DEICING ON GROUND OPTIMIZING PROCESS OF AIRCRAFT'S

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Handling-ul este una dintre activităţile esenţiale în vederea pregătirii pentru zbor a aeronavelor. Datorită numărului şi complexităţii activităţilor specifice, precum şi a importanţei fiecărei activităţi, optimizarea serviciilor de handling constituie o problemă complexă de organizare şi gestionare a resurselor.

În cadrul activităţii de handling un element important îl constituie procesul de degivrare şi antigivrare a aeronavelor, atunci când condiţiile meteorologice impun acest lucru. În lucrare, se propune un model de optimizare a procesului de degivrare cu scopul reducerii întârzierilor aeronavelor, datorate condiţiilor meteo dificile. Această optimizare este o problemă cu restricţii multiple, având în vedere anumite constrângeri ce urmăresc definirea procesului ca unul eficient şi în beneficiul tuturor părţilor implicate.

Handling activity is one of the essential activities in preparation for the flight of an aircraft. Due to the number and complexity of specific activities and the importance allocated to each activity, optimizing handling services is an interesting organization and resource management.

In this work an important element is the deicing and antiicing process of an aircraft conducted by the handling companies when the weather conditions require. There is proposed an optimization model for the deicing process in order to reduce aircrafts' delays, due to difficult weather conditions. This issue is seen as an optimization problem with multiple restrictions, given certain constraints aimed at defining the process as being efficient and for the benefit of all parts involved.

Keywords: handling, deicing, optimization, restrictions.

1. Introduction

In the process of aircraft ground handling, there are implemented a series of operations to support the air transport activity. Handling activity is one of the most important and plays a significant role in services offered to passengers and aircrafts. It is an activity internationally regulated by procedures, standards and recommended practices designed to provide a certain level of safety in the evolution of business activity.

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One of the most important operations of the handling activity is deicing. While it is an activity that takes place over a relatively short period of the year, becomes interesting by providing methods and means necessary to handle it, but also by organizing the process itself, as to provide a minimum time of progress and maximum effect of protection against ice deposits on the surface of the aircraft.

Optimising this process provides multiple benefits both for the airline operator by reducing delays on the ground, which according to some authors represents 50% of the total delays [1] and for the handling company through a better management of human and technological resources.

This paper aims to talk about this subject from two perspectives:

- that of the airline operator that aimes a faster deicing, providing maximum protection in time on the phenomenon of icing at a low cost;

- and that of the handling company which aims to use a small number of equipment in a balanced way and serving all operators as soons as possible.

This is a multiple restrictions problem that should provide solutions for both parties involved in the process.

2. Deicing process management

In order to properly handle this process, we must take into consideration some key points, as follows:

- aircraft type and the contamination degree of the aircraft's surface, established by the thickness of the deposit layer;

- weather conditions and the concentration of the deicing agent used, a function that must take into account the recommendations of the regulatory organizations [2];

- time left until the scheduled time of departure Standard Time Departure - STD;

- the number of successive transits of the deicing equipment, in one or two steps;

- the amount of equipment used in the process;

- the water quantity and the amount of deicing fluid for the aircraft – ADF, available in the deicing equipment tanks;

- the time in which the water and the deicing fluid warm up to the optimal temperature for use.

Given these issues, we should identify a mathematical form that will result into minimizing aircrafts'delays, and also into reducing the lapse between the movements of the equipment, from the stationary position to the work position.

If the aircrafts'delay is a complex problem determined by many factors, the problem of the equipment's delay during its movement, from and to the

aircraft is a little easier to control. In our case, aircraft's delay is regarded as a problem closely linked to the deicing. For a better management of the deicing process it is important to enforce the following restrictions:

   - the allocation of the parking positions for the equipments used in the process, to be made so that they move on the shortest route in the maintenance process. In this respect it should be known before hand the position of the aircraft at the stand long enough so that they are properly positioned;

   - moving equipment from and to the aircraft must be carried out on the same path or a different path in case of repositioning for a new more efficient service.

