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A NEW APPROACH FOR AIRCRAFT LANDING SCHEDULING PROBLEM BASED ON THE DEADLINE MONOTONIC ALGORITHM

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ABSTRACT

Historically, the Aircraft Landing Scheduling (ALS) problem remains one of the complex problems in the air traffic management domain. In the last years the number of air traffic increases on almost all airport platforms in the world, so the aircraft landing scheduling optimization become a critical problem. In the practice the ALS problem can be considered as an optimization problem under constraints and that requires real-time approach to solve it. Several methods of optimizing the landing cost of a sequence of aircraft have been proposed, such as methods using the approach of linear programming and other optimization methods based on meta-heuristics algorithms. These methods have shown great advantage over the method first-come-first served (FCFS) currently used for air traffic management. In this paper, we propose a method that optimizes the aircraft landing scheduling problem based on real time scheduling algorithm deadline monotonic (DM). This approach solves the ALS problem in two steps. First, it gives a mathematical model of aircraft landing scheduling problem, thereafter in the second step, our approach schedules.

Keywords: aircraft landing scheduling, real time scheduling algorithm, deadline, monotonic first-come-first-served.

INTRODUCTION

Since the last ten years, air traffic has grown on almost any airport in the world. For example, in Morocco the number of passengers reached 13176939 passengers in September 2014 versus 12336475 in September 2013 that corresponds to an increase of 6.81%. In most cases, the airports don't have a large number of runways, so the optimization of the scheduling of the aircrafts landing sequence is required.

The aircraft landing scheduling consists to determine the landing time for each aircraft in order to get a minimum total landing time of a sequence of aircraft. Also the aircraft landing scheduling (ALS) is considered a complex problem of Air Traffic Management (ATM). The landing scheduling problem of a sequence of aircraft can be divided into two sub-problems; the first is to determinate the order of landing aircraft and the second to optimize the landing time for each aircraft, in order to have a minimum global landing cost, and ensure the safety aviation through the application of the national and international standards of civil aviation.

Currently, the widely used method for scheduling the landing of a set of aircraft is FCFS – First Come First Served -, where landing aircraft is done in the order of their arrival on the Traffic Management Advisor (TMA) of the airport. In this case, the air traffic controller provides the minimum required separation time between two aircraft. FCFS has two advantages; it is easy to implement and it also minimizes the number of aircraft deviations. The major drawback of this method is that the aircraft of low speed can affect the landing time of others of high speed, subsequently, the global cost of landing. Also, FCFS don't offer more flexibility to air traffic controllers. These limitations have motivated a large number of scientists to study the Aircraft Landing Scheduling problem. Actually, there are many advanced methods and algorithms based on linear programming methods and meta-heuristic approaches to solve this problem. In this contribution, we propose a new method for aircraft landing scheduling. It based on real-time scheduling algorithm such as deadline monotonic (DM).

The paper is organized as follows; Section 2 presents the definition and the model of the aircraft landing scheduling. In section 3, we present in more details our algorithm. Section 4 is devoted to the evaluation of the results of the proposed algorithm. The result analysis is presented in Section 5. In the final section, we conclude and give some perspectives.

AIRCRAFT LANDING SCHEDULING PROBLEM DEFINITION

Problem definition

The management of air traffic in the space defined by the TMA (Traffic Management Advisor) is provided by the air traffic controllers from the airport control tower. In general the TMA is a space with a cylindrical shape and the runway is placed in the center of its base. Each aircraft entering the TMA through the predefined points, named points of entry, and flying until a holding position that defined by radio-navigation equipment, named VOR (Very high frequency Omni Range). When the aircraft is vertical VOR equipment, it becomes ready to land and expects a landing clearance from the control tower when the runway becomes free.

In general the air traffic controllers use the FCFS method; the first arrived on the holding point is the first receiving the landing clearance when the runway becomes free and other constraints required by the national and international norms are satisfied such as the minimum separation distance between two aircrafts imposed by ICAO (International Civil Aviation Organization).

In this work we considered a cylindrical TMA space with a single runway.

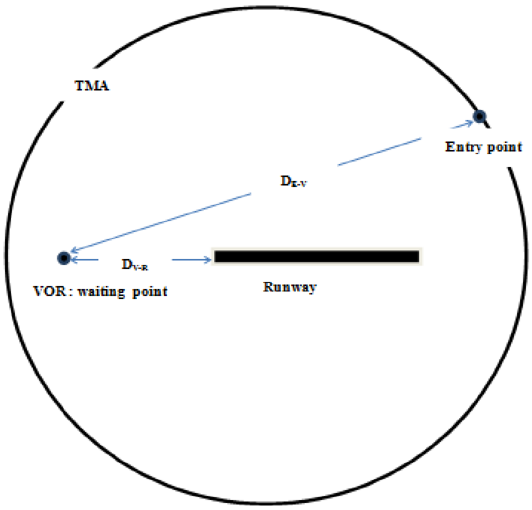

Figure-1. Description of the landing procedure.

