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Resource planning for aircraft refueling in airport parking area

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Abstract

This paper studies a scheduling problem application for the optimization of the employees used in aircrafts' refueling in a medium size airport. The problem is modelled as a particular resource leveling problem for which we provide a mixed integer mathematical formulation that we solve with CPLEX. The model allows to evaluate and analyse different scenarios that could be considered by the company in place of the current one in order to rearrange the available human resources used in refueling activity. Experimental results on a set of real test cases provided by an oil & gas company are discussed.

Keywords: Ground Aircraft Refueling, Resource Leveling Problem, Mixed Integer Programming

1. Introduction

This work is focused on refueling activities in an airport area using real data at our disposal. The study that will be presented has been made to support companies operating in the oil & gas industry to plan in the most efficient way the personnel management for airplane refueling at the airport area.

When an aircraft arrives at an airport, after landing it is moved toward the assigned park position and then engines are turned off. At that time, the process of aircraft ground handling starts and it lasts until the time when the aircraft leaves its parking position for the next take-off. During this time period many activities are executed including aircraft refueling. This activity may be performed using refueling trucks, a hydrant system or a combination of the two.

In this paper we focus on the refueling process using refueling trucks. This type of aircraft refueling is usually used at airports with small and medium traffic volume, while at airports with high traffic volume aircraft refueling using

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trucks is usually combined with a hydrant system. Considering that most airports in the world have small and medium traffic volumes, aircraft refueling using trucks is a very common practice at airports.

Aircraft refueling activities play an important role in airport departure planning. Other important activities are for example deicing and anti-icing on the wings and fuselage of an aircraft during winter time (Mao et al., 2006). The importance of aircraft refueling and the high cost of required resources justify the necessary efforts to analyse and optimize aircraft refueling activities (Babić, 1987) and consequently solve the problem to assign shifts to workers (Alvarez-Valdes et al., 1999).

During aircraft refueling, the resources utilized are represented by the ground crew, who drive the trucks used for aircraft refueling, and by the trucks themselves. Assuming aircraft arrivals being known a priori, it is possible to decide the number of resources needed to carry out the refueling during the period in which the aircraft are in the parking area without interfering with the other activities such as embarkation and landing of passengers and luggage.

In this paper we consider the problem of planning (scheduling) the aircraft refueling activities during a working day at a medium/small airport in order to optimize the use of the resources involved. We propose to model the problem as a Resource Leveling Problem (RLP), that is a scheduling problem where the aim is to schedule and assign required resources to activities while balancing resource usage over time. In fact, in our application context, we are particularly interested in leveling the usage of the resources (the human resources, e.g., operators driving the tankers and executing the aircraft refueling).

The Resources Leveling Problem represents a class of well-known optimization models in the project scheduling field (see, e.g., Demeulemeester and Herroelen 2002). Gather et al. (2011) present an exact method for a project-scheduling problem subject to general temporal constraints where the utilization of a set of renewable resources has to be smoothed over time. Rieck et al. (2012) proposed a mixed-integer linear programming formulation for the resource leveling problem and solve problems with 50 activities and tight deadlines. For a survey on exact methods for RLPs the reader is referred to, e.g., (Rieck and Zimmermann, 2015).

Harris (1990) proposed an improved multi-pass heuristic algorithm called the MOM, which established the minimum moment as the performance measure for minimizing the daily fluctuations in resource use while keeping the total project duration unchanged. He named it the packing method (PACK), this method recognizes network interactions with a more in-depth analysis. Ponz-Tienda et al. (2013) proposed an Adaptive Genetic Algorithm for the RLP, and its novelty lies in using the Weibull distribution to establish an estimation of the global optimum as a termination condition. Hongbo et al. (2017) developed a genetic algorithm able to obtain near optimal solutions with less than 2% optimality gap for small instances in a very short time.

