AN OPTIMIZING PLANNING MODEL OF SCHEDULED TIMETABLE IN THE RUNWAY CAPACITY UTILIZATION

Sui-Ling Li
Assistant Professor,
Marine Management Department
National Penghu Institute of Technology
300, Liow-Her Road, Maa-Gong, Penghu Shiann,88042 Taiwan, R.O.C.
Fax: 886-06-9279812,Tel: 886-09-9264115-3121.
E-Mail:suiling@ms15.hinet.net
No8,Alley 41, Lane 20, Shou-Chang Street, Taoyuan,33039 Taiwan, R.O.C.

Abstract: This paper proposes a simple optimizing two-stage planning model, in order to make the best arrangement of flight take-off/landing sequence which is based on the advantageous separation time and given demand in peak one hour. The first stage is constructed the flight take-off/landing separation patterns to measure the maximum capacity. The second model is constructed the scheduled timetable delays to measure the minimum delays. The outcomes not only show that the optimizing runway capacity in peak one hour are 46 separation patterns (47 flights), but also demonstrate how to arrange the vacant rule of flight take-off/landing runway on the timetable. This paper develops the planning strategies of scheduled timetable and enhances the management of available maximum capacity to improve slot allocation.

Key words: Flight take-off/landing sequences; Scheduled timetable delay; Optimization model; Vacant rule of flight take-off/landing runway; Slot allocation

1.INTRODUCTION

Many worldwide congested airports have encountered flight delay problems because of the increasing demands for air transportation such as available take-off/landing slots during peak hours of operation. Once the scheduled timetable is not well planned and operated, it will cause the delay of flights and the loss of customers. Therefore, it is important that how to develop precisely timetable to meet the utilization of airport capacity and demands of air transportation, and decrease exist insufficient capacity problems.

Many researches (Newell, 1979; Venkatakrishnan, 1993; Rutner et al., 1997; Luo, 1997; Li et al., 2000; ICAO, 2000) have been identified that limited runway capacity is the leading reason to cause flights delay. Related approaches such as constructing new runways, improving the geometry of runways, taxiways, air traffic control facilities, and changing air traffic control procedure. Thus, modifying the take-off/landing sequence could enhance airport capacity appropriately and decrease flight delays. However, these methods either involve huge expenditures or have impact on the environment. Furthermore, these changes generally take a long time to implement. Therefore, for long term improvements, first stage is to understand how to effectively utilize an airport's limited capacity with scheduled timetable allocation of flight take-offs and landings. Meanwhile improving the ability of the airport management is the first priority but not the lower management cost. So, in order to evaluate the performance of timetable planning and to reach available maximum capacity, it is necessary to develop a planning model of scheduled timetable delays analysis.

In fact, some flight take-offs/landings timetables may not make the optimal utilization of runway capacity, which worsens congestion problems. Therefore, This paper first reviews the concept of the utilization of available maximum capacity and indicates how to allocate the sequence of flight on the timetable in order to clarify and measure the model of timetable planning. Secondly, the paper proposes two-stage mathematical models to measure and the maximum capacity and scheduled timetable delay to generate strategies of planning timetable. The first model is the optimal composition of the take-off/landing patterns on the runway, which is considered the constraints of the actual demand in peak hours and the quality of separate safety for the take-off/landing of flight. The second model is the optimal sequences of take-off/landing patterns on the timetable, which is considered the constraints of connecting flight take-off/landing separation patterns, the assignment of aircrafts on the runway, and the ideal maximum demands of take-off/landing composition. Thirdly, the two stage models are applied to aircraft separation data of Taipei airport during peak hours. Finally, this paper analyzes the suitability type of time point and aircraft amounts at each time point.

2.THE SCHEDULED TIMETABLE PLANNING OF RUNWAY CAPACITY MANAGEMENT

A suitable timetable must meet the maximum flight demands and minimum flight delays. Especially, the flight demands at peak hours are near the saturated runway capacity to reflect the service of runway. Therefore, a good timetable must consider all capacity to be effective utilizing and planning. This paper considered the concept of vacant rule for flight take-off/landing runway to allocate and evaluate timetable planning to effectively utilizing practical or maximum capacity. This concept comes from maximum utilization of runway capacity and flight take-off/landing separated patterns (Wong et al., 1997). Wong et al. proposed the minimum separation time of take-off/landing is the pre-flight departing and followed by incoming flight (=DA) among flight take-off/landing patterns.

Related research discussing how to improve airport delays and enhance the airport capacity, which are often found in operations research literature on the queuing theory (Newell, 1979; Gilbo, 1997). These studies discuss the basic relationship between capacity and delay by air traffic management. A series of aircrafts in waiting queues for take-off /landing are generated to meet the expected flight schedules and the random characteristics. If an airport does not have enough capacity to meet the demand, the result is increased delays. The relationship between the shortfall capacity and delay is nonlinear, so when the ratio of the demand to capacity approaches near one, the time of delay increases rapidly. Therefore, some researchers (Marchi, 1996) object to trying to simulate delay levels in capacity studies, arguing that the delay is non-linear and that slight errors in analysis parameters will probably cause exaggerated and inaccurate changes in calculating delays. They claimed delays are a symptom of insufficient capacity, and the quantity of the capacity is better measured by the maximum throughput per time unit.

Gilbo (1997) considered the interaction between arrivals and departures of aircrafts, speculating that the arrival/departure ratio of aircraft will have significant impact on delays. He believed that airport capacity is not fixed, but variable. However, the capacities of the arrival/departure fixes were roughly simplified as ten flights per 15 minutes. He neglected the mutual flow interaction among arrival/departure routes and the limitation of runway capacity.

