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CONTROL MODEL FOR GROUND CREW SCHEDULING PROBLEM AT SMALL AIRPORTS: CASE OF SERBIA

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Abstract. Present-day airline industry is quite a competitive field and crew scheduling represents one of the crucial problems due to significant impact on the airline's cost. The crew scheduling problem is based on the assignment of crew members to operate different tasks of route. The main goal of this paper is to provide an analysis and a solution to one of the biggest problems detected on a small airport in the Serbia – the problem of ground crew scheduling. The paper presents the main characteristics, goals and limitations of a real-life problem identified at this small airport. In order to solve the problem, we developed a dynamic discrete simulation model. The model is developed in a spreadsheet environment of *Microsoft Excel*. Some of the main limitations found in the development of the model are strong constraints and multiple goals. The model presented in the paper is designed as a useful management tool for smaller airports and is aimed at the improvement of operative processes.

Keywords: crew scheduling problem, modelling, air transport, small airport, management, spreadsheets.

Notations

a_j – discrete time unit related to the start of activity j ($j \in N$);
b_j – discrete time unit related to the end of activity j ($j \in N$);
e_i – auxiliary variable related to the end time of the shift for a steward ($i \in S$);
J – objective function;
k_j – activity j category ($j \in N$);
kv_i – steward i category ($i \in S$);
N – set of activities;
$NDRV$ – the longest work time;
$NKRV$ – the shortest work time;
NMP – minimum duration of break;
p_{tj} – binary parameter related to the beginning of activity j in time period t ($t = 1, \ldots, T; j \in N$);
ps_i – auxiliary variable related to the start of all activities for a steward i ($i \in S$);
pz_i – auxiliary variable related to the end of all activities for a steward i ($i \in S$);
S – set of available stewards;
s_i – auxiliary variable related to the start time of a shift for a steward i ($i \in S$);
T – finite time horizon;
tp_j – activity j duration ($j \in N$);
tr_{tj} – binary parameter; 1 – activity j in progress in time period t; 0 – otherwise ($t = 1, \ldots, T; j \in N$);
x_{ij} – binary variable; 1 – steward i realizes activity j; 0 – otherwise ($i \in S, j \in N$);
z_{tj} – binary parameter related to the ending of activity j in time period t ($t = 1, \ldots, T; j \in N$);
za_{it} – binary variable; 1 – steward i is at the airport in time period t ($t = 1, \ldots, T; i \in S$); 0 – otherwise;
"ground crew" – terms steward/stewardess are used interchangeably in this paper;
UDF – user-defined function.

Introduction

Air transport represents a significant industrial sector, in constant evolution since the late 1950s. According to Kasirzadeh *et al.* (2017), the importance of this industry is characterized by its own operations, as well as the influence on related industries, such as tourism and aircraft

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manufacturing. Considering the competitiveness of the air traffic industry, the development and implementation of high-level systems of monitoring and control is a necessity. Large aviation centers, such as airports in European capitals, have highly developed monitoring and management systems, that operate in accordance with their numerous needs. However, beside the central ones, there are many small and medium-sized airports (regional or secondary airports) that enable a better connection with different locations, facilitate business and holiday travels and improve the overall air transport efficiency (Pavlin *et al.* 2007). The scope of services at these airports is often much narrower than at big airports. Consequently, management is not oriented towards processes optimization, the development of specific tools for monitoring and control of operations, and the formulation of global procedures. The functioning of smaller airports is frequently based on employees' expertise and their own experience.

"Constantine the Great" airport in the city of Niš can be classified as one of the smaller airports, while the largest airport in the Serbia is located in its capital – Belgrade. The "Constantine the Great" airport was initially a military airport, transformed into a military-civilian airport, to be used today as a civilian airport. This change additionally affected the organization and control of operations and activities on this airport. The airport became increasingly significant in the South Balkans after 2003. From 2007, in accordance with the development plan 2007–2022, the airport's business operations radically improved. Through collaboration with low-cost carriers and an expanded destinations list, "Constantine the Great" became an important airport for passenger traffic. According to statistics (NCGA 2019), there has been a sharp increase in passenger traffic in the past several years.

The described changes required the development and implementation of control methods and tools. Additionally, in accordance with the increased level of operative processes, the problem of human resources capacity shortage arose. This shortage implies the crew-scheduling problem. Some research shows that after the cost of fuel, which cannot be controlled by the airline, the second highest expense is the crew scheduling cost (Oketch 2013).

The aim of this paper is to develop a model for solving the ground crew scheduling. The start of the modelling process will be to identify the problem parameters. The following step will include the definition of variables, objective function and constraints. In order to solve the problem and facilitate understanding of the scheduling process for employees, authors propose a simulation model implemented in the *Microsoft Excel* environment. *Microsoft Excel* is chosen because it is generally accepted in the business world; it is accessible, flexible and easy to use, without formal rules or training required. The developed simulation model is dynamic, flexible, affordable and relatively easy to use.