D_{E-V}: The distance between the entry point and holding point of the TMA.
D_{V-R}: The slant distance between the holding point and runway threshold.
D_{min}: The minimum separation distance between two aircrafts.

Each aircraft is characterized by:
V_{mini}: The minimum aircraft landing speed, it depends on the aircraft type and weather conditions.
V_{maxi}: The maximum aircraft landing speed, it depends on the aircraft type and weather conditions.
V_i: The real aircraft landing speed, it is considered constant during the landing procedure.
$T_{TMAEntryi}$: The aircraft entry time to TMA.
$T_{landingStarti}$: The aircraft start landing time
$T_{theoricalLandingi}$: The aircraft theoretical landing time

$$T_{theoricalLandingi} = T_{TMAEntryi} - (D_{E-V} + D_{V-R})/V_i \quad (1)$$

$T_{realLandingi}$: The real aircraft landing time
$T_{latesti}$: The latest landing time of aircraft

$$T_{latesti} = T_{TMAEntryi} + (D_{E-V}+D_{V-R})/V_{mini} \quad (2)$$

$T_{earliesti}$: The earliest landing time of aircraft

$$T_{earliesti} = T_{TMAEntryi} + (D_{E-V}+D_{V-R})/V_{maxi} \quad (3)$$

In this paper we formulate the ALS problem under a mathematical model and we consider the landing of each aircraft as a periodic real time task having the following temporal constraints:

T_i: The period of aircraft landing task.
R_i: The time of activation of aircraft landing task

$$R_i = T_{TMAEntryi} + (D_{E-V} / V_i) \quad (4)$$

D_i: The deadline of aircraft landing task

$$D_i = D_{V-R} / V_{mini} \quad (5)$$

C_i: The maximum time of aircraft landing task

$$C_i = D_{V-R} / V_i \quad (6)$$

The aircraft landing task is:

- Blocked: when the aircraft is flying between the entry point and the waiting point.
- Ready: the aircraft is flying over the waiting point.
- Executed: the aircraft is flying between the waiting point and the runway.
- Terminated: the aircraft cleared the runway.

So each aircraft landing task has a state index ($State_i$) at a given time.

For each aircraft we define the landing cost by:

$$Xi = T_{realLandingi} - T_{theoricalLandingi} \quad (7)$$

The ALS problem studied in this paper is formulated as the following problem:

$$Minimize\ (X_{total} = \sum_{i=1}^{n} Xi) \quad (8)$$

Under constraints:

$$Di \leq Ci$$
$$\sum_{i=1}^{n} \left(\frac{Di}{Ti}\right) \leq 1$$
$$V_{min} \leq V_i \leq V_{max}$$
$$T_{earliest} \leq T_{theoricalLanding} \leq T_{latest}$$

In equation (8), X_{total} is the total -landing cost of a sequence composed by n aircrafts.

The equations (9) and (10) present the feasibility conditions of Deadline Monotonic (DM) algorithm.

Related Work

The ALS problem presents a key problem for optimization of the air traffic management. It was the subject of several researches work. In this subsection, we briefly review the previous work and categorize them as of three types: (i) FCFS, (ii) mathematical optimisation methods and (iii) meta-heuristic approaches.

FCFS or First-Come-First-Served strategy is the most commonly used approach to solve ALS problem. It schedules the landing sequence of aircrafts in the order that they enter the TMA space. There are two advantages of the FCFS method. It is easy to implement when satisfying the constraints such as the minimum separation requirements between two successive aircrafts. Also, it minimizes the standard deviation of time delays. But this method requires some verification of feasibility conditions.

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As FCFS seldom leads to the optimal schedule, many approaches based on the optimisation algorithms have been proposed to get the optimal solution of the ALS problem. Proposed a linear programming based tree search to solve the problem with optimal manner. Their algorithm was reported to obtain best solutions but the computational cost is rather high. Also (Yu, S., *et al* 2011 and Boysen, N., *et al* 2011) used the linear programming method and they treated the ALS problem as a job scheduling problem. Since the linear programming algorithms have been shown to be good for finding the optimal solutions, but they generate the high computational cost.