Meanwhile, the number of flights passing through for the associated arrival/departure fixes were not well counted. In addition, Gilbo's model estimated the total flight delay as equal to the cumulative queue multiplied by the associated time period, all the waiting flights do not arrive/depart at the same time in every time period, and the waiting time for each aircraft is not the same. That measuring method will cause errors.

The origin of delays may come from either insufficient facility capacity or a poor schedule planning. Therefore, the scheduled timetable delays should be distinguished from the other delay so as to capture the essence of delay and propose the necessary countermeasure correctly. Therefore, this paper considers the performance measurement of timetable planning, such as the more accurate estimation of timetable delays and properly formulating the interacting behavior of the arrival/departure aircrafts. Meanwhile, this study aims to propose how to allocate the capacity of flight take-off/landing runway and evaluate timetable planning of maximum capacity. This research not only considers the satisfactory of demand feature, but also discussed on how to evaluate and enhance the performance of scheduled timetable.

3.MAXIMUM CAPACITY MEASUREMENT AND SCHEDULED TIMETABLE DELAYS MEASUREMENT

3.1 Maximum Capacity Measurement

Regarding runway utility in general, there should be no more than two aircraft on the runway at the same time. Incoming flight should have priority on the runway then departing aircraft. Departing aircraft must keep a safe distance from the pre-incoming flight. There are four important control operations as follows.

(1)Not until does the pre-incoming aircraft descend and leave the front of the runway, when controller can announce landing permission to next descending aircraft.

(2)While pre-aircraft descends to runway, then controller announces permission of next departing aircraft to enter the front of the runway to wait, not until does the pre-aircraft leave the runway, when the next aircraft will get the takeoff permission.

(3)After the pre-aircraft takes off, the controller announces permission for next the incoming aircraft to descend to the runway.

(4)It takes no more than one minute for the separation of two consecutive take-off aircraft. Therefore, by means of identifying the minimum safe-separation for the aircraft of four different takeoff/landing patterns to estimate the hour the number of aircraft permitted to takeoff/land on the runway.

Thus, under normal operating conditions runway capacity is referred to the permitted numbers of take-off/landing aircraft in a certain period of time on the existent runway facility. Because runway capacity varies in every hour within the peak time is the characteristic of maximum capacity. The saturation of takeoff/landing aircraft tends to be attained during peak one hour, when the airport operation is equivalent to the capacity. Under this definition, the assumption is for all flights could not take off or arrive earlier than scheduled, the separation time of each flight is related to the take-off/landing pattern between pre-flight and behind-flight.

There are four take-off/landing patterns: the consecutive arrival pattern (AA), the arrival-departure pattern (AD), the departure-arrival pattern (DA), and the consecutive departure pattern (DD). There exists only one exact pattern between pre-flight and behind-flight among four patterns; the other three patterns disappear at the same time. Therefore, if no consideration of the demand constraints, the maximum flight take-off/landing separation patterns at one hour must be satisfied as follows: $S_{AA} \cdot AA + S_{AD} \cdot AD + S_{DA} \cdot DA + S_{DD} \cdot DD \leq 3600$, where AA, AD, DA, and DD represent the take-off/landing separation patterns of flights, which are integer variables, and $AA, AD, DA, DD \geq 0$. $S_{AA}, S_{AD}, S_{DA}, and\ S_{DD}$ represent the separation time of corresponding take-off/landing patterns, respectively. Therefore, the efficiency of runway utilization depends on whether the actual take-off/landing of aircrafts in a specified time period is close to the theoretical capacity or not. In order to effectively utilize the runway, consideration should be given to the features of different separation times so as to make the best arrangement of flight take-off/landing sequence according to the advantageous separation time, and enhance the efficiency of runway utilization.

3.2 Measure the Scheduled Timetable Delays

Considering the shortest separation of flights will not only make the total aircraft throughput to be maximized, but will also effectively improve the efficiency of the runway utilization. On the other hand, due to the limitation of runway capacity, there exists some reasonable range of flight take-offs/landings during a specified time period. If the planned timetable demands take-offs/landings behind this range, it will lead to the scheduled timetable delays spreading to the take-off/landing operation of behind-flights. In order to avoid a scheduled timetable delay ripple, the best approach is to use the shortest separation time in arranging the take-off/landing sequence of aircrafts to achieve the best utilization of the runways, that is, setting the objective to minimize scheduled timetable delay of total aircraft through predetermined maximum capacity on first stage.

In fact, due to the limitation of runway capacity, even if airlines can make their flights obey the scheduled plan of take-off or arrival at the runway, the take-off/landing slots associated with each time point will not always suffice for the scheduled operations. Due to insufficient capacity at the previous time point cause the ensuing flights delays. Therefore, the first flight at every time point cannot always be on time as assumed in the above description. These delays caused by overloaded flight timetable may ripple all over the peak periods and are defined in this paper as the "scheduled timetable delays." These delays of course will result in increase of the effective delay. Thus, to measure the effectiveness management, the scheduled timetable delays at every time point should be taken into account.

As for the measurement of scheduled timetable delays, it is assumed that the flights scheduled at p time point must wait for take-off/landing until all flights scheduled at the p-1 time point have completed their operations. Based on this assumption, the scheduled timetable delays can be calculated by using the information of the shortest completion time of the flight operations at every time point. The shortest completion time of the flight operations is derived from the flight sequence arranged with the least flight separation. If the completion times at some time points are earlier than the time allocated in the flight timetable, there will be no scheduled timetable delays at those time points. Otherwise, there will be scheduled timetable delays. The amount of the scheduled timetable delay is equal to the difference between the expected completion time and the time timetable allocated.