Starting from this point, the paper is organized as follows. Section 1 addresses the background of the study and describes the ground crew scheduling problem in the airline industry. Section 2 points out some of the main characteristics of the problem and challenges related to crew scheduling at the airport "Constantine the Great". Section 3 presents the mathematical formulation of a discrete time control process corresponding to the ground crew scheduling problem at the airport. In Section 4, the developed model is implemented as a simulation model in a spreadsheet environment of *Microsoft Excel*. Section 5 includes a sensitivity analysis and a comparative review of numerical results obtained through the simulation. Finally, the last section outlines the conclusions and summary of the above mentioned.

1. Background and related work

Human resources represent one of the most important resources in all areas of business. When it comes to services, that importance is even more pronounced. A great deal of human resource management problems in services comes from demand variation. For example, production planning as a result has production quantity. Consequently, the number of employees required for a plan to be fulfilled is based on the normative and process description. However, in the services industry, the varying number of customers directly affects the workload.

The airport, used as an example in this paper, was faced with a significantly increased number of passengers due to collaboration with low-cost carriers. Although this was a great potential for the airport business, it imposed new requirements to the existing infrastructure and organization of the airport (Pavlin *et al.* 2007; Ivković *et al.* 2018). Numerous arrivals and departures of airplanes, supporting activities, and possible changes in flight schedules, required improvement in workforce scheduling. This improvement includes scheduling methods and techniques, and their incorporation into the airport information system, as one of the crucial elements for good performance of an airport as a system (Rodič, Baggia 2017).

Many researchers have studied the crew scheduling problem as an attractive and frequently observed problem in transport (Giachetti *et al.* 2013; Duque *et al.* 2016; Bach *et al.* 2016; Zhou *et al.* 2016; Pour *et al.* 2018; Wang *et al.* 2018, Boyer *et al.* 2018). Scheduling problems in air transport industry refer to aircraft crew and ground crew scheduling. This paper is oriented towards ground crew scheduling and aimed at designing a useful tool for the management of small airports and the improvement of various operative processes.

The planning of airport ground workforce poses a number of challenging optimization problems (Herbers 2005). Crew scheduling problems affect crew operations. The scheduling problem is directed towards the execution of a required sequence of tasks within the planned time frame and employing a minimum number of employees (Rodič, Baggia 2017). Groundwork tasks usually entail passenger check-in and baggage loading/unloading. According to Herbers (2005) staff scheduling typically comprises several stages: aggregation and analyses of workloads during demand planning; shift planning and appropriate shift duties; and finally rostering, which implies generating lines of duty for the workers.

The complexity of the airport crew scheduling problem arises from a large number of specifics. Flight frequency and the number of arrivals and departures vary during the day. Moreover, there are peaks in certain parts of the day. Consequently, the required number of workers differs depending on the day and part of the day. Demand changes within a flight. The number of passengers passing through an airport 2 h before departure is much lower than the number of passengers in the last half hour. Some destinations are more demanding and cause crowds, while those with less traffic constantly imply fewer passengers. Furthermore, qualifications of employees differ. Due to many tasks within ground services, the employees at the airport attend series of trainings. Qualification level represents a constraint in employee selection for different positions. In addition to work limitations, there are legal restrictions related to the number of working hours and working days during the week.

In summary, the solution to the airport ground crew scheduling problem should result in a schedule that is able to meet the anticipated demand, whereby employees should be assigned to activities in accordance with their qualification level and with respect to legal restrictions, which affects the assignment of employees by shifts and days. Certainly, labour costs minimization must be taken into account with maximum utilization of employees' capacity. In accordance with the specificities of different airports, many models and algorithms have been developed in order to provide support in solving this problem.

Brusco *et al.* (1995) directed their research towards effective scheduling of employees at counters and gates in airline stations of United Airlines (US). As a result, 2 modules are developed and implemented in order to enhance the tour scheduling process associated with United Airlines' Pegasys Manpower Planning System. Employee shifts are organized using column generation. A local search heuristic based on simulated annealing is used for the improvement of an initial feasible tour scheduling solution. In research by Chu (2007), the author proposes goal programming models for an integrated problem of crew duties assignment, in particular for the baggage services section staff at the Hong Kong International Airport. A goal programming based algorithm is used to determine the number of staff needed per hour and per day, and to generate daily schedules. Clausen (2010) described optimization problems from the perspective of airport ground handling. They consider specific optimization problems, which range from generalized approaches for workforce planning to highly detailed scheduling problems arising in the dynamic airport business. Soukour *et al.* (2013) presented a staff scheduling problem model for an airport security service. The problem is solved in 3 steps: (1) days off scheduling, (2) shift scheduling, and (3) staff assignment. For the staff assignment phase, the authors developed a memetic algorithm, which merged an evolutionary algorithm and local search techniques. An extensive amount of literature deals with models and methods for airport crew scheduling, for example – Herbers (2005); Yen, Birge (2006); Santosa *et al.* (2010); Oketch (2013); Bazargan (2010); Kasirzadeh *et al.* (2017). However, a literature review indicates that more papers are focused on the problem of aircraft crew scheduling than on ground crew scheduling. More significantly, the majority of papers relevant to the topic considered in this paper discuss the problem of large international airports, while the problems of smaller airports are usually not taken into account.

