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Research Article/Araştırma Makalesi

A Mixed Integer Linear Program Model to Minimize both Arrival and Departure Delays for Single Runway Airport

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Abstract

Airports play an important role for air transportation industry. Using airport facilities effectively such as runways provide opportunities to decrease delays and increase the runway capacities. Otherwise, delays cause more congestion and reduce the capacities. To handle this problem, we present two mixed integer linear models to minimize total delay for combined arrival and departure operations in a single runway. The first model does not allow to change aircraft runway sequence whereas the second model allows to change aircraft runway sequence within the delay limits. The separation time between aircraft pair changes according to wake-vortex effects and operation types. When we compare the first and second model, the results demonstrate that total delay decreases in the second model.

1. Introduction

Air transportation network has a significant impact on international trade. Air transport is a growth market more than 60% growth over the last ten years (Airbus Global Market Forecast, 2018: 6). As the air traffic number increases rapidly, airport capacities are insufficient to meet this demand. Consequently, congestions occur in terminal maneuver areas (TMA) and airports. In order to cope with this congestion and reduce the aircraft delays, Careful sequencing and scheduling can decrease long separation time therefore creating opportunities for new arrival and departure operations. While determining the runway scheduling, aircraft separation constraints are also taken into consideration. The separation times must be applied to aircraft pairs to prevent wake vortices and to obtain suitable arrival and departure scheduling that can help to reduce the delays significantly.

Runway scheduling problems search to obtain effective aircraft schedules for one or multiple runways. To solve this problem, not only exact both also heuristic algorithms have been presented (Bennell et al. 2011: 116) a broad survey of operations research methods is explained such as, branch and bound, heuristics, dynamic programming and metaheuristics that have been used to schedule aircraft landing and departures. (Bayen et al., 2004: 2761), (Brentnall, 2006: 963)

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and (Balakrishnan and Chandran, 2006: 3) present models using dynamic programming, (Brinton 1992: 268), (Abela et al: , 1993: 72), (Ernst et al:, 1999: 230), (Beasley et al., 2001:484) propose models using branch-and-bound/cut algorithms. (Bianco et al., 1999: 48), (Hansen, 2004: 446), (Capri and Ignaccolo, 2004: 346) and (Hu and Chen, 2005: 190) present a wide spectrum of heuristics and metaheuristics.

2. Problem Description

In this section, we present two mixed integer linear models for runway scheduling problem. Both arrival and departure operations take place on the same runway for the two models. Consider set of flights I and each flight has its own performance category type (t_i), flight status (p_i) and scheduled operation time (g_i). All parameters are sorted in ascending order which means if $i_1, i_2 \in I$ then $i_1 < i_2$ implies $g_{i_1} < g_{i_2}$. This order also gives the initial runway operation sequence. The required separation time ($ST_{s_1 s_2 v_1 v_2}$) between aircraft pairs should be maintained. These values change according to aircraft pair's flight statuses and performance categories. The minimum separation times that are implemented in this paper are specified in Table 1. Aircraft can use runway after scheduled operation time within the limits. This situation causes an aircraft delay (w_i). That should be lower than ten minutes. Delays are used to find a suitable timetable of runway operation. Two types of models are presented to evaluate the total delays. The first model aims to minimize total aircraft delay without changing the initial runway operation sequence obtained by scheduled operation time with an ascending order whereas the second model allows to change initial runway operation sequence to minimize total delay.

Table 1. Minimum separation times (second) (Sherali et al. 2010: 1050).

Leading/Following	Heavy	Large	Small
Arrival-Departure case			
Heavy	40	40	40
Large	35	35	35
Small	30	30	30
Leading/Following	Heavy	Large	Small
Arrival-Arrival case			
Heavy	99	133	196
Large	74	107	131
Small	74	80	98
Leading/Following	Heavy	Large	Small
Departure-Departure case			
Heavy	60	90	120
Large	60	60	90
Small	60	60	60
Leading/Following	Heavy	Large	Small
Departure-Arrival case			
Heavy	50	53	65
Large	50	53	65
Small	50	53	65

Complete mathematical model of MILP and explanation of all expressions are presented below.