The condition of positioning and repositioning of the machine can be expressed as:

$$\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{s,h}(K_k,t_i) - \sum_{t=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{h,p}(K_k,t_{i+1}) = 0 \qquad (1)$$

where:

$\Delta t_{s,h}$ - represents the time on which the K_k equipment moves from s to h position, at the specified moment in time (t_i);

$\Delta t_{h,p}$ - represents the time on which the K_k equipment moves from h to p position, at the specified moment in time (t_{i+1});

$s, h, p \in \{1,...,N\}$ with $s \neq h, p \neq h$, but it can be that $s = p$ in case of repositioning the equipment to the initial point or $s \neq p$ in case of assigning of a better standing point from a time perspective, regards to the next maintenance process.

   N - represents a number of parking positions on the movment area;

   R – represents timp in which the process;

   K_k - represents the mobile units available for deicing, $(\forall) k \in \{1,...,M\}$;

   t_i - is moment of the day when there is movement for $i \in \{0,...,1440\}$ min.

It may be that some of the equipment shifts to be made without load, for example racing to refuel. This is determined by:

   - type and number of aircraft maintaned daily;

   - the amount of water and ADF consumed in each process.

If a resource type ADF, water or fuel exhaustes the equipment becomes temporarily unavailable. This should be taken into account by setting a new restriction, such as the process is carried out only once. It is possible to have extreme weather phenomenon, such as "*freezing rain*" when the aircraft stationed on the platform during a night with consistent deposits of ice or snow. In this situation deicing process can be resumed due to the exhaustion of one of the equipment resources (water, ADF). Does this study this is intended to eliminating the inefficient action.

This is the precise aim of this study, to eliminate the inefficient processes by establishing a mathematical connection like that:

$$\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{s,h}(K_k,t_i)-\sum_{t=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{h,p}(K_k,t_{i+1})=\Delta t_{s,p}(K_k,t_{i+1}) \qquad (2)$$

How not always moving equipment is the same way or at the same speed, there is a time difference that is generally not very high, unlike the refueling which implies a longer period of time and which should be restricted to not split into a inefficient process of a particular aircraft deicing. In this case, the problem becomes one boolean by establishing relationships form:

   - if the deicing shares was not completed due to the exhaustion of one resource, the mathematical expression (2) becomes:

$$\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{s,h}(K_k,t_i)-\sum_{t=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{h,p}(K_k,t_{i+1})=1 \qquad (3)$$

   - if the deicing shares was completed properly, the mathematical expression (2) becomes:

$$\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{s,h}(K_k,t_i)-\sum_{t=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R}\Delta t_{h,p}(K_k,t_{i+1})=0 \qquad (4)$$

To better identify the processes in time and to properly separte them it is necessary to establish a condition to assigne the equipments for a new iteration only after the previous activity. This condition is expressed by the equation:

$$ARDT_{i-1}(K_k)<ARDT_i(K_k) \qquad (5)$$

   where: ARDT - *Actual Ready Time*, it is time the equipment is ready to begin the movement on the platform for a new service.

This scheduling of activities is determined by the ability of the staff to properly evaluate the activity established on the basis of existing ADF and water resources in relation to environmental conditions in which the process takes place. In this regard, it is compulsory the strict control of existing resources in tanks, and also an evaluation of resources needed in regards to them, establishing whether the equipment participates or not in the process.

At the same time, we must ensure that the deicing equipment moves to refueling position before the entire working fluid is finished (deicing or water) or fuel. For this reason, the staff will be forced to evaluate the required amount of ADF and water before beginning each deicing process, taking into account the following:

   - the concentration of the deicing agent, as established by the aircraft's commander;
   - the weather conditions (ambiental temperature, work surface temperature, wind direction, type of rainfall, the thickness of the deposited layer);

- aircraft type (material, size).