2. Problem and characteristics of crew scheduling on the "Constantine the Great" airport

The airport "Constantine the Great" in the city of Niš is the third largest international airport in Serbia – IATA coding: INI (IATA 2019); ICAO coding: LYNI (ICAO 2019). Based on the number of passengers, it is the second largest civil airport in Serbia, after the "Nikola Tesla Airport" in Belgrade. In 2019, the number of passengers reached 422255 (NCGA 2019). Since 2015, the airport is focused on passenger flights of low-cost companies, thus contributing to the overall development of the city of Niš and Southern Serbia. In addition to passenger flights, the airport facilitates cargo flights as well. Air transport is carried out in cooperation with 2 low-cost airline companies (*Ryanair* and *Wizz Air*) and one traditional (*Swiss Air*). It is important to note the increased number of passengers and cargo between years 2014→2015, 2015→2016, 2016→2017 (Table 1).

The increased number of flights and passengers, which have gone through the airport daily since 2015, influenced the processes modification and the overall organization at the airport in order to support the current business volume. Today, organization comprises 3 basic sectors (top management, logistics and operational sector) and accompanying subsectors.

Table 1. Number of passengers and cargo statistics of "Constantine the Great" airport (NCGA 2019)

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number of passengers	25130	27426	21700	1335	36258	124917	331582	351581	422255
Cargo [t]	705	322	343	285	553	1967	2537	688	1180

The largest sector of the airport is the operational sector with its subsectors: ground handling service, rescue and fire department, physical and technical security service, and technical maintenance service. One of the most important subsectors is the ground handling service. This subsector is related to passenger servicing and it has been directly influenced by the changes at the airport "Constantine the Great" in recent years. The ground handling service staff are responsible for the check-in procedure, access control, boarding, disembarkation, customs and baggage. These processes are grouped so that they operate without congestion and mixing of passengers. The groups include: flight preparation, passenger registration, access, security and passport control, gate, sorting of luggage, incoming and outgoing passengers.

2.1. Characteristics of passenger servicing within ground handling service

Passenger servicing within the ground handling service encompasses a total of 5 categories of employees. The categories are ordered according to difficulty level, the first being of the highest and the fifth of the lowest difficulty. Employees are trained for activities, starting from the easiest. Consequently, employees in higher categories are able to perform lower-category activities. The fifth category implies guiding the passengers from the plane landing spot to the exit gate and vice versa, which is part of the process of incoming and outgoing of passengers. It lasts an average of 30 min, from landing to take-off. After completing training, the stewards move on to the fourth category, which refers to work on gates. The gate is open for 60 min, during flight preparation until departure. The third category stewards perform passenger registration, including passport and reservation checks, boarding ticket printing, and hand baggage sorting. "Constantine the Great" has 4 counters assigned to such activities, while the number of engaged stewards depends on their availability and the number of passengers. The registration counter is open 2 h before the flight to 40 min before the flight, which is 80 min in total. The following, second category of stewards is in charge of access control. Access control involves checking the validity of passports, visas and other personal documents, as well as ensuring the compliance of data on the boarding pass with the data in the documents and the airport system. Access control counter is open during flight preparation, i.e. 120 min. The first and the highest category stewards are supervisors on a flight. These stewards organize and monitor all subprocess related to incoming and outgoing passengers and solve adhoc problems. When the plain take-off supervisors send reports to landing airports and to the airline companies, and the flight is closed.

2.2. Ground crew scheduling problem characteristics

Crew scheduling problem is one of the core problems at "Constantine the Great". Airport activities depend on travel intensity, flight structure, seasonality, etc. Working hours have to be adjusted to daily needs, with no regular shifts. An additional constraint is to match the activities and categories of stewards. The scheduling problem requires inactivity minimization. There is free time between flights, in which the stewards are paid but perform no tasks.

Employees scheduling depends on a flight plan. A lack of activities outside the boarding and flight preparation time implies that employees should not be scheduled within that period. Ground handling services are realized about 2 h before flights. During those 2 h, the number of passengers varies. The required number of employees should be defined for each workplace and each time interval. Shorter time intervals generate a more precise schedule. Furthermore, departures at the airport can overlap, which causes the doubling or even tripling of the required number of employees.

One of the main goals of crew scheduling is demand satisfaction. This goal can be defined as a constraint of the model. Another goal is to minimize passenger waiting time. However, this goal is conflicted with the goal of cost minimization, which requires a decrease in the number employees and engaged working hours. Therefore, minimization of hours without activities spent at the airport can be defined as a goal. In order to reconcile all of these goals, a minimum number of stewards should be defined and the objective function can be set as minimum divergence between the scheduled and minimum number of stewards. The complexity of the scheduling problem arises from conflicted objective functions and a wide range of constraints. Many authors have tackled this problem. Table 2 presents a comparison of the characteristics of the scheduling problem at the airport "Constantine the Great" and the characteristics modelled in some of the papers mentioned in Section 1.