In our context, differently from the classical RLPs studied in project scheduling, (refueling) activities are independent in the sense that in general there are no precedence relations among them. We propose a mixed integer formulation for our RLP for optimizing resource usage in aircraft refueling at an airport that we solve with CPLEX. In particular, we propose to use specific versions of the model to optimize a set of different application scenarios. An experimental analysis on a set of real test cases provided by an oil & gas company is provided to validate the proposed optimization models.

The paper is organized as follows. Section 2 describes the aircraft refueling process and provide a mixed integer model to optimize the employees' usage. Section 3 is devoted to the analysis of the computational results on real and realistic test cases. Finally, in Section 4 we give some conclusions.

2. Activities description, problem definition, and model formulation

The study that will be presented has been made upon request of a major company operating in the oil & gas industry. The purpose was to improve its asset management of airplane refueling in the airport area. Each week a series of flights is assigned to the company and the landing and departure plan of them is provided, then the company has to define for every day of the programmed week the appropriate number of workers to carry out the aircraft refueling activities.

The refueling operation of an aircraft i being an activity of duration d_i must be done within a time window [ES_i, LF_i] included between the arrival (landing) time and the next departure time of the aircraft: ES_i and LF_i are the earliest start time and the latest finish time of the refueling activity, respectively. In fact, the time in which an aircraft is at the refueling operator's disposal is bounded by many factors, the most important are: the sequence of ground service activities, the duration of each of these activities, the arrival time and departure time which can be influenced by many other factors, etc.

In practice, the left limit ES_i of the refueling time window (i.e., the earliest time at which refueling can start) corresponds to the time in which the pilot declares that the aircraft is ready for refueling. The right limit LF_i of the time window (i.e., the latest possible finish time for refueling) is determined by the condition that the refueling activity should not delay the next departure time of the aircraft, considering the time necessary to ultimate the airport checks. Each refueling activity can be subdivided in three sub-activities with different durations. The first is a set up phase: before pumping the fuel oil the operator reaches the airplane with its tanker and then connects the junction pipe to the airplane. The second one regards pumping fuel into the airplane tank and the last concerns disconnecting the junction pipe and fills out the documents related to the oil product that tankers are carrying. The first and the third sub-activities have fixed durations, while the duration of second one depends on the amount of requested fuel and on the flow rate of the used pump. The duration d_i of the refueling activity i (represented in green in Figure 1) is therefore the sum of the durations of its three sub-activities. In general, each refueling activity requires a given number of resources of different types for its whole duration: at least one operator is included among the required resources. All the resources are "renewable" in the sense that at the end of the execution of an activity the used resources will be available to perform the next ones. As for the human resources (operators) involved, typically they work during one of a set of shifts of a given length (e.g., 8.5 hours). Finally, from time to time the fuel oil company in charge of aircraft refueling activities may decide to not perform a few of them that will be assigned to a third-party refueling company (i.e., these activities are then outsourced).

Therefore, given a set of feasible operators' shifts and a set of aircraft refueling activities, the problem we consider is deciding the number of operators used in each shift and scheduling refueling activities (and then assigning them to available operators) to maximize the productivity of involved operators. As it will be clear from the results presented in Section 3, the above aim will also imply the maximization of the number of executed activities and the minimization of the total number of operators used per day.

Next, we provide a mixed integer mathematical formulation for the problem that we solve with CPLEX.

We assume the daily working planning horizon discretized into T time slots of a given duration (e.g., 10 minutes). The notation used for the sets, parameters and variables is shown below.

Sets and parameters used in the model:

- T: set of time slots $[t, t + 1)$, indexed with $t = 0, 1, \ldots, |T| - 1$;
- S: set of daily shifts, indexed with h;
- K: set of resource types, indexed with k;
- A: set of daily activities, indexed with i;
- a_h: start time of shift h;
- b_h: end time of shift h;
- c_k: unit cost of resource of type k;
- R_k: maximum total amount of resource of type k that can be used;
- r_{ik}: amount of resource of type k required by activity i;
- d_i: duration of activity i;
- ES_i: earliest start time of activity i;
- LS_i: latest start time of activity i, $LS_i = LF_i - d_i$;