Taken these into consideration there is estimated the minimum amount required for the deicing process to begin, only if the estimated amount is higher than that existing one in each machinery available. In order for this to happen, according to the established concentration, it will be used one of the following formulas: formula (6.a) for a concentration of 50/50, formula (6.b) for a concentration of 75/25 and formula (6.c) for a concentration of 100/0 (ADF / water):

$$\left[\begin{array}{l} -1.57957 + (-6.74898\,)x_{1t} + (-16.36183\,)x_{2t} + \\ +(-10.14606\,)x_{3t} + (-8.94051\,)x_{4t} + (12.10622\,)x_{5t} \end{array}\right](1+\varepsilon) \geq \cdot q_{k\ curent} \qquad (6.a)$$

$$\left[\begin{array}{l} 82.68841 + (-35.04799\,)x_{1t} + (-3.46221\,)x_{2t} + \\ +(9.59209\,)x_{3t} + (-7.91976\,)x_{4t} + (23.13539\,)x_{5t} \end{array}\right](1+\varepsilon) \geq \cdot q_{k\ curent} \qquad (6.b)$$

$$186.25311 + (-26.01344\,)x_{1t} + (13.38123\,)x_{2t} + (3.12677\,)x_{3t} + (5.36763\,)x_{5t} \qquad (6.c)$$

where: x_{1t} - ambiental temperature, $\left[{}^{0}C\right]$;

x_{2t} - dew point temperature, $\left[{}^{0}C\right]$;

x_{3t} - the surface temperature of the aircraft, $\left[{}^{0}C\right]$;

x_{4t} - the thickness of the layer grown on the surface of the aircraft, $\left[mm\right]$;

x_{5t} - wind speed, $\left[m/s\right]$, all this is identified at the t_i moment;

ε - the correction factor due to the lack of establishing the precise quantity of ADF or water available for deicing;

$q_{k\ curent}$ - the normal existent quantity of ADF and water on the bord of the equipment available at the evaluation time, for k equipment, $k \in \{1,...,M\}$;

Another challenge in solving this process is to identify an optimal solution that will lead to the compliance of the time established for the conclusion of the deicing process, according to the standard operating schedule and conjunct with the *Estimated taXi-Out Time* (EXOT). In this regard it must be a decision based on the following considerations:

- the time when the deicing begins it is not always the established one according to the operating schedule. Delays occur at landing, at the processes durring the previous turnover that took place before the deicing process.

- the time spent in taxi at the takeoff is fluctuating and is based on the average number of the aircraft's movements on the ground per unit time, the hour at which is implemented the movement on the range of motion, beacause at the rush hour its value is greatly increased;

- the estimated time to carry out deicing, given the determined weather conditions;

- aircraft's size, the technological performance of the equipment used, the professionalism of the staff taking care of the equipment.

Based on these considerations there must be made a decision to allow the aircraft's deicing as soons as possible, without delays in the operating software using 1, 2, 3 or 4 deicing equipment. This decision is taken by:

- existing time available to scheduled departure, STD;
- the estimated duration of defrost;
- the number of existing equipment available at the time and the resources available on board;
- the length of travel of the equipment to aircraft.

Depending on the number of de-icing equipment assigned to an aircraft handling company can achieve a reduction in total service time, which leads to a reduction in delays caused by icing. For example, if have four scenarios which in turn allocate 1, 2, 3 or 4 machines, then reduce cosiderably working time. In this regard we have:

- in the first scenario, the K_1 machine is moving in the time period $\Delta t_{25}(t_2)$ from the parking position (2) to the service position (5) and to the t_2 time of day;

- in the second scenario, the K_1 machine performs the same movement, but joins this process and the K_2 machine is moving in the time period $\Delta t_{45}(t_2)$ from the parking position (4) to the service position (5) to the t_2 time of day;

- in the third scenario, we have three machine: K_1, K_2 and the K_5 machine is moving in the time period $\Delta t_{35}(t_2)$ from the parking position (3), to the service position (5), to the t_2 time of day;

- in the fourth scenario, we have four machine: K_1, K_2, K_5 and the K_3 is moving in the time period $\Delta t_{15}(t_2)$ from the parking position (1), to the service position (5), to the t_2 time of day.

In all these scenarios each machine makes the distance from the parking to the servie position in a different time, $\Delta t_{s,h}(t_i)$.

The moment when the machine has reached the maintenance position, it is staying a while $\Delta ts_{k,h}(t_i)$ necessary to prepare the deicing process. This interval is linked to the professionalism of the deicing team and also to the capacity of the ramp agent to manage the processes.