All analysed models have some similarity with the characteristics of the scheduling problem at the airport "Constantine the Great". However, the following specificities of this airport scheduling problem prevent their implementation:

- objective function of the model that describes the scheduling problem at the "Constantine the Great" airport has to include minimization of working hours with no activities;
- scheduling has to consider activities divided by categories;
- time constraints.

3. Mathematical formulation

We consider a discrete time system control process corresponding to the ground crew scheduling problem at "Constantine the Great" airport. Based on input data on the flight beginning, the model enables the calculation of number of activities for a given time period. Working hours and activities are defined in accordance with discrete time units of time horizon. Working day is discretized in intervals of 5 min in order to encompass all

Table 2. Comparison of scheduling problem characteristics

Problems described in the papers	Characteristics								
"Constantine the Great" airport	categories of activities	fixed duration of activities	shifts are not strictly defined	working hours per week are constrained	defined minimum of non-working hours	minimum 2 free days per week	maximum of overtime hours exists	the path between work places is not significant	objective function includes minimization of working hours without activities
Chu (2007)	activities are not categorized	fixed duration of activities	shifts are not strictly defined	working hours per week are not constrained	minimum of non-working hours is not defined	2 consecutive free days per week	overtime hours constraint does not exist	the path between work places is not significant	objective function includes minimization of labour costs
Soukour *et al.* (2013)	categories of activities	duration of activities is not fixed	defined shifts	working hours per week are constrained	defined minimum of non-working hours	adapted to different time constraints	adapted to different time constraints	the path between work places is not significant	objective function includes minimization of labour costs
Brusco *et al.* (1995)	activities are not categorized	activities are not divided	shifts are not strictly defined	working hours per week are constrained	defined minimum of non-working hours	minimum 2 free days per week	overtime hours constraint does not exist	the path between work places is not significant	objective function includes minimization of labour costs
Clausen (2010)	activities are not categorized	activities are not divided	shifts are not strictly defined	working hours per week are constrained	defined minimum of non-working hours	adapted to different time constraints	adapted to different time constraints	the path between work places is significant	objective function includes minimization of transportation costs

possible flight beginnings. Finite time horizon T consists of 144 time periods in accordance with airport working hours (from 7:00 to 19:00). Every flight involves 5 basic activities. The categories and the number of stewards and the time of execution are known for each activity within the flight realization. Activities are unique. If an activity requires more than one steward, it has to be divided into more activities with the same characteristics. All identified activities are denoted with a unique code and make a set of activities N. Parameter k_j defines category of activity j, which conditions the assignment of stewards with appropriate qualifications. This parameter takes values from 1 to 5. Stewards' qualifications kv_i correspond to categories of activities and take values from 1 to 5. Acceptable differences between kv_i and k_j are 0 and 1, i.e. a steward cannot be assigned to an activity more than one level lower than his or her qualification.

Legal regulations impose minimum and maximum working time, as well as minimum duration of breaks within the day. Parameter $NKRV$ refers to the shortest work time and $NDRV$ refers to the longest. NMP stands for minimum duration of break.

The ground crew scheduling problem described in this paper considers several constraints. Availability constraint – Equation (1) – ensures that a steward can be assigned to one activity the most per one time unit:

$$\sum_{j \in N} x_{ij} \cdot tr_{tj} \le 1, \tag{1}$$

$i \in S$; $t = 1, \ldots, T$.

Activity coverage – Equation (2) – secures that each activity will be assigned a steward:

$$\sum_{i \in S} x_{ij} \cdot tr_{tj} = 1, \tag{2}$$

$j \in N$; $t = 1, \ldots, T$.

Maximum working time constraint – Equation (3) – forbids defining shifts longer than the predefined maximum:

$$\sum_{t=1}^{T} za_{it} \le NDRV, \tag{3}$$

$i \in S$.

Minimum working time constraint – Equation (4) – forbids defining shifts shorter than the predefined minimum:

$$\sum_{t=1}^{T} za_{it} \ge NKRV, \tag{4}$$

$i \in S$.

The minimum duration of a break is defined by constraint – Equation (5):

$$\sum_{t=1}^{T} za_{it} - \sum_{j \in N} \sum_{t=1}^{T} x_{ij} \cdot tr_{tj} \geq NMP, \quad (5)$$

$i \in S$.

Constraints related to upper (Equation (6)) and lower (Equation (7)) limits of categories imply the assignment of activities to stewards with the appropriate qualifications or a higher qualification level. Additionally, an activity assigned to a steward cannot be more than one category lower than the steward's qualification.

$$kv_i \cdot x_{ij} - k_j \cdot x_{ij} \leq 1, \quad (6)$$

$i \in S; j \in N$.

$$kv_i \cdot x_{ij} - k_j \cdot x_{ij} \geq 0, \quad (7)$$

$i \in S; j \in N$.