Alternative solutions based on meta-heuristics approach have been proposed to execute the ALS problem in a more efficient way. For example; (Tavakkoli-Moghaddan, R., *et al* 2012 and Hu, X.B. *et al* 2008) applied genetic algorithm (GA) with constrained position shifting (CPS) to the ALS problem, also Hu *et al.* [5-6] proposed one of optimal solution of ALS problem using several meta-heuristics, such as GA.

In this contribution, we propose another alternative solution, based on Deadline Monotonic (DM) algorithm. It is one of the most popular real-time scheduling algorithms.

PRESENTATION OF THE PROPOSED METHOD

A real time scheduling is a description of the execution manner of a set of tasks. This manner must respect the temporal constraints and constraints dependency of each task. Real time tasks are the basic entities of a real time scheduling. They are periodic, sporadic or aperiodic. Also, they may be dependent or independent. Each task has some temporal constraints such as period, deadline, execution time and activation time. If the process of scheduling doesn't respect these constraints, the real time system will fall.

There are many real-time scheduling algorithms such as (Zaffalon, L. 2007):

Rate Monotonic algorithm (RM): it was proposed by Liu and Layland. It is one of the most popular real-time scheduling algorithms and it is a preemptive, dynamic and fixed priority algorithm where the priority of a task is inversely proportional to its period, a task of a small period has a high priority, if two tasks have a same period, then the priority is assigned in a random manner. There are two advantages of RM algorithm. It's easy to implement this algorithm and it is optimal for deadline on request task. But we can't schedule aperiodic, sporadic and dependent tasks using it.

Deadline Monotonic (DM): Same as RM, it is a pre-emptive, dynamic and fixed priority algorithm, except that the priority of a task is inversely proportional to its deadline or term. DM algorithm offers the same advantages and disadvantages as RM algorithm.

Earliest Deadline First (EDF): it is pre-emptive, dynamic and variable priority. The priority is granted to the task which has the term or deadline time is the closest. EDF is characterized by two advantages; (i) the rate of use of CPU can reach 100% for the set of tasks deadlines on requests (ii) it offers less dead-time compared to RM and DM, but EDF presents difficulties to implement and priority inversion problem can be generated.

Least Laxity First (LLF): It is pre-emptive, dynamic and variable priority algorithm. The priority of a task at a given moment is inversely proportional to its laxity. LLF is optimal for a single CPU and better than EDF for multi-processors architecture and it has the same disadvantages as EDF algorithm.

We note that each real-time scheduling has its own scheduling policy, its feasibility conditions, its advantages, its limitations and its application context. In this work we use the Deadline Monotonic algorithm to propose a solution of Aircrafts Landing Scheduling problem.

Our approach allows us to give the optimal solution of Aircrafts Landing Scheduling problem. It has the following objectives:

- Minimize the gap between the theoretical execution time and real execution time of each aircraft landing operation.
- Minimize the remaining fuel costs of all aircrafts to be landed by meeting their most economic target landing times at preferred speed.
- Ensuring air traffic safety in accordance with international regulations.

The main steps of the proposed approach are shown as follows (Chougdali, S., *et al* 2015):

Step 1: Initialize a set of the aircraft that flying inside the Traffic Management Advisor (TMA) at a given time.

Step 2: Eliminate the aircrafts that had completed their landing.

Step 3: Check the DM feasibility conditions as a real-time scheduling algorithm.

Step 4: Schedule landing aircrafts operation according to the Deadline Monotonic scheduling strategy, and calculate the landing cost of each aircraft.

Step 5: Determine the landing global cost of a sequence of aircrafts.

Algorithm (pseudo code):
Input:

Q $Q_0=\{A_1, A_2, A_3,\ldots, A_n\}$:	Aircraft set that flying in the TMA.
V V_{mini}, V_{maxi}, V_i, $T_{TMAEntryi}$, T_i, $State_i$:	Input data of each aircraft as shown in section 2
$D_{E\text{-}V}$:	The distance between the entry point and holding point of the TMA.
D $D_{V\text{-}R}$:	The slant distance between the holding point and runway threshold.
D D_{min}:	The minimum separation distance between two aircrafts.

Output:

$(T_{realLanding1},\ldots,T_{realLindingn})$:	The real landing time for each aircraft.
(($(X_1, X_2, \ldots, X_n)$:	The landing cost for each aircraft.
X X_{total}:	The global landing cost of aircrafts sequence.

Step 1:
Set t= t_c // t_c is a current time.
Initialize the landed aircraft sequence
Q_0= {A1, A2, A3… An}, from data set.
// we use the XML file to organize and save the input data of each aircraft.