Variable used in the model:

- $x_{i,t}$: binary variable, $\forall\, i \in A, \forall\, t \in T$ such that $x_{i,t} = 1$ if and only if activity i starts at the beginning of time slot t;
- y_{kh}: non-negative integer variable, representing the number of resources of type k activated in shift h;
- $\rho_{kt} \geq 0$: number of resources of type k needed in time slot t;
- $Y_{kt} \geq 0$: number of (internal) resources of type k available in time slot t;
- $e_{kt}^{-} \geq 0$: negative excess of resource of type k needed with respect to its availability in time slot t.
- $\alpha \in [0,1]$: minimum fraction of activities to be executed

The problem can be modelled as follows:

$$\min z = \sum_{t \in T} \sum_{k \in K} c_k e_{kt}^- \quad (1)$$

subject to:

$$\sum_{t \in T: ES_i \le t \le LS_i} x_{i,t} \le 1 \qquad \forall\, i \in A, \quad (2)$$

$$\sum_{i \in A} \sum_{t \in T: ES_i \le t \le LS_i} x_{i,t} \ge \alpha |A| \quad (3)$$

$$\sum_{t \in T: t < ES_i} x_{i,t} = 0 \qquad \forall\, i \in A, \quad (4)$$

$$\sum_{t \in T: t > LS_i} x_{i,t} = 0 \qquad \forall\, i \in A, \quad (5)$$

$$\sum_{\substack{h \in S: \\ a_h \le t \le b_h - 1}} y_{hk} = Y_{kt} \qquad \forall\, k \in K, \forall\, t \in T, \quad (6)$$

$$\sum_{i \in A} \sum_{\substack{\tau \in T: \\ t - d_i + 1 \le \tau \le t}} r_{ik} x_{i,\tau} = \rho_{kt} \qquad \forall\, k \in K, \forall\, t \in T, \quad (7)$$

$$\sum_{h \in S} y_{hk} \le R_k \qquad \forall\, k \in K, \quad (8)$$

$$\rho_{kt} - Y_{kt} \le 0 \qquad \forall\, k \in K, \forall\, t \in T, \quad (9)$$

$$Y_{kt} - \rho_{kt} \le e_{kt}^- \qquad \forall\, k \in K, \forall\, t \in T, \quad (10)$$

$$x_{it} \in \{0,1\} \qquad \forall\, k \in K, \forall\, t \in T, \quad (11)$$

$$y_{hk} \ge 0 \text{ and integer} \qquad \forall\, h \in S, \forall\, k \in K, \quad (12)$$

$$\rho_{kt} \ge 0 \qquad \forall\, k \in K, \forall\, t \in T, \quad (13)$$

$$Y_{kt} \ge 0 \qquad \forall\, k \in K, \forall\, t \in T, \quad (14)$$

$$e_{kt}^- \ge 0 \qquad \forall\, k \in K, \forall\, t \in T. \quad (15)$$

Objective function (1) minimizes the total cost of unused resources over time. Constraints (2) and (3) impose the range of the number of activities that should be executed, constrains (4) and (5) ensure that activities cannot be scheduled outside the given time windows.

Constraints (6) determine the number of available resource for each type *k* and time slot *t*, on the basis of the resources decided to be at work for each shift. Constraints (7) define the total amount of resources used in each time slot *t* and for each resource type *k*. Constraints (8) require that total amount of resources of each type *k* does not exceed the maximum value. Finally, constraints (9) and (10) establish that the number of available resources must be at least equal to the number of resources used and provide a lower bound on the number of unused resources, respectively, for each resource type *k* and time slot *t*.