The ground crew scheduling problem at the "Constantine the Great" airport does not correspond to a common objective function of cost minimization of engaged stewards, because of fixed fees. The scheduling problem is characterized by breaks between flights during which the stewards have no activities. Consequently, the aim of this model is the minimization of working hours without activities. The objective function – Equation (8) – is defined as the minimum deviation of the duration of shifts of all stewards and the duration of all activities.

$$\min J = \sum_{i=1}^{S} \sum_{t=1}^{T} za_{it} - \sum_{j=1}^{N} tp_j. \quad (8)$$

All model variables are considered in discrete time units and all relations of the model are linear.

4. Spreadsheet implementation

In order to test it, the developed model is implemented as a simulation model in a spreadsheet environment *Microsoft Excel*. The spreadsheet simulation model improves and facilitates the understanding of the scheduling process through the dynamic, flexible, easy to use and affordable tool. The model consists of 3 modules: (1) input, (2) calculation and (3) output.

Direct input data include the beginning of each flight during the day, as well as the start, the duration, the number of required stewards and category for each activity within the flight. Start time of a flight expressed in a real time unit has to be converted to a discrete time unit number. The cells in yellow are intended for user input (Figure 1). The start and end of all activities is defined based on a time unit reflecting the flight beginning. The number of flights defines the total number of activities. Each activity has to be coded. The code consists of 3 elements. The first element represents a two-digit serial number of the activity, the second is a one-digit category of the activity, the third part is information related to the number of required stewards. An example of activities arrays, including code, start a_j, end b_j, duration tp_j and category k_j, are presented in Figure 1.

Parameters p_{tj}, z_{tj} and tr_{tj} ($t = 1, \ldots, T$; $j = 1, \ldots, N$) are calculated in accordance with the start and end time. Their values are represented through the matrix defined by rows, which indicate time units and columns, which indicate activities. Binary parameter p_{tj} takes value 1 in the time unit of beginning, otherwise it is zero. The same logic applies to parameter z_{tj}. Binary parameter tr_{tj} depends on p_{tj} and z_{tj}. It is 1 if activity j is in progress in time unit t, i.e. for periods greater than or equal to the start period and less than the end time.

Input data related to stewards include their qualifications kv_i. A steward's qualification defines her or his training level and competence for different activities. The qualification level of stewards corresponds to categories of activities.

Calculation module implements a mathematical model described in the previous section. In order to facilitate simulation, the model includes one main control variable x_{ij} that should be entered by end-users. An example of the control variable values is presented in Figure 2, with matrix defined by rows i and columns j.

Auxiliary variables are calculated based on x_{ij} values. Variable s_i is related to the start time of a shift for a steward, i.e. the earliest beginning of the first activity ($i = 1, \ldots, S$). Auxiliary variable ps_i is used for the calculation of the start of all activities for a steward, while s_i takes the minimum value for every steward. Defining the end of a shift implies a similar logic. Auxiliary variable pz_i refers to time units when all activities of a steward end, i.e. the end of a shift. Additional variable e_i is the maximum of pz_i. Based on the shift beginning and ending time unit, variable za_{it} indicates whether the steward is at the airport during the specific time period.

	A–B	C	D	E	F	G
1	FLIGHT NUMBER	01	02			
2	FLIGHT BEGINNING (real time)	11:30	13:35			
3	FLIGHT BEGINNING (time period)	55	80			
4	ACTIVITIES	Supervision	Access control	Registration	Gate	Guiding
5	START	0	0	0	12	18
6	END	24	24	16	24	24
7	NO OF STEWARDESSES	1	1	2	1	4
8	CATEGORY	1	2	3	4	5
9						
10		Activities				
11		Parameters	k_j	a_j	b_j	tp_j
12		Code	Category	Start	End	Duration
13		0111	1	55	79	24
14		0121	2	55	79	24
15		0131	3	55	71	16
16		0132	3	55	71	16
17		0141	4	67	79	12
18		0151	5	73	79	6
19		0152	5	73	79	6
20		0153	5	73	79	6
21		0154	5	73	79	6
22		0211	1	80	104	24
23		0221	2	80	104	24
24		0231	3	80	96	16
25		0232	3	80	96	16
26		0241	4	92	104	12
27		0251	5	98	104	6
28		0252	5	98	104	6
29		0253	5	98	104	6
30		0254	5	98	104	6

Figure 1. Example of activities arrays including code, category, start, end and duration

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
6	x_{ij}	0111	0121	0131	0132	0141	0151	0152	0153	0154	0211	0221	0231	0232	0241	0251	0252	0253	0254
7	S1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	S2	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
9	S3	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
10	S4	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
11	S5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
12	S6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0
13	S7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0
14	S8	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
15	S9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Figure 2. Example of control variable x_{ij} values, 1– steward *i* realizes activity *j*; 0 – otherwise