The five-flight example is expressed as follows. The period time between the first time point and the next time point is set to five minutes. That is to say, only five minutes are assigned in the timetable to operate these five flights. Besides, to avoid the scheduled timetable delay, the first aircraft at the next time point must also need enough time to meet the separation requirement. Using the shortest separation time to arrange the five take-off/landing sequences, the total operation time is 4 minutes 52 seconds. The last 8 seconds left is not enough to separate the next flight. The minimum separation time between the fifth flight and the first flight at the next time point is 65 seconds. So, the first flight at the next time point will not be on time. The scheduled timetable delay at the first time point is 57 seconds (65-8=57). Mathematically, it can be expressed as follows.

$$X_1^+ = \left[\sum_{j=2}^{6} (S_{AA} \cdot AA_j + S_{AD} \cdot AD_j + S_{DA} \cdot DA_j + S_{DD} \cdot DD_j) - 300 \right]^+$$

where AA_j, AD_j, DA_j, DD_j are binary integer variables, which represent the take-off/landing separation of consecutive arrival, arrival-departure, departure-arrival, and consecutive departure patterns of flights at j[th] aircraft , and AA,AD,DA,DD$\geq$0. $S_{AA}, S_{AD}, S_{DA}, and\ S_{DD}$ represent the separation time of corresponding take-off/landing patterns, respectively.

If the scheduled timetable delay of the subsequent time point is still unable to disappear, it will continuously influence the take-off/landing time of the ensuing flights. Therefore, the scheduled timetable delay at any time point p should be formulated as Eq. (1).

$$X_p^+ \geq \left\{ X_{p-1}^+ + \left[\sum_{j=2}^{F(p)} \left(S_{AA} \cdot AA_{p,j} + S_{AD} \cdot AD_{p,j} + S_{DA} \cdot DA_{p,j} + S_{DD} \cdot DD_{p,j} \right) - T_p \right] \right.$$

$$\left. + \left(S_{AA} \cdot AA_{p+1,j} + S_{AD} \cdot AD_{p+1,j} + S_{DA} \cdot DA_{p+1,j} + S_{DD} \cdot DD_{p+1,j} \right) \right\}^+ \quad \forall p \tag{1}$$

where $X_p^+ = \begin{cases} X_p & X_p \geq 0 \\ 0 & X_p < 0 \end{cases}$ 。

X_p^+ is determined from the least separation time of take-off/landing sequence at the time point p, which will not influence the best take-off/landing sequence at the time point p+1, and its value influences only the delays of flights scheduled at the ensuing time point. The total scheduled timetable delay of flights at the time point p+1 is $X_p^+ \cdot F(p+1)$ If the time period analyzed includes M time points, the accumulated scheduled timetable delay of M time points is stated as Eq. (2).

$$\sum_{p=1}^{M-1} X_p^+ \cdot F(p+1) + \left(S_{AA} \cdot AA_{p+1,j} + S_{AD} \cdot AD_{p+1,j} + S_{DA} \cdot DA_{p+1,j} + S_{DD} \cdot DD_{p+1,j} \right) \tag{2}$$

The scheduled timetable delay causes the same amount of delay for each flight at following time point. Therefore, it seems that the best flight sequence is nothing to do with the flight sequence of the previous time point.

4.TWO STAGE OPTIMIZATION MODEL

4.1 Notation and Description

The notations used in the following sections are defined as follows.

AA, AD, DA, DD : Represents the consecutive arrival pattern, the arrival-departure pattern, the departure-arrival pattern, and the consecutive departure pattern.

$S_{AA}, S_{AD}, S_{DA}, S_{DD}$: Represents the separation time between flights of consecutive arrival patterns, arrival-departure patterns, departure-arrival patterns, and consecutive departure patterns.

aa^l, ad^l, da^l, dd^l: Represents the low bound numbers of consecutive arrival pattern, the arrival-departure pattern, the departure-arrival pattern, and the consecutive departure pattern.

$AA_{p,j}$: Represents the binary variable of consecutive arrival pattern, the pre-flight incoming and followed by incoming flight j at the p time point. If at the p time point the pre-flight of the j flight arrives and is followed by the j flight incoming, then $AA_{p,j}=1$, otherwise, $AA_{p,j}=0$.

$AD_{p,j}$: Represents the binary variable of arrival-departure pattern, the pre-flight incoming and followed by departing flight j at the p time point. If at the p time point the pre-flight of the j flight arrives and is followed by the j flight departing, then $AD_{p,j}=1$, otherwise, $AD_{p,j}=0$.

$DA_{p,j}$: Represents the binary variable of departure-arrival pattern, the pre-flight departing and followed by arriving flight j at the p time point. If at the p time point the pre-flight of the j aircraft departs and is followed by the j flight arriving, then $DA_{p,j}=1$, otherwise, $DA_{p,j}=0$.

$DD_{p,j}$: Represents the binary variable of consecutive departure pattern, the pre-flight departing and followed by departing flight j at the p time point. If at the p time point the pre-flight of the j flight departs and is followed by the j flight departing, then $DD_{p,j}=1$, otherwise, $DD_{p,j}=0$.

n: Number of aircrafts.

M: Number of the time points in the scheduled flight timetable.

T_p: Duration of the p time point.

$F(p)$: Number of flights scheduled at p time point.

A_0, D_0: The total scheduled arrivals at peak one hour, and the total scheduled departures at peak one hour, respectively.

X_p^+: The scheduled timetable delay at the p time point.