Sets

I set of aircraft $i, i_2 \in I$

S set of flight status $s, s2 \in S$

V set of aircraft performance category $v, v_2 \in V$

Parameters

M= big enough number

g_i= scheduled runway operation time of aircraft *i*

t_i = performance category of aircraft *i*

p_i= flight status of aircraft *i*

$ST_{s_1 s_2 v_1 v_2}$ = separation time between aircraft pair for flight status s_1 and s_2 with aircraft performance category v_1 and v_2

Scaler

M= big number enough

Variables

q_i= actual runway operation time of aircraft *i*

w_i = delay of aircraft *i*

$e_{i_1 i_2}$= 0-1 variable that is 1 if aircraft i_2 use the runway before aircraft i_1; otherwise, it is zero

Mathematical Formulation

$$\min \sum_i w_i \quad (1)$$

Such that

$$q_i = g_i + w_i \ \ \forall i \quad (2)$$

$$w_i \leq 600 \ \ \forall i \quad (3)$$

$$q_{i_2} - q_{i_1} \geq ST_{s_1 s_2 v_1 v_2} - e(i_1, i_2) \cdot M \quad (4)$$

$$\forall \ i_1, i_2, s_1, s_2, v_1, v_2 \ | i_1 \neq i_2, s_1 = p(i_1), s_2 = p(i_2), v_1 = t(i_1), v_2 = t(i_2)$$

$$q_{i_1} - q_{i_2} \geq ST_{s_2 s_1 2 v_1} - (1 - e(i_1, i_2)) \cdot M \quad (5)$$

$$\forall \ i_1, i_2, s_1, s_2, v_1, v_2 \ | i_1 \neq i_2, s_1 = p(i_1), s_2 = p(i_2), v_1 = t(i_1), v_2 = t(i_2)$$

$$q_{i_1} < \ q_{i_2} \ \ \forall \ i_1, i_2, | i_1 < i_2, \quad (6)$$

The objective function (1) aims to minimize total delay. Constraint (2) calculates the actual time of arrival, Constraint (3) limits the delays with 600 seconds for each aircraft. Constraint (4) and (5) ensure the runway operation times of aircraft by controlling the separation times between each aircraft pair. Constraint (6) guarantees that runway operation times are obtained according to initial scheduled runway operation sequence for the first model. Constraint (1), (2), (3), (4) and (5) are used for second model. All equations and constraints are used in the first model.

3. Results

The proposed two models are compared for the generic airport that include 15-35 aircraft per hour. We aim to minimize the total arrival delay. For each traffic flow rate, ten different scenarios are tested. The solutions and CPU times obtained from the all scenarios are given in Tables. 2-7. GAMS/CPLEX solver is chosen to solve the scenarios. In all tests, a computer with a memory value of 16 GB with 2.3 GHz Intel Core i7 processor is used.

Table 2. Average delays per aircraft for runway operations with 15 aircraft

Scenarios	First Model (min.)	CPU Time (sec.)	Second Model (min.)	CPU Time (sec.)
1	0,18	3,27	0,18	4,08
2	0,24	3,07	0,15	3,98
3	0,31	4,28	0,13	4,41
4	0,09	3,86	0,09	4,77
5	0,26	3,87	0,25	4,50
6	0,21	3,40	0,21	3,50
7	0,19	3,52	0,15	3,80
8	0,13	5,20	0,13	5,75
9	0,04	5,35	0,04	6,31
10	0,55	3,78	0,55	4,74
Average	0,22	3,96	0,19	4,58

Table 3. Average delays per aircraft for runway operations with 20 aircraft

Scenarios	First Model (min.)	CPU Time (sec.)	Second Model (min.)	CPU Time (sec.)
1	0,19	2,79	0,19	3,60
2	0,45	5,17	0,37	6,08
3	0,40	8,79	0,32	8,92
4	0,14	2,68	0,14	3,59
5	0,56	3,38	0,42	4,01
6	0,61	4,00	0,38	4,10
7	0,99	4,68	0,73	4,96
8	0,26	1,81	0,23	2,36
9	0,11	3,64	0,11	4,60
10	0,46	3,15	0,39	4,11
Average	0,42	4,01	0,33	4,63