	A	B	C	D	E	F	G
1							
2	(min)		$\sum_{i=1}^{S}\sum_{t=1}^{T} za_{it} - \sum_{j=1}^{N} tp_j$				
3	(min)	-20	=SUM(B114:J257)-SUM('Input data'!G13:G30)				

Figure 3. Spreadsheet implementation of the objective function

	C	D	E	F	G
3	SCHEDULE FOR STEWARDESSES				
4	Stewardess	Name and surname	Beginning	End	Duration
5					
6	S1	Savičić Danica	11:30	14:25	2:55
7	S2	Ilić Milica	11:30	14:25	2:55
8	S3	Ikonić Dragana	11:30	13:45	2:15
9	S4	Živić Marija	11:30	13:45	2:15
10	S5	Savičić Marija	12:30	14:25	1:55
11	S6	Ikonić Marija	13:00	14:25	1:25
12	S7	Stančić Dunja	13:00	14:25	1:25
13	S8	Todorović Katarina	13:00	14:25	1:25
14	S9	Đorđević Milica	13:00	14:25	1:25

Figure 4. Example of stewards' schedule, resulting from the model

The objective function (Equation (8)) is defined as minimum deviation of the duration of shifts of all stewards and the duration of all activities. Consequently, this deviation cannot be less than zero. Value less than zero indicates that tasks are not covered by stewards. Example illustrated in Figure 3 represents a case where stewards are not assigned for 20 time units of activities. Conditional formatting technique is used for spreadsheet implementation of the objective function.

The spreadsheet simulation model enables end-users to vary values of control variable x_{ij}. The previously described constraints are implemented in such a manner that guide the user to feasible solutions. Availability constraint – Equation (1) – shows that some activities assigned to stewards overlap. The number of overlapping time units cause a negative value of the objective function. Activity coverage constraint – Equation (2) – ensures that each activity has one steward assigned. Constraints – Equations (3) and (4) – ensure that the working time of stewards is not longer than 10 or shorter than 4 h. Constraint – Equation (5) – refers to a break of minimum 30 min. Constraints – Equations (6) and (7) – define upper and lower limits of categories of activities and assigned stewards. If all deviations result in zero value, it means that categories of activities correspond to qualifications of assigned stewards.

The described simulation model enables comparison of different scenarios by assigning activities to stewards, whereby conditionally formatted constraints signal an inadmissible solution. Output module represents a report that reflects a schedule for stewards, considering the shift start and end, as well as shift duration (Figure 4).

In order to facilitate data preparation, constraint implementation and reporting, the authors developed UDFs in *Visual Basic for Application*. UDFs are used for the transformation of real-time data to time units, the definition of activities in accordance with the selected flight, the minimization of breaks, and the creation of reports.

5. Sensitivity analysis and numerical results

In order to evaluate the developed control model for ground crew scheduling and analyse its efficiency, preliminary test was performed on 5 randomly generated instances for one to 5 flights.

The following assumptions were considered during the model evaluation:

- duration, order and number of activities per flight is predefined and cannot be changed (Table 3);
- activities within the flight start at defined time units, which are unchangeable and interconnected (Figure 5);
- each activity has to be assigned to a single steward, i.e. one activity cannot be realized by more than one steward;
- the total number of qualified stewards has to correspond to the defined categories of activities. As mentioned previously, stewards' qualifications kv_i correspond to the categories of activities and take values from 1 to 5. There are 9 available stewards for the defined number of 5 activities (Table 4);
- overlapping of flights is not allowed. If this happens, it is necessary to engage a completely new shift of 9 stewards. Scheduling of 9 stewards in a parallel shift for an overlapped flight is the same as in the described problem;
- maximum working time is defined as 8 regular working hours and 2 h overtime, i.e. 40 h per week and 2 days off. Minimum duration of a shift is 4 h;
- total break duration has to be at least half-hour for a regular shift.

Based on the duration of activities per flight presented in Table 3 and Figure 5, it can be concluded that the difference between the start of the 2 consecutive flights has to be at least 2 h and 5 min (25 time units × 5 min). Otherwise, an overlap of the ending of activities within the first flight and the beginning of activities of the same category within the second one will cause an infeasible solution to the scheduling problem (Figure 6).

Taking into consideration all the assumptions previously described and ranges of input data presented in Table 3, a control model for the ground crew scheduling problem is evaluated for the instances of 2, 3, 4 and 5 flights. Control variables values are defined in accordance with categories of stewards and activities (Table 3 and Table 4) and constraints – Equations (6) and (7).

Analysis results for the instance of 1 flight are not shown in detail because the total duration of activities within the flight is far shorter than the total available working hours of stewards. Therefore, scheduling is easy, but unfeasible from the aspect of the minimum working time constraint.

Input data for instance of 2 flights are already presented in Figure 1. The results in Table 5 indicate that non-working hours of engaged stewards are 68% of maximum working hours. Nevertheless, the obtained solution is also unfeasible, for the same reason as for the first instance. Non-working hours are considered as the difference between maximum working time and shift duration. Shift duration represents the time between the start of the first activity and the end of the last one for a steward. Shift duration, presented in the tables with numerical results, includes periods with no assigned activities for stewards within a shift.