4.2 Model Assumptions and Formulation

4.2.1 Model limitation and assumption

Due to the runway is always a bottleneck for airport capacity, taxiways and gates only indirectly influence the scheduled timetable. These subsystems of ground operation are not included in the analysis of this paper. This paper assumes that the maximum capacity is equal to real demand of take-off/landing, because in reality there is hardly surplus slot in peak hours. The estimated parameters of the separation between take-off and landing are assumed under continuous and stable flight flow within one hour under good weather when control works are not under pressure. So this paper is assumed every scheduled flight can normally operate at airport. There are no traffic handling delays, aircraft turnaround delays, aircraft technical delays, air traffic control and weather delays (Shaw, 1987) to cause flight delays and scheduled timetable delays. Only due to a poor schedule planning will cause scheduled timetable delays to happen.

4.2.2 First stage model

Thus, the analysis of compositions and sequences consists of two stages. The first stage model is to maximized four patterns of flight take-off and landing, which has taken into account the flight separation and demand constraints. The objective Eq. is the maximum aircraft in peak one hour as (3) shows; Eq. (4) is the total time of the four-type takeoff/landing for aircraft occupying runway, which must be less than 60 minutes (3600 seconds). Eq. (5) to (8) represent the restrictions on the frequency of four actual takeoff/landing patterns. Eq. (9) represents the constraint of the absolution about figure differences between arrival-departure and departure-arrival pattern, which must be less than one aircraft. Eq. (10) is the total of consecutive arrival pattern and departure-arrival pattern, which must be larger than the scheduled requirement of arrival aircraft in one hour. Eq. (11) represents the total frequency of arrival-departure pattern and consecutive departure pattern, which must be larger than the scheduled requirement of departure aircraft in one hour. Eq. (12) represents integer variable.

$$MAX \quad AA + AD + DA + DD \tag{3}$$

$$ST. \quad S_{AA} \cdot AA + S_{AD} \cdot AD + S_{DA} \cdot DA + S_{DD} \cdot DD \le 3600 \tag{4}$$

$$AA \ge aa^l \tag{5}$$

$$AD \ge ad^l \tag{6}$$

$$DA \ge da^l \tag{7}$$

$$DD \ge dd^l \tag{8}$$

$$|AD - DA| \le 1 \tag{9}$$

$$AA + DA \ge A_0 \tag{10}$$

$$AD + DD \ge D_0 \tag{11}$$

$$AA, AD, DA, DD \ge 0, \text{ are integer variables} \tag{12}$$

4.2.3 Second stage model

The second stage model is to minimize flight delay, which constraints consider the separation of flight take-off/landing, the flight connection, the flight relation between take-off and landing in the sequences, and given maximum take-off/landing patterns form the outcomes of first stage model. This planning timetable model of the objective function (13) sums up the accumulated p stage scheduled timetable delay and the separation between the last aircraft of p stage and first aircraft of next p+1 stage. The constraint (14) represents the formula to calculate scheduled timetable delay, and its value must be non-negative. Inequality (15) shows the scheduled timetable delay at each time period should be greater than or equal to 0. The constraint (16)-(19) represents respectively the accumulated take-off/landing patterns at each time point, it must equal to the outcomes of optimizing take-off/landing patterns at the first stage model. Inequalities (20) and (21), represent the connections between any two flights. Eq. (22) states the assignment of flight to take off/land from/into runway.

$$Min \sum_{p=1}^{M-1} X_P^+ \cdot F(p+1) + \left(S_{AA} \cdot AA_{p+1,j} + S_{AD} \cdot AD_{p+1,j} + S_{DA} \cdot DA_{p+1,j} + S_{DD} \cdot DD_{p+1,j}\right) \tag{13}$$

$S.T.$

$$X_p^+ \geq \left\{ X_{p-1}^+ + \left[\sum_{j=2}^{F(p)} \left(S_{AA} \cdot AA_{p,j} + S_{AD} \cdot AD_{p,j} + S_{DA} \cdot DA_{p,j} + S_{DD} \cdot DD_{p,j} \right) - T_p \right] + \left(S_{AA} \cdot AA_{p+1,j} + S_{AD} \cdot AD_{p+1,j} + S_{DA} \cdot DA_{p+1,j} + S_{DD} \cdot DD_{p+1,j} \right) \right\} \quad \forall p \tag{14}$$

$$X_p^+ \geq 0 \tag{15}$$

$$\sum_{j=1}^{F(p)} AA_{p,j} = AA \tag{16}$$

$$\sum_{j=1}^{F(p)} AD_{p,j} = AD \tag{17}$$

$$\sum_{j=1}^{F(p)} DA_{p,j} = DA \tag{18}$$

$$\sum_{j=1}^{F(p)} DD_{p,j} = DD \tag{19}$$

$$AD_{p,j} + AA_{p,j} \leq 1 - \left(AD_{p,j-1} + DD_{p,j-1} \right) \ \forall\ p, j \tag{20}$$

$$DA_{p,j} + DD_{p,j} \leq 1 - \left(AA_{p,j-1} + DA_{p,j-1} \right) \ \forall\ p, j \tag{21}$$

$$AA_{p,j}, AD_{p,j}, DA_{p,j}, DD_{p,j} \quad \text{are binary integer variables} \tag{22}$$

5.MODEL APPLICATION: THE CASE OF TAIPEI AIRPORT

5.1 The Analysis of the Safe Separation of Aircraft

First of all, this study utilizes the flight takeoff/landing data of Taipei airport from March 1995 to July 1996. In order to obtain the representative time-separation parameter of runway capacity in peak hours, the peak hour is divided into clusters of 15 minutes, 30 minutes and 60 minutes. By classifying the previous three situations and the takeoff/landing patterns into consecutive departure, consecutive arrival, arrival-departure, departure-arrival to analyze the frequency, and time separation of aircraft and choose the representative and viable data in peak one hour.