3. Results and discussion

In this paragraph we present the realistic tests and discuss the related results obtained by the proposed model. Test instances are collected from aircraft data related to three-real days of work in an Italian medium size airport in which were planned 54, 57 and 63 aircraft refueling activities, respectively. Each working day, starting at 05:00 a.m. and ending at 02:30 a.m. of the next day, is divided in 129 times slots (from time slot 0 up to time slot 128) each one of 10-minutes length. For each refueling activity *i* we have at our disposal the duration $d_i > 0$ expressed in number of time slots, from a minimum of 2 time slots for the faster activity to a maximum of 7 for the slowest activity (i.e. from 10 to 20 minutes to carry out the fastest activity and from 60 to 70 minutes to carry out the slowest one), the earliest start time ES_i, and the latest finish time LF_i . In all tests we assume that only one resource of the same type ($|K|=1$), i.e, the refueling operator, is needed to carry out an activity and that will be used for the whole activity duration. Moreover, without loss of generality, we assume the unitary cost $c_1 = 1$ for the unique resource type. With this choice the model minimizes the total amount of refueling operators idle time, and hence maximize their productivity.

For the experimentation we considered the 7 (current) shifts imposed by the company lasting 8.5 hours each, starting at: 05:00 a.m. ,08:00 a.m. ,10:30 a.m. ,12:30 p.m. ,01:30 p.m. ,03:30 p.m. ,06:30 p.m.

Given the starting and the ending time of working day we have considered a new set of available shifts beginning from 05:00 a.m. every 30 minutes of the same duration of the originals; in this way we consider 27 possible (new) shifts. We analysed two different cases: the first one requires that all activities must be carry out, i.e. $\alpha = 1$, and in the second case at most 5% of the daily activities could be assigned to a third-party refueling company, i.e. $\alpha = 0.95$. Both cases are evaluated considering both actual and new shifts. Results for all the test cases are obtained solving the proposed model with CPLEX 12.3 in a few seconds.

Next, we discuss and compare the results. All the figures below, related to the day with 57 aircraft refueling activities, show the available resource profile (in blue) and the amount of used resources in each time slot (in red). In particular:

- The vertical axis represents the number of resources (refueling operators) and the horizontal axis represents daily time slots starting at 05:00 a.m. and finishing at 02:30 a.m. of the next day, so the number of time slots is T = 129, starting from the time slot indexed with 0, i.e., time slot [05:00 a.m., 05:10 a.m.), and ending with time indexed with 128, i.e., time slot [02:20 a.m., 02:30 a.m.), next day.
- The two rows under the horizontal axis provides the start and finish times of the shifts: the first row shows the start time of each shift, in the second row we can read their finish time. In this way it is possible to identify the shifts' overlaps.
- The blue curve shows the refueling operators availability over time, given the number of operators decided to be working for each shift; the vertical red lines (one for each time slot) represent the total number of operators used to carry out the activities in execution during each time slot. The diamond mark (if present) represents the earlier starting time of the activity that is assigned to a third-party refueling company.

The optimal solution when outsourcing is not allowed, and the current shifts are considered (Scenario 1) makes use of 5 operators: 2 operators for the 1st shift; 1 operator for the 2nd, 5th and 6th shifts. Figure 1 shows the operators availability profile and the number of operators used for each time slot for this scenario.