The model is tested in the same manner for other instances, for up to 5 flights. Flights beginnings are set up with a predefined difference of 2 h and 5 min. Numerical results are presented in Tables 6–8.

Experiments carried out for instances of 3 and 4 flights generate feasible solutions. Additionally, numerical results (Table 6 and Table 7) show a reduction in the percentage of non-working hours with the number of flights increment. The break duration constraint is not considered in these experiments, given that shift duration does not reach 8 working hours in almost all cases.

In the case of 5 flights (Table 8), the solution is unfeasible because shift duration for stewards S1 and S2 exceeds maximum working time for 20 min. Additionally, for stewards S3 and S4, the minimum break duration constraint is violated.

Table 3. The ranges of input data

Flight number	01	02	03	04	05
Flight beginning (real time)	11:30	13:35	15:40	17:45	19:50
Flight beginning (time period)	55	80	105	130	155
Activity	supervision	access control	registration	gate	guiding
Start (time period)	0	0	0	12	18
End (time period)	24	24	16	24	24
No of stewards	1	1	2	1	4
Category	1	2	3	4	5

Table 4. Stewards' qualification level (category)

Steward	Qualification kv_i
S1	1
S2	2
S3	3
S4	3
S5	4
S6	5
S7	5
S8	5
S9	5

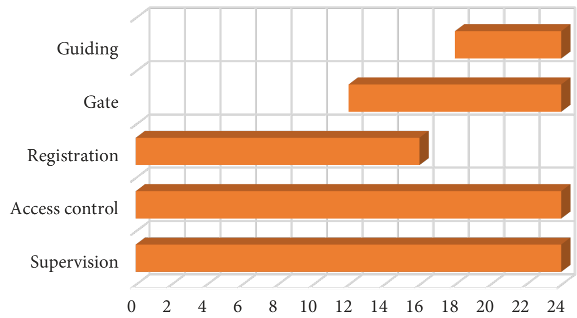

Figure 5. Activities within the flight (start and duration)

	A	B	C	D	E	F	G
1	FLIGHT NUMBER		01	02			
2	FLIGHT BEGINNING (real time)		11:30	12:00			
3	FLIGHT BEGINNING (time period)		55	61			
4	ACTIVITIES		Supervision	Access control	Registration	Gate	Guiding
5	START		0	0	0	12	18
6	END		24	24	16	24	24
7	NO OF STEWARDESSES		1	1	2	1	4
8	CATEGORY		1	2	3	4	5
9							
10			Activities				
11			Parameters	k_j	a_j	b_j	tp_j
12			Code	Category	Start	End	Duration
13			0111	1	55	79	24
14			0121	2	55	79	24
15			0131	3	55	71	16
16			0132	3	55	71	16
17			0141	4	67	79	12
18			0151	5	73	79	6
19			0152	5	73	79	6
20			0153	5	73	79	6
21			0154	5	73	79	6
22			0211	1	61	85	24
23			0221	2	61	85	24
24			0231	3	61	77	16
25			0232	3	61	77	16
26			0241	4	73	85	12
27			0251	5	79	85	6
28			0252	5	79	85	6
29			0253	5	79	85	6
30			0254	5	79	85	6

Figure 6. Example of overlapped activities for 2 flights

Table 9 presents a summary of results for all analysed instances. This comparative analysis includes total unused hours during a shift, which is actually the objective function defined by the model. The unused hours during a shift refer to periods with no assigned activities for stewards within a shift. The results indicate that, although it generates the lowest percentage of total unused hours during a shift, the 1 flight instance implies the longest non-working time per shift. 1 flight instance results can be argued by total shift duration of only 9:40 h for all stewards. As previously mentioned, non-working hours are considered as the difference between maximum working time and shift duration. Shift duration represents the time between the beginning of the first activity and the end of the last one for a steward, including periods without assigned activities. 1 flight schedule is unfeasible because of the minimum working time constraint. Instance of 4 flights generates the best feasible solution, with 33% of total unused hours during the shift and non-working hours of 24:05 h. Despite the infeasible solution in the instance of 5 flights because the constraint of maximum working time and minimum duration of break is violated, the total number of unused hours during a shift and non-working hours is the lowest.

