualification group is Specialist. **Table 2** contains all the results from optimization calculations. Activities which were completed by Specialist are now completed by Marshall and with activity 23 qualification group – Loader was assigned. You can see which qualification group was assigned to which activity from process of technical handling as well as the worker from each group.

Table 2 ***Results of computational experiment***

Phase 1			
Activity	Assumed Qualification	Deployed Qualification	Employee
1	2	2	1
2	2	2	1
3	3	2	1
4	2	2	1
5	2	2	1
6	4	4	1,3

7	4	4	6
8	4	4	1,4
9	4	4	1,2,3,4,5,6
10	1	1	1
11	7	7	1
12	6	6	1
13	3	2	1
14	3	2	1
15	5	5	1,2,3,4,5
16	4	4	1,2,3,4,5,6
17	4	4	2,4
18	4	4	3,5
19	1	1	1
20	1	1	1
21	4	4	2,3
22	3	2	1
23	2	4	6
24	2	2	1
25	2	2	1
26	2	2	1

5 CONCLUSIONS

Traffic at regional airport Ostrava is mainly seasonal, in the winter months is minimal. Summer months are distinguished by increase of traffic as well as increase of requirements for staffing. The base for mathematical modeling of process of technical handling of aircraft at apron is time plan created on the base of CPM. Every particular activity was identified and process of technical handling was designed to suit real conditions. Results of CPM (mainly time reserves) serve as input informations for follow-up calculations.

Result of mathematical model, created for solution of proposed problem and described in article, is to obtain information about minimal number of staff needed for process of technical handling of aircraft in defined time time span. With the minimization of workers by one qualification group the flight schedule must not be disrupted and no delay cannot be created.

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