Such a process takes a different time interval, expressed as a function of the type $f_i(p, HF, A/c, x_{it}, n)$, in i minutes. This time is based on the following factors:

- the number of steps the deicing is performed in (in one step or two steps) p ;

- the cooperation ability between team members. This depends of the communication, the training and the integration of each individual in team, it is rather a matter of human factors - HF ;

- the aircraft type - A/c ;

- ADF and the amount of water used, they are depending on weather conditions, x_{it} ;

- the amount of equipment involved in the process with $\max(n) = 4$.

This function is a correction factor of the estimated outcome taking into account the performance of the work teams, which can be highlighted only after a careful monitoring of each individuale and of each team. To such a process, we must take into account a deviation from the estimated length of time for each process, ζ . For a deicing of 50/50 concentration, the data collected has shown a deviation from the maximum time accepted for weather conditions frequently encountered and for the aircraft type studied (A320), as $\zeta = 15\%$ and for a deicing of 75/25 concentration, as $\zeta = 9\%$.

Another factor to take into account is the *Time Ending Deicing* process - TED_i - expressed in minutes, a value that may be lower or higher than the scheduled S*tandard Time Departure - STD* , see in figure 1.
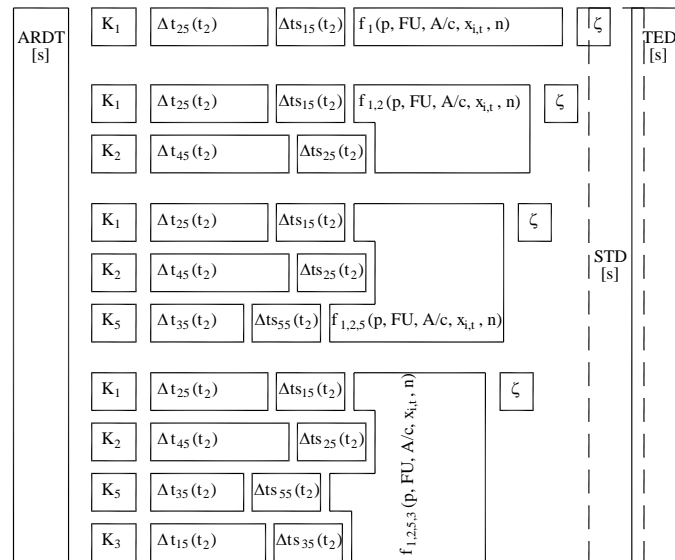

Fig. 1 The decision to allocate a given number of equipment

Depending on this is made the decision to allocate a given number of available machines. The condition that determines the amount of equipment that need to participate in this process is:

$$ARDT_i + \frac{\sum_{s=1}^{N}\sum_{k=1}^{M}\sum_{i=1}^{R} \min\left(\Delta t_{s,h}(K_k, t_i)\right), \Delta t s_{k,h}(t_i)}{n} + \max\left(f_i(p, HF, A/c, x_{it}, n)(1+\zeta)\right) \leq TED_i \tag{7}$$

A process is considered optimized if it ends without exceeding the standard time departure (STD), because it is not subject of a penalty condition. In this case we must take this into account as not to prejudice the airline and neither the handling company by financial losses that may occur due to delays [3]. With regard to this, it is necessary to establish a condition that the process does not exceed a time constraint.

$$TED_i \leq STD_i - AWIT_i \tag{8}$$

where: $AWIT_i$ - *Average Waiting Time in Taxi*, the average roll time in taxi.

Defining this time for $AWIT_i$ is made through dynamic allocation, using an existing statistical data in a database obtained rolling average times in each hour and every day of the week. It is generally considered an accepeted delay if it is under 15 minutes, without charging penalties. For this reason it is considered necessary to establish working procedures leading to the process efficiency and to a low delay rate beyond the accepted limit. The rules underlying the aircrafts' meintanance are:

  - *first come, first served* is a generally accepted rule,

  - a*ccording to custom airline*, used as a second rule designed to solve the situations when the first is not enough. This rule takes into account the risk that crew members work than is covered on duty time.