The 15-minute cluster, which are divided into 68 units from the operative time of 17 hours (06:00-23:00), are chosen the maximum-aircraft capacity and the time separation of aircraft shouldn't last more than 2 minutes. The 30-minute cluster, which are divided into 34 units from operative time of 17 hours, are chosen the maximum-aircraft capacity and the time separation of aircraft shouldn't last more than 2 minutes. Obviously the workload of this cluster is heavier and is not lasting. Therefore, choosing lasting 30 minutes in peak one hour, is better than 60 minutes for the acceptance of controller, because this workload is less heavy. In this situation, chose sample relatively decreases, and obviously chosen cluster is less than 15 minutes. The 60-minute cluster, which are divided into 17 unit from the operative time of 17 hours, are chosen the maximum-aircraft capacity and time separation of aircraft shouldn't last more than 2 minutes. Obviously the workload of this cluster is heavier and is not lasting. Therefore, choosing lasting 60 minutes of peak hour operation, obviously the separation is dependent on the sustenance of controller, because of safety consideration, controller can't sustain too long workload period for a consecutive one hour of actual operation.

From the sampling and statistic process of the three previous situations, we got the outcome shown in Table 1. The 15 minutes situation, which the time separation of aircraft is least, but the deviation of sample is biggest. It means that the 15 minutes will lead to lower estimation of time separation standard and the big deviation. It represents that the time separation is not enough for safe operation controllers are under heavy-working pressure. Only the chosen 60-minute is best: although their average separation is biggest, deviation is smallest. This means that 60-minute shows the controllers are in good state, this situation is safe. Therefore, this paper will propose the 60-minute to be the separation parameter.

Table 1. The separation of aircraft (minute)

Pattern	15-minute	30-minute	60-minute
Consecutive arrival	(1.14,0.785,1064)	(1.26,0.753, 805)	(1.52,0.658,133)
Consecutive departure	(1.02,0.612,1434)	(1.14,0.591,1034)	(1.22,0.577,152)
Arrival-departure	(1.41,0.561,2789)	(1.47,0.501,2061)	(1.48,0.500,417)
Departure-arrival	(0.93,0.575,2825)	(1.03,0.574,2086)	(1.08,0.559,417)

(means standard error, sample)aircraft arrival time means aircraft descending runway time; aircraft departure time means aircraft takeoff runway time, not the time of pass through a point on the runway

5.2 The outcome of estimating peak one hour capacity analysis

Applying the flight separation of Table 1 to Eq. (4). The lower bound of actual flight take-off/landing patterns at peak hours during March 1995 to July 1996 state as follows. The consecutive landing pattern (ad^l) is 3, consecutive take-off (dd^l) is 3, landing and take-off (ad^l) is 16, and take-off and landing (da^l) is 16. Separately 3,16,16,3 are put into Eq. (5) to (8). The maximum aircraft of arrival/departure (A_0 / D_0) on the schedule timetable of peak one hour (09:00-10:00) during March 1995 to July 1996 is 22/21. 22,21 are put into Eq. (10) and (11). The outcome of the maximum capacity is 47 aircraft (=46 patterns). There are four optimization compositions, which are AA=3,AD=18, DA=19, DD=6; AA=3,AD=19, DA=20, DD=4; AA=3,AD=19,DA=19,DD=5; AA=3,AD=20,DA=20, DD=3.

5.3 The Scheduled Timetable Analysis

5.3.1 Planning aircraft number at each time point

The 5-minute, 10-minute, 15-minute, 20-minute, and 30-minute time point are possible classification of airlines. If the probability of distributed emergence for four parameters of take-off/landing separation pattern are equal and assumed the separation of first aircraft is not counted. Table 2 shows the probability of the scheduled timetable delays for the different time point. Thus, Table 2 shows arranging 4 aircraft (3 patterns) of take-off/landing separation during one period at 5-minute time point, and there are 16 ($=2^4$) situations (AAAA, AAAD, AADA, AADD, ADAA, ADAD, ADDA, ADDD, DAAA, DAAD, DADA, DADD, DDAA, DDAD, DDDA, DDDD) not to exceed 5 minutes of operation time. But arranging.5 aircraft(4 patterns) to take-off/landing during one period at 5-minute time point, there are 24 situations (AAAAA, AAAAD, AAADA, AAADD, AADAA, AADAD, AADDA, AADDD, ADAAA, ADAAD, ADADA, ADADD, ADAA, ADDAD, ADDDA, ADDDD, DAAAA, DAAAD, DAADA, DAADD, DADAA, DADAD, ADDA, DADDD, DDAAA, DDAAD, DDADA, DDADD, DDDAA, DDDAD, DDDDA, DDDDD). There are 32 (=2^5) situations to exceed 5 minutes of operation time, only 8 situations (DDDDA, DDADA, DADDA, ADDDA, DDADD, DADDD, DDDAD, DDDDD) not to exceed 5 minutes of operation time. The delay probability of arranging 5 aircraft at 5-minute time point period is 0.75(=24/32).Furthermore, the 5-minute time point is easier to produce scheduled timetable delays than others. There are 12 periods in one hour for 5-minute time point must be arranged average 3-4 aircraft. If aircraft number exceeds aircraft at anyone period, the delay probabilities are from 0.75 to 1. If arranged 4 aircraft will not produce the scheduled timetable delays, only the timetable will be wasted 47 maximum aircraft not to be finished throughputs. There are the same scheduled time delays to happen for 10-minute, 15-minute,20-minute and 30-minute time point separately over 7-8, 11-12, 15-16, and 23-24 aircraft at each period of time point.

