OPTIMAL SCHEDULING OF AIRPORT'S RUNWAY OPERATIONS
A CASE STUDY IN TAN SON NHAT INTERNATIONAL AIRPORT

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Abstract. Based on the necessity of expanding airplane capacity of Tan Son Nhat International Airport (ICAO: VVTS) which is going to increase the density of aircraft runway traffic, this paper would like to focus on the scheduling of aircraft landing and take-off on multiple runways at VVTS. The objective is to give an optimal sequence of runway operations which minimize the total deviation from the preferred operation time of all flight in a short period of time, while all safety constrains are calculated simultaneously. The gate assignment problem, which is similar to the machine job reservation scheduling without slack, will also be included in this thesis; the aim is to maximize the number of aircraft that can be assigned to fixed gate on time with the highest profit.

Keywords: Runway scheduling, Mix Integer Programming, Gate Assignment Scheduling, Reservation without Slack.

1. INTRODUCTION

Since the very beginning of civilization, humans always have a desire to conquer time and space. Transportation helps people be together. It has been a hundred and three years since the day Wright brothers made their historic flight at Kitty Hawk in 1903. Their invention have created a new industry so-called Aviation Industry. In the nascent days, Aviation only serve military purposes. The innovation of modern technology has associated with Aviation Industry, satisfy the needs of civil traveling and cargo transporting with high safety and efficiency, and therefore, becomes an important factor in the economy. In this Paper, We study the problem of landing and take-off planes as well as the Gate assignment problem at Tan Son Nhat International Airport (ICAO: VVTS), which is the largest international airport in Vietnam in term of both area and passengers handled. For this airport, the flight plan is given at the beginning of the day, the job of air traffic controller (ATC) is determine the operation time for each flight such that each flight operates within a predetermined operation time windows while all the safety constraint are strictly obeyed.

The time window is bounded by an earliest and a latest operation time of each flight. The earliest time represents the earliest a flight can operate: for the landing operation, it is the time that the aircraft reach the destination with its maximum speed, for the take-off operation, it is the time that a flight ready to departure. The latest time represents the latest time a plane can operate: for the landing operation, it is the time that the aircraft reach the destination with its most fuel efficient air speed, for the take-off operation, it is the time that the aircraft have to departure such that another aircraft can land. Each plane also has a most economical speed so call cruise speed, base on this speed and the distance between two destinations, the target operation time is calculated.

For the sake of safety, the minimum separation between two consecutive flights is applied. This separation is based on the time to eliminate the wake vortices, which created when a flight operates. The wake vortices is different for different aircraft categories. For the take-off operation, the separation is time while the separation of the landing operations is usually by distance. The distance of each flight of landing operations can also convert to time

The problem of assigning to each plane an operation time such that each operates within its time window and as close as its target operation time is called Airport Runway Scheduling, which include Aircraft Take-off Problem (ATP) and Aircraft Landing Problem (ALP). There are various research interested in ATP and ALP and many approach for solving it. Dear and Sherif (1976) interested in the ALP problem, they introduced a very famous concept of Constraint Position Shipping (CPS), follow their study Psaraftis (1978-1980) developed algorithms using dynamic programing, his objective is minimize the maximum landing time and total delay. Bianco et al. (1999) considered the ALP similar to the scheduling of a single machine problem with release times and sequence dependent processing times, he proposed two heuristic algorithms with objective is to minimize the makespan. Linear programming (LP) is being employed by Beasley et al. (2000) to design branch-and-bound algorithms-based tree search approaches for both single- and multiple-runway problems.

Using a constraint satisfaction approach for the ATP and the ILOG solver, van Leeuwen et al. (2002) map flights onto activities, and model the taxiways, runways, and exit points of an airport as resources, the model is applied to real data from Prague airport, however the model fail to find a solution with the large problem size. To improve this, van Leeuwen and van Hanxleden Houwert (2003) introduce constraint relaxation techniques to overcome the highly complex or conflicting requirements that have to be considered in practice. Anagnostakis and Clarke (2002, 2003) research in two-stage heuristic algorithm of ATP, they used integer programming model with the objective of maximize the throughput. Balakrishnan and Chandran (2006), Balakrishnan and Chandran (2007) introduce a dynamic programming algorithm for the ATP. multiple runways can also be extended.