Table 4. Average delays per aircraft for runway operations with 25 aircraft

Scenarios	First Model (min.)	CPU Time (sec.)	Second Model (min.)	CPU Time (sec.)
1	0,63	5,84	0,49	6,65
2	0,23	4,56	0,20	5,47
3	0,58	5,88	0,56	6,01
4	0,10	2,96	0,10	3,87
5	0,80	5,76	0,60	6,39
6	1,04	8,27	0,71	8,37
7	0,60	10,40	0,50	10,68
8	0,39	6,42	0,30	6,97
9	0,13	5,65	0,13	6,61
10	0,23	4,11	0,21	5,07
Average	0,47	5,99	0,38	6,61

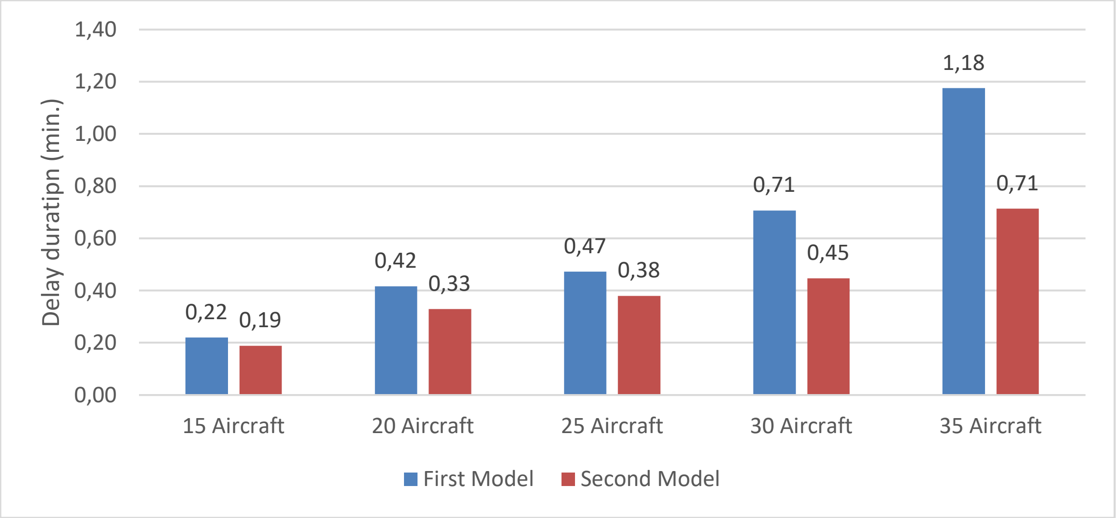
Table 5. Average delays per aircraft for runway operations with 30 aircraft

Scenarios	First Model (min.)	CPU Time (sec.)	Second Model (min.)	CPU Time (sec.)
1	0,44	5,64	0,29	6,45
2	0,50	5,28	0,37	6,19
3	1,52	4,15	0,86	4,28
4	1,21	2,66	0,74	3,57
5	1,31	5,10	0,59	5,73
6	0,24	4,23	0,16	4,33
7	0,31	6,18	0,27	6,46
8	0,72	6,14	0,53	6,69
9	0,41	6,88	0,37	7,84
10	0,41	1,68	0,29	2,64
Average	0,71	4,79	0,45	5,42

Table 6. Average delays per aircraft for runway operations with 35 aircraft

Scenarios	First Model (min.)	CPU Time (sec.)	Second Model (min.)	CPU Time (sec.)
1	1,47	15,93	0,85	16,74
2	0,74	8,75	0,71	9,66
3	0,84	5,85	0,52	5,98
4	1,20	20,99	0,84	21,90
5	0,39	9,39	0,31	10,02
6	1,34	25,54	0,99	25,64
7	1,15	12,17	0,74	12,45
8	1,82	9,42	0,82	9,97
9	0,77	4,01	0,54	4,97
10	2,03	6,71	0,81	7,67
Average	1,18	11,88	0,71	12,50

Figure 1. Average delays per aircraft for each traffic numbers



The results indicate that average delay per aircraft increases when the traffic number increases. The average delay for the first model is higher than the second model for each traffic flow rate. As a result, the second model presents a better performance than the first model. The average delays for the scenario with 15 aircraft, 20 aircraft, 25 aircraft, 30 aircraft and 35 aircraft decrease approximately 17.4%, 21.4%, 19.14%, 36.61% and 39.83% when we compare the two models results.

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