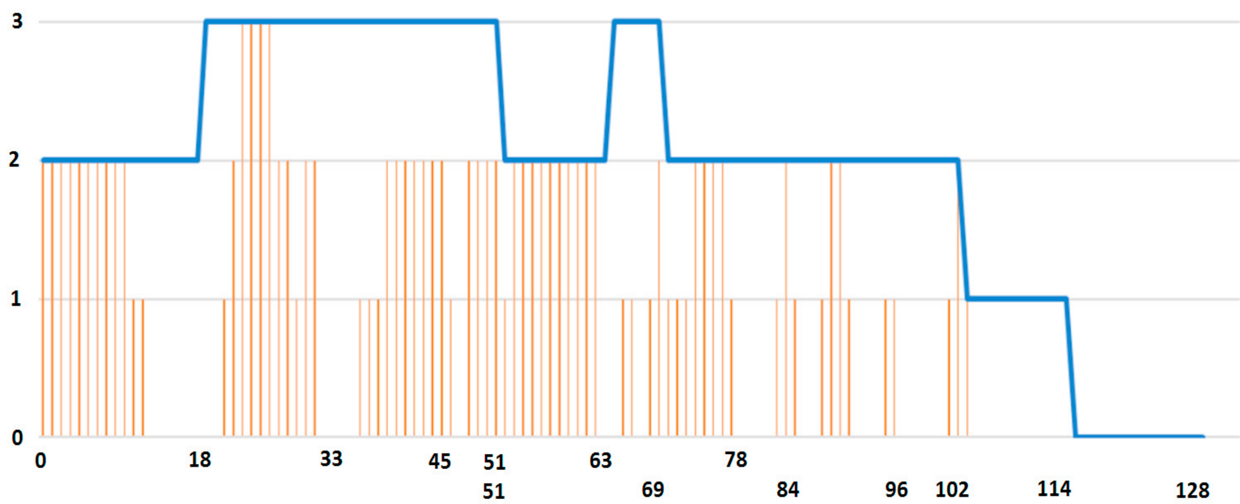

Figure 1: The resource profiles of the solution for Scenario 1 (no outsourcing allowed, 7 current shifts).

In Figure 1 the blue curve, representing the operators availability, shows that we start at the beginning of the 0th time slot with two operators in the 1st shift, then at the start of the 2nd shift (at the beginning of 18th time slot) one additional operator is available; since at that time the 1st shift is not yet ended, the total number of available resources is three until the end of the 50th time slot, when the 1st shift ends. At this point the two operators working during the 1st shift finish their working period and, in the same time slot, a new operator starts to work (in the 5th shift), so that the number of available workers decreases to two until the 63rd time slot, when a new operator begins to work (in the 6th shift) and the total number of available operators becomes three. At the 69th time slot another operator finishes his working shift and, finally, from the 102nd time slot only one worker remains available until the end of his working shift. As for the actual resources used (red vertical lines), we note that the number of employed operators never exceeds the number of available operators. However, a large amount of idle time, represented by the white space between the red lines and the blue profile, is present.

Figure 2 shows the results obtained for the same case (no outsourcing allowed) but with the new 27 shifts (Scenario 2). The solution in this scenario makes use of four operators: one in the first shift, starting at 05:00 a.m.; one in the shift starting at 05:30 a.m.; one in the shift starting at 01:30 p.m. and the last one from 02:00 p.m.

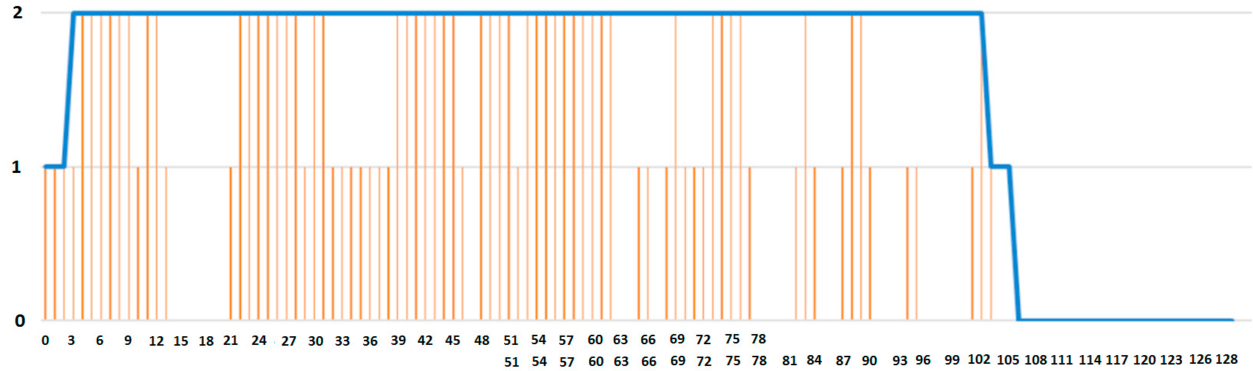

Figure 2. The resource profiles of the solution for Scenario 2 (no outsourcing allowed, 27 new shifts).