Table 5. Numerical results for instance of 2 flights

Steward	Beginning of the shift	End of the shift	Shift duration [h]	Maximum working time [h]	Non-working hours [h]	Non-working hours [%]
S1	11:30	15:35	04:05	10:00	05:55	59
S2	11:30	15:35	04:05	10:00	05:55	59
S3	11:30	14:55	03:25	10:00	06:35	66
S4	11:30	14:55	03:25	10:00	06:35	66
S5	12:30	15:35	03:05	10:00	06:55	69
S6	13:00	15:35	02:35	10:00	07:25	74
S7	13:00	15:35	02:35	10:00	07:25	74
S8	13:00	15:35	02:35	10:00	07:25	74
S9	13:00	15:35	02:35	10:00	07:25	74
		Total:	28:25	90:00	61:35	68

Table 6. Numerical results for instance of 3 flights

Steward	Beginning of the shift	End of the shift	Shift duration [h]	Maximum working time [h]	Non-working hours [h]	Non-working hours [%]
S1	11:30	17:40	06:10	10:00	03:50	38
S2	11:30	17:40	06:10	10:00	03:50	38
S3	11:30	17:00	05:30	10:00	04:30	45
S4	11:30	17:00	05:30	10:00	04:30	45
S5	12:30	17:40	05:10	10:00	04:50	48
S6	13:00	17:40	04:40	10:00	05:20	53
S7	13:00	17:40	04:40	10:00	05:20	53
S8	13:00	17:40	04:40	10:00	05:20	53
S9	13:00	17:40	04:40	10:00	05:20	53
		Total:	47:10	90:00	42:50	48

Table 7. Numerical results for instance of 4 flights

Steward	Beginning of the shift	End of the shift	Shift duration [h]	Maximum working time [h]	Non-working hours [h]	Non-working hours [%]
S1	11:30	19:45	08:15	10:00	01:45	18
S2	11:30	19:45	08:15	10:00	01:45	18
S3	11:30	19:05	07:35	10:00	02:25	24
S4	11:30	19:05	07:35	10:00	02:25	24
S5	12:30	19:45	07:15	10:00	02:45	28
S6	13:00	19:45	06:45	10:00	03:15	33
S7	13:00	19:45	06:45	10:00	03:15	33
S8	13:00	19:45	06:45	10:00	03:15	33
S9	13:00	19:45	06:45	10:00	03:15	33
		Total:	65:55	90:00	24:05	27

Table 8. Numerical results for instance of 5 flights

Steward	Beginning of the shift	End of the shift	Shift duration [h]	Maximum working time [h]	Non-working hours [h]	Non-working hours [%]
S1	11:30	21:50	10:20	10:00	00:00	0
S2	11:30	21:50	10:20	10:00	00:00	0
S3	11:30	21:10	09:40	10:00	00:20	3
S4	11:30	21:10	09:40	10:00	00:20	3
S5	12:30	21:50	09:20	10:00	00:40	7
S6	13:00	21:50	08:50	10:00	01:10	12
S7	13:00	21:50	08:50	10:00	01:10	12
S8	13:00	21:50	08:50	10:00	01:10	12
S9	13:00	21:50	08:50	10:00	01:10	12
		Total:	84:40	90:00	06:00	7

Table 9. Summary results for instances of 1 to 5 flights

Number of flights	Number of stewards	Total shift duration for all stewards [h]	Non-working hours for all stewards [h]	Non-working hours for all stewards [%]	Total unused hours during the shift [h]	Total unused hours during the shift [%]
1	9	09:40	64:20	71	00:45	8
2	9	28:25	61:35	68	09:50	35
3	9	47:10	42:50	48	18:55	40
4	9	65:55	24:05	27	21:50	33
5	9	84:40	06:00	7	12:10	14

Conclusions and final remarks

The focus of this paper was the ground crew scheduling process at a small airport in the city of Niš (Serbia). Inflexibility of staff management with regard to different numbers of passengers by flight is detected as one of the focal problems of the airport processes. Limited capacities were not deployed in accordance with variable demand. The schedule for stewards was universal and consequently the system performance depended on the number of passengers. Subsequently, the problem of long queues arises, as well as wasting employees' time on flights with a small number of passengers.

In order to solve the problem, the authors developed a mathematical model implemented as the spreadsheet simulation model. Entry of flight schedules input data is realized through *Microsoft Excel* forms. Generic data is derived from the system and incorporated in the spreadsheet template. This data is rarely changed. Since the topic of this research was the control model for ground crew scheduling problem at small airports, spreadsheet is chosen as a tool, which requires no significant resources. Spreadsheet applications are widely accepted, flexible and easy to use without the need for complex trainings. The developed spreadsheet model facilitates understanding of the scheduling process and enables solving larger-scale problems. The understanding is further supported through visualization of constraints and of model behaviour caused by change in parameters, and by the incorporated UDFs.

Numerical results of experiments conducted for a different number of flights show that feasible solutions can be generated for 3 and 4 flights, and that an increased number of flights implies the reduction of lost hours. Based on a detailed analysis of unfeasible solutions generated for 5 flights (Table 8), it can be concluded that violation of maximum working time and minimum duration of break constraints is only 20 and 10 min, respectively. Authors of the paper propose time and motion study for the described activities to reduce their duration in order to make the instance of 5 flights feasible. Consequently, the airport management should make schedules for 5 flights per day, which requires 9 stewards. In the case of more than 5 flights per day, from the aspect of stewards' time utilization, the most cost-effective is another 5 flights and a completely new shift of 9 stewards.

Disclosure statement

Authors of the paper do not have any competing financial, professional, or personal interests from other parties.

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