Table 2. The Probability of Scheduled Timetable Delays at Each Time Point

Time point Aircraft	5-minute	10-minute	15-minute	20-minute	30-minute	Time point Aircraft	5-minute	10-minute	15-minute	20-minute	30-minute
4	0	0	0	0	0	14	1	1	1	0	0
5	0.75	0	0	0	0	15	1	1	1	0.008	0
6	1	0	0	0	0	16	1	1	1	0.385	0
7	1	0	0	0	0	17	1	1	1	0.982	0
8	1	0.060	0	0	0	18	1	1	1	1	0
9	1	0.898	0	0	0	19	1	1	1	1	0
10	1	1	0	0	0	20	1	1	1	1	0
11	1	1	0.001	0	0	21	1	1	1	1	0.001
12	1	1	0.192	0	0	22	1	1	1	1	0.012
13	1	1	0.958	0	0	23	1	1	1	1	0.339

5.3.2 Time point and aircraft planning of timetable

From one outcome of first model, which is AA=3, AD=19, DA=20, DD=3, is applied to the second model to compare the scheduled timetable delays of different time point and the deviation of aircraft shows Table 3-7. The deviation of aircraft and scheduled timetable delays in each time point are described as follows. As the samples of Table 3-7, the least scheduled timetable delays of samples' aircraft arrangement are near 3-4 aircraft at each 5-minute time point, 7-8 aircraft at each 10-minute time point, 11-12 aircraft at each 15-minute time point, 15-16 aircraft at each 20-minute time point, and 23-24 aircraft at each 30-minute time point. The least total schedule timetable delays of Table 4-7 samples are near one minute, such as the delay of sample 14 (8,7,8,7,8,9) in Table 4 is 1.75 minutes, sample 2 (11,12,11,13) and sample 11 (12,11,11,13) in Table 5 are 1.62 minutes, sample 2 (15,15,17) in Table 6 is 1.62 minutes, sample 2 (23,24) in Table 7 is 0.80 minutes. Only the total scheduled timetable delays of Table 3 is large, which is exceed 6 minutes as above samples. In addition, Table 8 shows the delay ranking of time point is 30-minute$\succ$20-minute $\succ$15-minute $\succ$10-minute $\succ$5-minute.Therefore, the short operation time at each period is hard to utilize the advantage of shortest separation. If aircraft arrangement at each period are very deviation for the every time point, which the aircraft numbers of previous-periods are bigger than behind-periods, it will cause ripple delay effects of the behind-periods and worsen total delays. The figures of delays on Table 3-7 also shows the balance of aircraft amounts for take-off/landing pattern at each time point, a suitable length of time point are least delay. These findings should better improve heavy delays of the current practice timetable in Taipei Airport.

Table 3. The Total Scheduled Timetable Delays of Samples at 5-Minute Time Point (minute)

Sample	Aircraft number at each time point	Aircraft standard error	Delays	Sample	Aircraft number at each time point	Aircraft standard error	Delays
1	3,3,3,3,4,4,4,4,4,5,5,5	0.79	31.53	16	2,2,2,3,4,4,4,4,5,5,6,6	1.44	70.25
2	3,3,3,3,3,4,4,4,5,5,5,5	0.90	48.83	17	1,2,2,3,4,4,4,4,5,6,6,6	1.68	86.52
3	3,3,4,4,4,4,4,4,4,4,4,5	0.51	14.95	18	2,2,3,3,4,4,4,5,5,5,5,5	1.16	79.48
4	2,4,4,4,4,4,4,4,4,4,4,5	0.67	20.25	19	2,2,3,3,3,4,5,5,5,5,5,5	1.24	108.28
5	2,3,3,4,4,4,4,4,4,5,5,5	0.90	34.73	20	2,2,3,3,3,3,5,5,5,5,5,6	1.38	112.95
6	2,2,4,4,4,4,4,4,4,5,5,5	1.00	38.47	21	3,4,4,4,4,4,4,4,4,4,4,4	0.29	17.43
7	2,3,3,3,4,4,4,4,5,5,5,5	1.00	51.63	22	3,3,3,3,3,3,3,3,3,3,8,9	2.15	55.42
8	1,4,4,4,4,4,4,4,4,4,5,5	1.00	29.15	23	3,3,3,3,3,3,3,4,4,5,6,7	1.38	42.82
9	2,3,4,4,4,4,4,4,4,4,5,5	0.79	22.92	24	3,3,3,3,3,3,3,4,5,5,5,7	1.31	54.43
10	1,3,4,4,4,4,4,4,4,5,5,5	1.08	38.47	25	3,3,3,3,4,4,4,4,4,4,4,7	1.08	12.18
11	3,3,3,4,4,4,4,4,4,4,5,5	0.67	16.78	26	3,3,3,4,4,4,4,4,4,4,4,6	0.79	10.83
12	1,3,3,3,3,4,4,5,5,5,5,5	1.27	58.22	27	3,3,3,3,3,4,4,4,4,4,4,8	1.38	11.13
13	2,2,3,3,3,4,4,5,5,5,5,6	1.31	82.87	28	3,3,3,3,3,3,4,4,4,4,4,9	1.68	10.48
14	2,2,2,3,4,4,4,5,5,5,5,6	1.38	86.33	29	3,3,3,3,3,3,3,4,4,4,7,7	1.51	36.05
15	1,2,2,3,4,4,4,5,5,5,6,6	1.62	98.53	30	4,3,4,3,4,3,4,3,4,3,4,8	1.38	6.47