In this paper, we also focus on the Airport Gate Assignment Problem (AGAP). There are more than 40 research about AGAP since 1974. The objectives of this problem depended on the point of view. In the point of view of airport owner the objectives are to minimize the number of ungated flight [16], maximize the utilization of available gate [15] and minimize the flight delay due to the gate conflicts [15,24], In the point of airlines, the goal is to maximize the passenger satisfaction by minimize the traveling distance of passengers and minimize the travelling distance from runway to gate [18,2].

2. AIRCRAFT TAKE-OFF AND LANDING MODEL

2.1 Notations

Indices and parameter:

I: the set of flights

R: the number of runways.

E_i: The earliest operation times for flight i ($i \in I$)

T_i: the preferred operation times for flight i ($i \in I$)

L_i: the latest operation times for flight i ($i \in I$)

U: the set of pairs (*i*, *j*) of flight which it is not sure that flight i operates before flight j or flight j operates before flight j, U can be defined by [(i,j)| $i,j \in I$, i # j ; $E_j \le E_i \le L_j$ or $E_j \le L_i \le L_j$ or $E_i \le E_j \le L_i$ or $E_i \le L_j \le L_i$].

V: the set of pairs (*i*, *j*) of flight for which flight *i* definitely operates before flight j but the separation time between i and j do not automatically satisfied, V can be defined by [(i,j)| $i,j \in I$, i # j ; $L_i < E_j$ and $L_i+S_{ij} > E_j$].

W: the set of pairs (*i*, *j*) of flight for which flight *i* definitely operates before flight j but the separation time between i and j is automatically satisfied, V can be defined by [(i,j)| $i,j \in I$, i # j ; $L_i < E_j$ and $L_i+S_{ij} \le E_j$].

S_{ij}: the minimize separation times between any to operations i and j if i and j operates on the same runway (flight i operates before flight j). $i,j \in I$; i # j

f_{ij}: the minimize separation times between any to operations i and j if i and j operates on different runway(flight i operates before flight j). $i,j \in I$; i # j

g_i: the penalty cost per unit of time of flight i if i operate before the target time T_i (i belong to I)

h_i: the penalty cost per unit of time of flight i if i operate after the target time T_i (i belong to I)

Decision variables:

x_i: The operation times for flight i ($i \in I$)

a_i: how soon flight i operates before the target time T_i ($i \in I$)

b_i: how soon flight i operates after the target time T_i ($i \in I$)

$d_{i,j}$: binary variable, equal 1 if flight i operates before flight j, 0 otherwise ($i,j \in I$, i # j)

y_{ir}: binary variable, equal 1 if flight i operates on runway r, 0 otherwise ($i \in I$, $r \in R$)

$z_{i,j}$: binary variable, equal 1 if flight i and flight j operate on the same runway, 0 otherwise ($i,j \in I$, i # j)

2.2 Problem formulation

Minimize the total deviation from the target time:

$$\text{Minimize} \sum_{i \in I} (a_i g_i + b_i h_i) \qquad (1)$$

Subject to:

$E_i \le x_i \le L_i \quad \forall\, i \in I$ *(2)*

$d_{ij} + d_{ji} = 1 \quad \forall\, i,j \in I$ *(3)*

$d_{ij} = 1 \quad \forall\, (i, j) \in V \cup W$ *(4)*

$a_i \ge T_i - x_i \quad \forall\, i \in I$ *(5)*

$0 \le a_i \le T_i - E_i \quad \forall\, i \in I$ *(6)*

$b_i \ge x_i - T_i \quad \forall\, i \in I$ *(7)*

$0 \le b_i \le L_i - T_i \quad \forall\, i \in I$ *(8)*

$x_i = T_i + b_i - a_i \; \forall\, i \in I$ *(9)*

$\sum_{r \in 1}^{R} y_{ir} = 1 \quad \forall\, i \in I$ *(10)*

$z_{ij} = z_{ji} \quad \forall\, i,j \in I,\, i<j$ *(11)*

$y_{ir} + y_{jr} - 1 \le z_{ij} \quad \forall\, i,j \in I, r \in R,\, i<j$ *(12)*

$x_j \ge x_i + z_{ij} S_{ij} + f_{ij}(1 - z_{ij}) \quad \forall\, (i,j) \in V$ *(13)*

$x_j \ge x_i + z_{ij} S_{ij} + f_{ij}(1 - z_{ij}) - (L_i + \max(S_{ij}, f_{ij}) - E_j) * d_{ji}$

$\forall\, (i,j) \in U$ *(14)*

$d_{ij} \in \{0,1\}, z_{ij} \in \{0,1\}, y_{ir} \in \{0,1\} \quad \forall\, i,j \in I, r \in R$

(15)

Equation (1) is the objective of this model which is minimize the total deviation from the preferred operation times (target time) of all flights.