We can notice from Figure 2 that, as for the solution of Scenario 1, the red vertical lines are always under the blue curve and all the aircraft refueling activities are carried out. The idle time of refueling operators decreases with respect to the solution of Scenario 1, as a result of different scheduling of the activities and of the smaller quantity of operators involved. Using different shifts provides a better solution in terms of both the number of workers and their productivity. Next, we analyse the solution for the case in which a small amount of refueling activities can be assigned by the oil company to a third-party for their execution; as we did before, we consider the same test case as before and define two scenarios, namely Scenario 3 (with 7 current shifts) and Scenario 4 (with 27 new shifts).

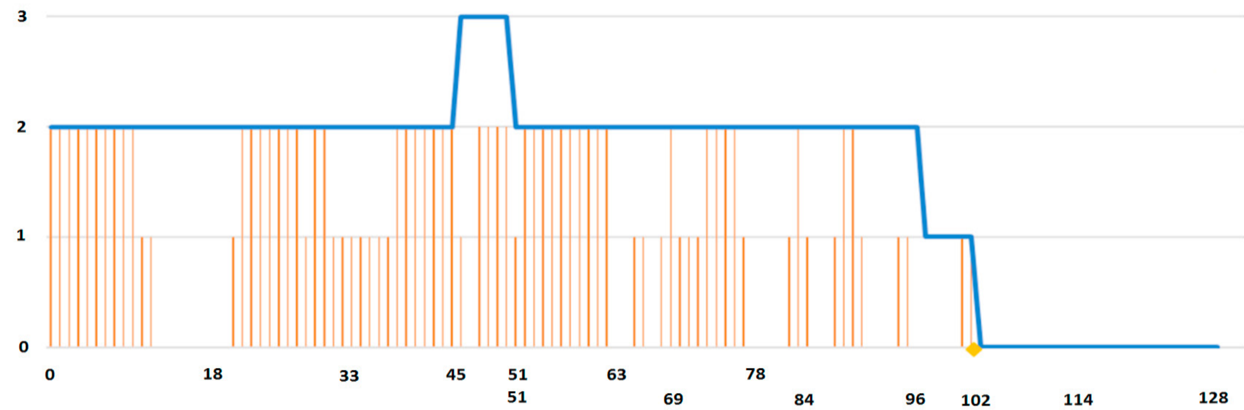

Figure 3. The resource profiles of the solution for Scenario 3 (outsourcing allowed, 7 real shifts).

Figure 3 shows the results obtained when outsourcing is allowed and when the original 7 real shifts are considered (Scenario 3). Note that we make use of four employees: two in the 1st shift, one in the 5th and in 6th shift, respectively. The diamond at the 102nd time slot indicates the earlier starting time of the activity that must be assigned to an external company (the activity should be acquired in outsourcing). However, we notice that the white area between the blue curve and the red lines (the idle time) is very small in comparison with that for Scenario 1. In fact, in Figure 3 only 80 white spaces are present (a white space corresponds to 10 minutes) as compared to 120 white spaces present in Figure 1, representing Scenario 1.

Finally, we analyse the results in which the outsourcing is allowed, with 27 new shifts (Scenario 4). As shown in Figure 4, the presented solution required only three employees: one in the first shift starting at 05:00 a.m., another one in the shift starting at 9:00 a.m. and the last one from 01.30 p.m. However, as in the previous Scenario, the solution presented below is such that not all the activities are carried out, as emphasized by the two diamond markers.