Calculate for each aircraft: $T_{theoricalLandingi}$, $T_{latesti}$, $T_{earliesti}$, R_i, D_i and C_i.
Determine the number of aircrafts that are flying inside TMA.

Step 2:
Eliminate the aircrafts that had completed their landing.

for every Ai in Q_0
repeat
{
if (State$_i$= Terminated)
{
NAT ++ // Number of aircraft that landed.
$X_i := T_{realLandingi} - T_{theoricalLandingi}$
$X_{total} := X_{total} + X_i$
}
else
{
insert $\mathbf{A_i}$ in the $\mathbf{Q_1}$
NANT ++ // Number of aircraft that not yet landed.
}
}

Step 3, Step 4 and Step 5:
Check the DM feasibility conditions as a real-time scheduling algorithm.
for every **Ai** in $\mathbf{Q_1}$
repeat
{
S := S + (D_i / T_i) // S is a variable that initialized to 0.
}
if (S <= 1) // the feasibility condition is checked, we can start landing aircraft scheduling
{
if (NAT < NA)
{
j = 0
while (State$_j$= Terminated and j<= NANT)
{
NAT++
Delete A_j from Q1
j ++
NANT –
}
if (j < NAT)
{
Sort the set Q1 in ascending order of D_i
for every Ai in Q1
repeat
{
if (State$_i$ = Blocked)
{
if$((t_c - T_{TMAEntryi}) * V_i >= D_{E-V})$)
{
State$_i$= Ready
$R_i := t_c$
}
}
else
{
if (State$_i$ = Ready)
{
State$_i$= Executed
Tread.sleep (D_{min} / V_i)
}
else
{
if (State$_i$ = Executed)
{
if $((t_c - T_{landingStarti}) * V_i >= D_{V-R})$
{
State$_i$ = Terminated
$T_{realLandingi} = t_c$
$X_i := T_{realLandingi} - T_{theoricalLandingi}$
$X_{total} := X_{total} + X_i$
}}}}}}
else the end of algorithm
}
else the feasibility condition of DM is not checked we can't apply this algorithm
}

EXPERIMENTS

The performance of our approach, we opted for a comparison of the proposed approach performance with those of FCFS method. We note the FCFS (First Come First Served) is the most popular solution of Aircraft Landing Scheduling problem. So both methods are implemented with Java using Real-Time Specification for Java (RTSJ) and they run on a Computer of 2.3 GHz CPU.

Parameter of selection

Two parameters may affect the performance of the proposed approach, they are: the number of aircraft that are flying inside the TMA and the standard deviation of the speeds of aircraft sequence.

To investigate the effects of the number of aircraft that will land, we schedule with our approach and with FCFS method a sequence of 5, 10, 20, 100 and 150 aircrafts. The global landing costs of both methods were illustrated in Figure-2. In this part we keep the same value of standard deviation of the speeds of aircraft sequence (σspeed= 0.000289).

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In the second part, we investigate the effect of the standard deviation of the speeds. We further set the number of aircrafts to 50 and varied the values of σ speed. Figure 3 illustrated the results of this part.

Comparative results

To evaluate the feasibility and efficiency of our approach, we compared it with FCFS method (First Come First Served); this is the most used method to solve the Aircraft Landing Scheduling problem. Both methods aim to find an optimal landing schedule.

Two comparative experiments have been carried out on the benchmark set to illustrate the performance of the proposed method. The Comparative study between our approach and existing algorithms such as FCFS method is based on calculation of the global landing cost. The results are presented in the Tables 1-2.

First experiment

We fixed the standard deviation of the speeds to σ speed = 0.000289 m.ms-1 and we scheduled the different sequences with the different number of aircraft. The comparative results were obtained by executing the algorithms of both methods for 10 independent executions, and averaging over the achieved results.

Table-1. Comparative experiment; Results of FCFS are compared to our method with fixed value of number of standard deviation of speeds.

σ_{speed} = 0.000289 m.ms-1		
Number of Aircraft	**X_{total} with proposed method (*106ms)**	**X_{total} with FCFS method(*106ms)**
5	0.875	0.723
10	3.123	3.875
20	4.822	4.991
50	10.577	15.209
100	13.233	54.674
150	11.564	102.345

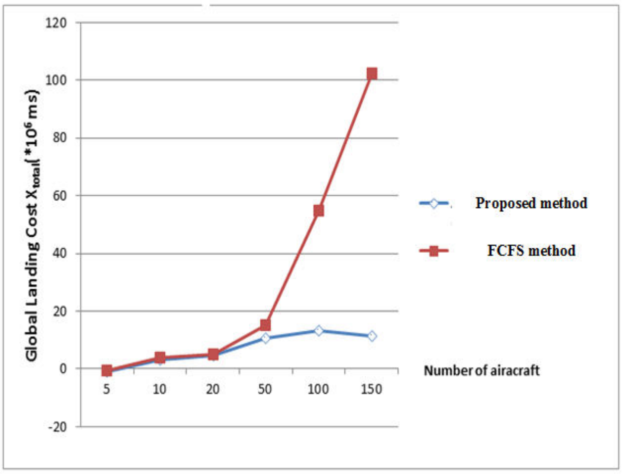

Figure-2. Experiment results of the effect of the number of aircraft. The σ_{speed} is set to 0.000289 $m.ms^{-1}$.