Table 4. The Total Scheduled Timetable Delays of Samples at 10-Minute Time Point (minute)

Sample	Aircraft number at each time point	Aircraft standard error	Delays	Sample	Aircraft number at each time point	Aircraft standard error	Delays
1	6,8,8,8,8,9	0.98	12.68	16	8,8,8,8,8,7	0.41	16.88
2	6,7,8,8,9,9	1.17	19.12	17	9,9,9,9,9,2	2.86	142.55
3	5,7,7,7,10,11	2.23	33.25	18	7,8,8,8,8,8	0.41	10.67
4	7,7,8,8,8,9	0.75	6.82	19	9,8,8,8,7,7	0.75	53.80
5	5,7,8,8,8,11	1.94	10.18	20	8,7,9,7,9,7	0.98	23.70
6	7,7,7,8,9,9	0.98	15.25	21	6,7,7,8,9,10	1.47	18.12
7	7,7,7,8,8,10	1.17	4.43	22	6,7,7,9,9,9	1.33	39.70
8	7,7,7,7,9,10	1.33	15.18	23	5,7,8,9,9,9	1.60	44.77
9	6,7,7,8,9,10	1.47	18.12	24	5,8,8,8,8,10	1.60	14.57
10	5,6,7,8,9,12	2.48	23.38	25	5,7,8,8,9,10	1.72	22.25
11	6,7,7,7,10,10	1.72	29.73	26	11,8,7,7,7,7	1.60	99.72
12	7,7,7,7,7,12	2.04	5.13	27	9,8,8,8,8,6	0.98	61.12
13	7,7,7,7,8,11	1.60	4.18	28	12,7,7,7,7,7	2.04	114.97
14	8,7,8,7,8,9	0.75	1.75	29	10,8,8,7,7,7	1.17	83.23
15	9,7,8,7,8,8	0.75	13.55	30	5,7,7,9,9,10	1.83	43.62

Table 5. The Total Scheduled Timetable Delays of Samples at 15-Minute Time Point (minute)

Sample	Aircraft number at each time point	Aircraft standard error	Delays	Sample	Aircraft number at each time point	Aircraft standard error	Delays
1	11,11,11,14	1.50	2.70	16	12,12,10,13	1.26	5.62
2	11,12,11,13	0.96	1.62	17	12,11,10,14	1.71	2.97
3	11,11,12,13	0.96	1.88	18	10,14,11,12	1.71	50.08
4	11,12,12,12	0.50	5.73	19	12,12,10,13	1.26	5.62
5	12,12,12,11	0.50	14.35	20	12,11,13,11	0.96	17.12
6	10,10,10,17	3.50	6.62	21	14,11,11,11	1.50	57.03
7	10,11,11,15	2.22	4.05	22	11,14,11,11	1.50	46.95
8	10,11,12,14	1.71	3.10	23	11,11,14,11	1.50	30.12
9	10,12,12,13	1.26	18.92	24	13,11,12,11	0.96	29.20
10	12,11,12,12	0.50	2.30	25	13,11,11,12	0.96	20.08
11	12,11,11,13	0.96	1.62	26	12,13,11,11	0.96	28.80
12	12,10,12,13	1.26	3.22	27	14,10,11,12	1.71	30.90
13	13,12,11,11	0.96	43.40	28	14,10,12,11	1.26	40.02
14	12,12,11,12	0.50	5.23	29	13,10,12,12	1.26	15.67
15	11,13,11,12	0.96	20.58	30	13,12,10,12	1.26	31.60

Table 6. The Total Scheduled Timetable Delays of Samples at 20-Minute Time Point (minute)

Sample	Aircraft number at each time point	Aircraft standard error	Delays	Sample	Aircraft number at each time point	Aircraft standard error	Delays
1	16,15,16	0.58	2.97	16	13,15,19	3.06	4.18
2	15,15,17	1.15	1.62	17	17,16,14	1.53	48.72
3	17,15,15	1.15	32.00	18	14,17,16	1.53	23.92
4	16,16,15	0.58	12.88	19	15,17,15	1.15	21.05
5	20,20,7	7.51	182.62	20	16,14,17	1.53	3.62
6	19,9,19	5.77	39.83	21	16,17,14	1.53	29.38
7	18,11,18	4.04	32.80	22	17,14,15	1.53	19.87
8	17,13,17	2.31	19.57	23	15,14,17	1.53	2.83
9	13,17,17	2.31	26.32	24	18,10,19	4.93	31.32
10	14,16,17	1.53	4.42	25	18,15,14	2.08	67.62
11	17,14,16	1.53	19.87	26	18,14,15	2.08	48.55
12	18,13,16	2.52	36.07	27	14,15,18	2.08	2.83
13	16,13,18	2.52	4.83	28	15,14,18	2.08	2.83
14	13,16,18	2.52	5.77	29	15,16,16	0.58	2.93
15	19,15,13	3.06	103.27	30	19,18,10	4.93	141.42

Table 7. The Total Scheduled Timetable Delays of Samples at 30-minute time point (minute)