Constraint (2) ensure that each flight will operate within its time window. constraint (3) ensure that with any pair of flight, either flight i must operate before flight j or flight j operate before flight i. Constraint (4) implies that if a pair of flight (i,j) belong to set of V or W, then flight i must operates before flight j. Constraint (5) ,(6) is the lower bound and upper bound of a_i. Constraint (7),(8) is the lower bound and upper bound of b_i. Constraint (9) relates the operations time of flight i (x_i) to the time i operate before or after the Target time. Constraint (10) ensure that each flight can only operate on one runway. Constraint (11) state that if flight i operates in the same runway with flight j, then flight j also operates in the same runway with flight i. Constraint (12) implies that if there is any runway r where y_{ir} and y_{jr} equal to one, the z_{ij} have to be forced to one also, in the other hand, If z_{ij} =0 then flight i and j can not operates in the same runway. Constraint (13),(14) ensure that for all flight i and j, if flight i land before flight j then the minimize separation time have to be satisfied. Equation (15) are required constraints

3. AIRPORT GATE ASSIGNMENT MODEL

The Airport Gate Assignment Problem is consider as a reservation without slack problem where flight is similar to job and gate is similar to machines. The objective is to maximize the flight assigned to available fixed gate with the highest weight. The flights which can not be assigned to fixed gate will be assigned to removed gate, then bus is used for passengers transportation and Truck is used to cargo transportations.

3.1 Notations

Parameter:
N: number of Flight
G: number of Gate
T: Time interval
w_{ig}: weight of flight i when assigned to gate g
y_{ig}: Binary parameter, equal to 1 if flight i can be assigned to gate j. 0 otherwise
h_{ig}: Binary parameter, equal to 1 if flight i can be assigned to any gate at time t
For each flight i:
P_i : the time flight i occupy gate
R_i: The earliest time that flight i can enter gate
D_i: The time flight i have to leave gate.
Decision variable:
x_{gi}: equal 1 if flight i is assigned to gate g, 0 otherwise

3.2 Problem formulation

$$Maximize \sum_{g=1}^{G} \sum_{i=1}^{N} w_{ig} x_{gi}$$

Subject to:

$\sum_{g=1}^{G} (x_{gi} * y_{ig}) \le 1, i = 1..N$ *(1)*

$\sum_{i=1}^{N} (x_{gi} * h_{ti}) \le 1, g = 1..G, t = 0..T$ *(2)*

The first constraint ensure that each flight can be assigned to at most one gate.

The second constraint ensure that at any time interval, one gate can be occupied by only one flight.

4. PARAMETER COMPUTATION.

In this section, we express the way we collect data and compute the parameter. All of the parameter using in this paper is computed from the real data at VVTS under the support of Civil Aviation Authority of Vietnam (CAAV).

Runway Occupancy Time (ROT):

Runway Occupancy Time is the time that each aircraft occupies the runway, ROT is measured based on an observation of 81 samples with the average of 71s. The method is described below:

- The point at which an aircraft crossed the landing threshold
- To the point at which both main and nose gear touched down
- To the point at which the aircraft is completely clear of the arrival runway (Runway Occupancy Time)

Separation time:

The separation time at VVTS is set higher than the standard of ICAO with the detail in table 1 and table 2

Table 1 Separation on different runway

S		Trailing		
		Small	Medium	Heavy
leading	Small	150	130	90
	Medium	220	150	120
	Heavy	240	188	120

Table 2 Separation on same runway

f		trailing		
		Small	Medium	Heavy
Leading	Small	30	30	30
	Medium	30	30	30
	Heavy	30	30	30

Gate Characteristic:

There are 12 fixed gate at VVTS, which include 4 gate serve domestic flight only, 7 gate serve international flight only and 1 gate serve both domestic and international flight. The detail is described in table 3.

Table 3 Gate characteristic at VVTS

Gate	1	2	3	4	5	6	7	8	9	10	11	12
Domestic	1	1	1	1	1	0	0	0	0	0	0	0
International	0	0	0	0	1	1	1	1	1	1	1	1

We also propose two algorithms to compute the $y_{i,g}$ and $h_{t,i}$ parameter.