The number of aircraft has a significant effect. We find that for a sequence of less than 20 aircraft, both methods have almost the same performance but if the number of aircraft increase, our approach offers a minimum global landing cost compared to FCFS method.

Second experiment

In this part, we tried to explore the effect of standard deviation of speeds. So we set the number of aircraft to value 50 and we scheduled 5 sequences of aircraft with different values of standard deviation. As in the first experiment, the comparative results were obtained by executing the algorithms of both methods for 10 independent runs, and averaging over the achieved results.

Table-2. Comparative experiment; Results of FCFS are compared to our method with fixed value of number of aircraft.

Number of aircraft = 50		
σ_{speed} m.ms-1	**X_{total} with proposed method (*106ms)**	**X_{total} with FCFS method (*106ms)**
0.000289	10.577	15.209
0.000291	14.013	13.015
0.000298	15.322	50.231
0.000304	16.345	72.156
0.000315	34.546	102.012

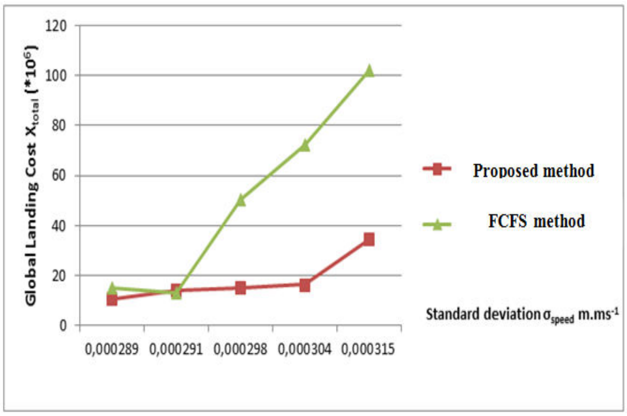

Figure-3. Experiment results of the effect of the standard deviation, Number of aircraft n=50.

The landing speed of each aircraft can affect the performance of our approach, we not the performance increase with standard deviation of speeds.

We proposed a new approach that offers the optimal solution of Aircraft Landing Scheduling problem; ALS problem is considered a complex problem (NP-hard problem). Experiments results show the performance of our approach compared to FCFS method, especially if we have a high number of aircraft and standard deviation of speeds value.

We note that for a sequence of 150 aircrafts the global landing cost obtained by our approach is the tenth of the global landing cost offered by FCFS method. Also, in the second part of experiment we find that the proposed method efficient if we have a sequence of aircraft with dispersed speed values. Knowing that air traffic is growing in the world and aircraft performances are varied, so we find that our proposed method is efficient compared to FCFS method.

Our approach allows checking the Deadline Monotonic feasibility by checking the necessary and sufficient conditions of this real-time scheduling algorithm. Also it ensures standards of aviation safety such as; it verifying the minimum distance between two required by air traffic management rules.

The proposed solution based on Deadline Monotonic as a real-time scheduling algorithm involves more aircraft deviation compared to FCFS method. So it gives a lot of flexibility to air traffic controllers to manage landing aircraft optimally.

CONCLUSION AND PERSPECTIVES

In this paper, we investigated the single runway Aircraft Landing Scheduling problem. A new approach based on Deadline Monotonic algorithm. Our approach presents high performances compared by FCFS method as one of most popular solution of Aircraft Landing Scheduling problem. The work starts by mathematical modeling that has been conducted to formulate the ALS problem as mathematical global landing cost function to optimize. Each aircraft landing operation is considered as a real-time task, that is characterized by a period Ti, a deadline Di, a maximum time of execution Ci and a time of activation Ri. The idea consists to apply the Deadline Monotonic algorithm as a real-time scheduling algorithm to solve the ALS problem in a more efficient way. Our approach achieved better solution compared to FCFS method, especially when we schedule the landing of aircraft sequence with high number of aircraft or high standard deviation of aircraft speeds. Furthermore, the proposed method can be adapted to multi runway Aircraft Landing Scheduling problem.

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