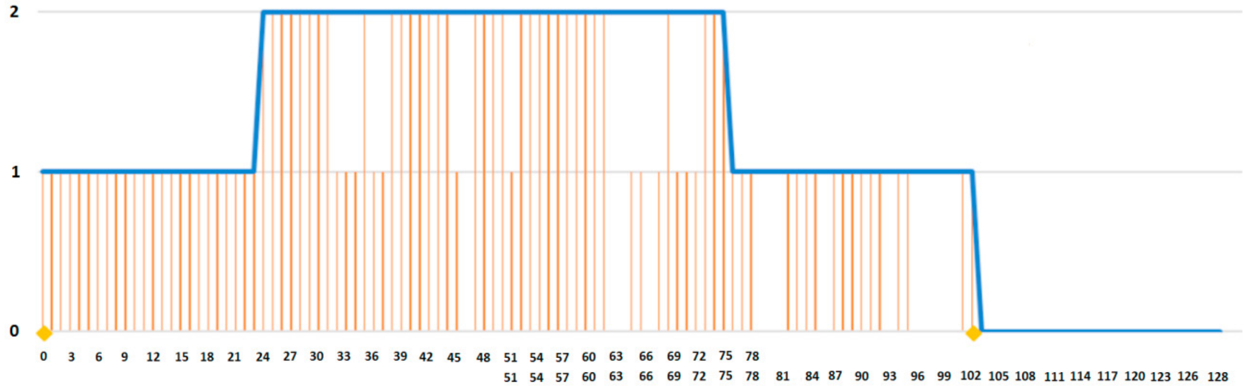

Figure 4. The resource profiles of the solution for Scenario 4 (outsourcing allowed, 27 new shifts).

In Table 1 we report the results obtained in all the test cases. Moreover, for every day, we list the overall amount of idle time during the working day, the total amount of refueling activities that should be served by the third-party company, the number of workers employed in a day.

Table 1. Numerical results.

	Cases	$\alpha = 1$		$\alpha = 0.95$	
	Shifts	Current	New	Current	New
Day 1 54 activities	Overall idle time	90	39	43	39
	Outsourced refueling activities	0	0	2	0
	Workers per day	4	3	3	3
Day 2 57 activities	Overall idle time	120	78	80	31
	Outsourced refueling activities	0	0	1	2
	Workers per day	5	4	4	3
Day 3 63 activities	Overall idle time	88	37	41	37
	Outsourced refueling activities	0	0	2	0
	Workers per day	4	3	3	3

The results presented in the table below show that for the first and third days, the execution of all the activity is guaranteed by employing only three workers using the new shift scheme. With the current shift scheme the company can choose either to schedule all the activities, making use of one more operator, or to assign two activities to the third-party company while keeping the same number of operators. In the second day, discussed in the figures above, it is possible to reduce the total number of employees by one unit with the introduction of the new shifts scheme without any outsourcing. If the outsourcing is allowed, as in the previous case the number of employed workers per day decreases by one unit but one further activity must be assigned to a third-party company.

4. Conclusion

This work is focused on refueling activities in a medium or small size airport, using real data given to us by a company operating in the oil & gas industry. We propose a mixed integer mathematical formulation to provide several solutions to increase the productivity of the operators for airplane refueling in the airport area.

Two different cases are analysed, first when all the aircraft refueling activities must be carried out and second when at most 5% of the daily activities could be assigned to a third-party refueling company (outsourced activities). The results with the operator shift scheme currently adopted by the company and with a new shift scheme are compared on both the cases and tests are carried out on real instances of three different working days. The model is solved with CPLEX 12.3.

The results show that, with the introduction of the new shift scheme, the number of daily operators decreases for all scenarios when the outsourcing is not allowed. The use of the new shift scheme, when the outsourcing is allowed, leads to two possible outcomes: either all activities are carried out by the company using the same numbers of operators (day 1 and day 3) or the number of workers per day can be reduced at the price of one further activity to assign to a third-party company (day 2). Finally, with the introduction of the new shift scheme the total amount of idle time decreases in all the evaluated scenarios.

A future work can be devoted to extending the planning model to consider a larger planning horizon (e.g., a week, considering that typically the flight timetable of an airport repeats with weekly periodicity) and/or to take into account also operators rostering policies. Another possible future research could be studying a stochastic version of the model capable to consider possible delayed aircraft arrivals.

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