$y_{i,g}$ computation:

Given a set of flight I and a set of gate G.

Each flight has a type of operations (international or domestic)

Set of gate is divided into two sub set:

G_k : set of gates that serve Domestic operations

G_i : set of gates that serve International operations.

Algorithms:

With $j \in I$, first j =1

Step 1: If j > n then STOP, else go to step 2

step 2: If operation of j is domestic then

{

$y_{jg} = 1 \quad j \in I, g \in G_k$

$y_{jg} = 0 \quad j \in I, g \in G_i$

j = j+1 go to step 1

}

else go to step 3

Step 3:

$y_{jg} = 0 \quad j \in I, g \in G_k$

$y_{jg} = 1 \quad j \in I, g \in G_i$

j = j+1 go to step 1

$h_{t,i}$ computation

Given the time interval t = 0..T
Given the set of flight i=1..n
Algorithm:

```
For t equal 0 to T do
    For i equal 1 to n do
        If t ≥ R_i and t < D_i then
            h_t,i = 1
        Else
            h_t,i =0
```

5. COMPUTATIONAL RESULT

A real-world data of one day operations at Tan Son Nhat International Airport (03/01/2016), which include 584 operations with the maximum 38 operations per hour was input to find the optimal solution of the model, we proposed three alternative, for each alternative, we focus on four criterion that are: Deviation from the target time of all flights, Maximize deviation of each flight, Computational Times, total profit of flight assigned to gates

The first alternative was generated base on the policy applied at VVTS. In this alternative, one runway is primary used for arrival and one runway is primary used for departure, The FCFS policy is applied, that is the flight which have the preferred operation time smallest will be operated first, similar with other flight.

In the second alternative, one runway is primary used for arrival and one runway is primary used for departure, the different between alternative one is that, the FCFS policy do not applied for this alternative.

In the third alternative, there are no primary of arrival and departure at any runway, both two runway can be used for departure and arrival and FCFS do not applied

Alternative 1 (FCFS policy)	
Deviation from the target time of all flights.	62070 (s)
Maximize deviation of each flight	660 (s)
Computational Times.	4.5 (minutes)
Total profit of flight assigned to gates.	10954
Alternative 2	
Deviation from the target time of all flights.	54962 (s)
Maximize deviation of each flight	850 (s)
Computational Times.	2.5(minutes)
Total profit of flight assigned to gates.	10923
Alternative 3	
Deviation from the target time of all flights.	41112 (s)
Maximize deviation of each flight	638 (s)
Computational Times.	8(minutes)
Total profit of flight assigned to gates.	10744

The complete run leads to three possible and not conflict alternatives (alt) with one or two out of four criteria per alternative has superior result than others. The specific analysis are:

Criteria 1 (Deviation from the target time of all flights): alt 3 has the best result (41112 seconds) since its deviation has minimum time. This criterion can save idle time for the passengers and increase the response time for unusual events. Alt 2 is the average of all three with the time of nearly 55000 seconds; alt 1 has the least optimal result. All three solutions have a large portion of gap: nearly 10000 seconds.

Criteria 2 (Maximize deviation of each flight): Similarly, alt 3 has the optimal result with the minimum deviation. It can helps tighten the flight schedule given by the program. Alt 1 has the second best solution with only exceed 22 seconds (with the total 660 s) more than alt 3. Alt 2 has a large deviation of total 850 seconds.

Criteria 3 (Computational Times): with two optimal result in criteria 1 and 2 given by alt 3, its disadvantage is the slow computational time (8 minutes), nearly 3 times slower than the best solution given by alt 1 (2.5 minutes). Alt 2 has the average time with 4.5 minutes.

Criteria 4 (Total profit of flight assigned to gates): Although alt 1 has the best result with 10954 points, the deviation between it and the other two are quite small. The different between the first and the second alternative are only 31 points (0.28%); the third alternative are 180 points (2%).

In order to rank the solution, the AHP analysis is applied, data input was collected from the Air Traffic Management Department of CAAV. From table … The rank is Alternative 3 > Alternative 1 > Alternative 2.

Due to the big size of solution, in this paper, we show a part of result of alternative 3 (table 4).