Another condition that should be taken into consideration is the allocation of the deicing equipment to a new process, that means those cannot participate to the aircrafts'deicing until they have finished the previous process, the condition is:

$$\sum_{i=1}^{R} TED_i + f_0(t_i) - Mnx_{s,h}(K_k, q_{max}) \leq \sum_{i=1}^{R} ARDT_{i+1} \tag{9}$$

where: $f_0(t_i)$ - refueling process of deicing machine length, with water or ADF, [min];

M - the possibility to start a process without completing it properly. From the research done it is $M = 0.001$.

n - the number of events in year when the defroster was not completed;

$x_{s,h}(K_k, q_{max}) = 1$, if the machine K_k performs a maintenance process at the time moment i, moving from its parking position s, to the position of service h,

before doing a process at the moment $i+1$, otherwise the value assigned is 0 (zero).

$ARDT_{i+1}$ - the amount of time allocated to the start time of a new process of deicing at the moment $i+1$ of the machine movement.

Unfortunately the equation (9) does not solve the problem entirely and requires an additional condition to guarantee the efficiency of the processes by establishing a minimum resource criterion to launch a process. This can be done by the following equation (10), if we have a good ADF and water resource estimated:

$$\min\left((1+\varepsilon)q_{ADF\,estim}\right) > q_{ADF\,real}(K_k),\; \min\left((1+\varepsilon)q_{apa_{estim}}\right) > q_{apa\,real}(K_k) \qquad (10)$$

where:

$q_{ADF\,estimat}$ - represent the minimum quantity of estimated ADF;

$q_{ADF\,real}(K_k)$ - the existent quantity of ADF in each available machine's tank;

$q_{apa\,estimat}$ - represent the minimum quantity of estimated water;

$q_{apa\,real}(K_k)$ - the existent quantity of water in each available machine's tank.

To complete this picture, it is not enough to know how long each process will take, but to also know when it ends! Those are essential elements in assigning the activities. If the relationship (7) does not satisfy the condition imposed, then records the current value of TED_i for each process. Otherwise, if the relationship (7) satisfy the condition imposed STD_i can be considered for closure for the equipment K_k, provided that $AWTT_i \le 15\,\text{min}$. If $TED_i > STD_i$ and $AWTT_i > 15\,\text{min}$ then delaying the flight of the aircraft is recorded as a late-icing operation for the machine K_k, at time t_i. This should be recorded for each aircraft and every day. This is interesting from two points of view:

- effectiveness of the activity on the main learn from mistakes;
- to honor contractual obligations due to financial penalties due to delays.

Cost is a function that has significance for both the airport operator and for the handling, if we think about that a minute of delay is considered to be equal to 72 Euro / min delay [4].

This model by processing successive should identify the minimum values of delay time, and movement of equipment from a stand to position of service in a short time, at a reduced frequency for each machine in part within time assessed (24 hours).

The objective function has the following form:

$$\min \sum_{i=0}^{R}\left(a \cdot TED_i + \frac{1}{b}\Delta t_{s,h}(K_k, t_i)\right) \qquad (11)$$

where: a - coefficient that depends on the value of the assigned to the objective function of the aircraft's delays, $a \in [0,....,1]$;

b - coefficient that depends on the value of the allocated time for equipment movement from parking position to work position, $b \in [0,....,1]$;

The initialization conditions of the process are:

$$t_i \geq 0, \quad ARDT_i \geq 0, \; \Delta t_{s,h}(K_k, t_i) \geq 1, \Delta t_{h,p}(K_k, t_i) \geq 1, \; f_i \geq 1,$$
$$\Delta ts_{k,h}(K_k, t_i) \geq 0, \; n \in [1,...,4] \tag{12}$$

By this function one tries to eliminate the risk that an equipment will not complete the assigned process and also that there is used the entire technological resource available in a unitary way.

3. Conclusions

By applying the optimization model is solved at least two important aspects: reducing delay and improved aircraft equipment defrost management. If you extend this model across activities of an airport, we see that the benefits are much higher. The airport will have a better management of aircraft parking positions, a better positioning of deicing equipment on the platform and why not increase the degree of efficiency of the airport. Integration in a similar pattern and other activities specific to the calling process, would reduce delays arising in the process of servicing the aircraft on the ground. A system for managing airport logistics activities completely and complex offers multiple integration and solving problems in benefit aeronautical agents involved.

If you were to consider that one minute of delay for an air operator represents a loss of about 72 Euro [5], then we have all the arguments to say that optimization of each process conducted ground can bring financial benefits enormous, not only to airlines, but also for passengers and the rest of aeronautical agents.

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