6. CONCLUSION

In this paper, we used Mix Integer Linear Programming for solving runway scheduling problem and gate assignment problem. Based on the runway policy at Tan Son Nhat International Airport, three alternatives were generated, after that, they were evaluated based on four criteria, namely, Deviation from the target time of all flights, Maximize deviation of each flight, Computational Times and Total profit of flight assigned to gates. Then, the best alternative will be selected based on the rank of them. Alternative 3, which mix departure and arrival in the same runway and do not follow FCFS is recommended to be implemented.

Theoretically, the thesis helps fill the gap in the literature that there is very few research on airport scheduling problem in Vietnam. By applying Mix Integer Linear Programming model in Tan Son Nhat International Airport, the research have shown a good results compared to the current schedule with FCFS policy.

Practically, the thesis have shown the better schedule for runway at VVTS. In comparison with the current schedule (FCFS policy), the proposed schedule yields about 34% improvement in deviation from the target time of all flights reduction.

Moreover, the research also helps reduce the computational time for runway scheduling and maximize the number of flights can assigned to gates with highest profit. At the present, the pre-sequencing at VVTS has been done manually, so it often takes a lot of time to compute and increase the workload. Thus, with the proposed model in thesis, the computational time is smaller than 10 minutes and very easy to implement with only few step to get the optimal solution, it can be a support tool for Air Traffic Controller.

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Table 4 Result Interface of Alternative 3

Flight no	requested	Scheduled	soon	late	25L/07R	25R/07L	Time EnterGate	Time Leave Gate	Gate Assigned
151	0:30	0:29:30	30	0	1	0	0:32:00	0:47:00	4
622	0:40	0:39:30	30	0	0	1	0:22:00	0:37:00	1
1424	0:40	0:38:30	90	0	1	0	0:26:00	0:36:00	2
1351	0:40	0:40:00	0	0	1	0	0:43:00	1:03:00	2
258	0:40	0:42:00	0	120	1	0	0:45:00	1:05:00	8
1412	0:50	0:48:20	100	0	1	0	0:36:00	0:46:00	5
621	0:50	0:50:30	0	30	1	0	0:53:00	1:08:00	5
375	0:50	0:50:00	0	0	0	1	0:53:00	1:13:00	7
781	0:55	0:55:00	0	0	1	0	0:58:00	1:13:00	4
7827	1:00	1:00:00	0	0	1	0	0:43:00	0:58:00	3
1362	1:00	0:58:00	120	0	0	1	0:41:00	0:56:00	1
368	1:00	1:00:30	0	30	0	1	0:43:00	0:58:00	11
624	1:00	0:57:30	150	0	1	0	1:00:00	1:15:00	6
8002	1:05	1:05:00	0	0	0	1	1:08:00	1:18:00	1
812	1:05	1:05:30	0	30	1	0	1:08:00	1:18:00	8
750	1:10	1:11:30	0	90	1	0	0:49:00	1:09:00	9

159	1:10	1:10:00	0	0	0	1	1:13:00	1:28:00	3
629	1:10	1:09:30	30	0	1	0	1:12:00	1:27:00	0
809	1:20	1:20:00	0	0	1	0	1:08:00	1:18:00	11
153	1:25	1:22:16	164	0	0	1	1:25:00	1:40:00	0
150	1:30	1:24:47	313	0	0	1	1:07:00	1:22:00	0
1813	1:30	1:29:22	38	0	0	1	1:07:00	1:27:00	2
7829	1:30	1:28:52	68	0	1	0	1:11:00	1:26:00	5
625	1:30	1:27:22	158	0	0	1	1:10:00	1:25:00	10
803	1:30	1:25:18	282	0	1	0	1:08:00	1:23:00	12
686	1:30	1:31:22	0	82	0	1	1:09:00	1:29:00	9
8050	1:30	1:23:08	412	0	1	0	1:26:00	1:36:00	5
8060	1:30	1:32:32	0	152	1	0	1:35:00	1:45:00	4
234	1:35	1:35:00	0	0	1	0	1:13:00	1:33:00	4
685	1:35	1:37:00	0	120	0	1	1:20:00	1:35:00	7
555	1:35	1:34:30	30	0	0	1	1:37:00	1:52:00	9
943	1:40	1:40:00	0	0	0	1	1:23:00	1:38:00	8
819	1:40	1:39:30	30	0	1	0	1:27:00	1:37:00	11
2322	1:40	1:42:30	0	150	0	1	1:45:00	2:00:00	6

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