Sample	Aircraft number at each time point	Aircraft standard error	Delays	Sample	Aircraft number at each time point	Aircraft standard error	Delays
1	24,23	0.71	9.95	16	37,10	19.09	170.92
2	23,24	0.71	0.80	17	38,9	20.51	166.05
3	25,22	2.12	36.32	18	39,8	21.92	157.42
4	22,25	2.12	1.88	19	40,7	23.33	147.28
5	26,21	3.54	63.05	20	41,6	24.75	133.65
6	27,20	4.95	84.42	21	42,5	26.16	118.92
7	28,19	6.36	105.88	22	43,4	27.58	99.62
8	29,18	7.78	122.25	23	44,3	28.99	79.45
9	30,17	9.19	138.45	24	45,2	30.41	56.25
10	31,16	10.61	149.82	25	46,1	31.82	30.02
11	32,15	12.02	160.75	26	17,30	9.19	8.23
12	33,14	13.44	167.12	27	18,29	7.78	7.02
13	34,13	14.85	172.78	28	19,28	6.36	5.67
14	35,12	16.26	174.15	29	20,27	4.95	4.45
15	36,11	17.68	159.70	30	21,26	3.54	3.10

Table 8. The Variation for Different Capacity Compositions of Scheduled Timetable (minute)

Compositions	5-minute	10-minute	15-minute	20-minute	30-minute
AA=3,AD=18,DA=19,DD=6	5.67	1.78	1.35	1.22	0.67
AA=3,AD=19,DA=20,DD=4	6.47	1.75	1.62	1.62	0.80
AA=3,AD=19,DA=19,DD=5	5.67	1.48	1.35	1.35	0.53
AA=3,AD=20,DA=20,DD=3	6.47	1.78	1.48	1.48	0.67

6.RESULT ANALYSIS AND DISCUSSION

The first stage model of Taipei airport case, this maximum outcome (47 aircraft) is better than the schedules 42 aircraft at peak one hour. The surplus capacity is 5 aircraft. Thought more demand of scheduled flights at peak one hour will cause the scheduled timetable delays heavier. If it is suitably managed the flight take-off/landing sequence, aircraft number between previous and behind time point period, it will still avoid the total scheduled timetable delays to be worst and get the object of maximum aircraft and minimum delays.

In the second stage model, our finding for the length of time point is not to short, the scheduled timetable delays of 5-minute time point are easily larger than others. It will cause the vacant rule of flight take-off/landing runway are not arranged scheduled flights and waste the cost of time slot. If timetable manager don't constrain aircraft numbers in each time point, only constrain the total demand in one hour. These scheduled strategies will cause total scheduled timetable delays to be large. It clearly shows that the variation of aircraft numbers in the previous-behind time point will cause scheduled timetable delays very large diversities. Even the same standard errors of aircraft, which are different the aircraft numbers in the previous-behind time point, are still different delay effects. Therefore, planning scheduled timetable not only arranges the shortest separation time to enhance runway utilization, but also suitably applies the vacant rule of flight between the last aircraft of previous period and the first aircraft of behind period.

The arrangement of the shortest separation pattern is "DA" to connect between previous and behind time-point period. Thus, while the aircraft numbers in some periods are less than the average aircraft of period, the "AA" pattern can arrange this period will not produce the scheduled timetable delays heavy. otherwise, will cause the total scheduled timetable delays to be heavy.

7.CONCLUSION

In this study, the maximum capacity and minimum scheduled delays model with the related constraints are formulated and analyzed. In addition, the length of time point, take-off/landing patterns and the sequence of scheduled flights are analyzed. To sum up, major findings from the study are briefly stated as follows.

(1) Results from the research sample show the optimizing aircraft in peak one hour to be 47 aircraft. There are four optimization compositions, which are AA=3,AD=18, DA=19, DD=6;AA=3,AD=19,DA=20,DD=4;AA=3,AD=19,DA=19,DD=5; AA=3,AD=20,DA=20, DD=3.This finding indicate if the suitable arrangement of timetable planning can be making, there are still more surplus capacities to be developed in peak hour.
(2) The figures of delays on Table 3-7 also shows the balance of aircraft amounts for take-off/landing pattern at each time point, a suitable length of time point are least delay. These findings should better improve heavy delays of the current practice timetable in Taipei Airport.
(3) The finding of outcome is that arranging aircraft sequence doesn't suitably achieve the vacant rule of flight take-off/landing, the optimizing scheduled timetable delays will be larger. That is to say, the balance of aircraft amounts for take-off/landing pattern at each time point is the key of timetable planning.
(4) The second stage model not only can assist to plan minimum scheduled timetable delays of the scheduled timetable, but also arrange the suitable time point, aircraft and sequence. It is important that arranging strategy of timetable must not exceed 1 aircraft for period deviation and aircraft at each time point must not exceed average aircraft of time point period. By arranging the more aircraft numbers into the last period, or the behind-periods to absorb delays. Above strategies can decrease the total scheduled timetable delays in one hour.
(5) Among previous designing time-points, 5-minute time point is worse delays of time point. But the controllers could be flexible and easy to assign the flight to take-off /arrival in the shorter length of time point under air traffic control situations. Therefore, airport authorities and airlines must be concerned between timetable planning and air traffic control problems.
(6) The second model can apply to the current scheduled timetable to analyze strategy. This study only analyzes the scheduled timetable to plan optimizing utilization of runway capacity, furthermore can exploit different aircraft separation of analysis to improve capacity management of slot allocation for airport authorities.
(7) The origin of delays may come from either insufficient facility capacity or a poor schedule

planning. Therefore, the scheduled timetable delays should be distinguished from the other delay so as to capture the essence of delay and propose the necessary countermeasure correctly.

(8) The basic assumption of optimization model is that flights must follow exactly the originally scheduled departure/arrival time. It dose not meet the actual flight operations and cause below-estimating the flight delays. In the future, searching and considering the other delays so as to make the developed model more realistic and reliable.

REFERENCES

Gilbo, E. P. (1997) Optimizing airport capacity utilization in air traffic flow management subject to constraints at arrival and departure Fixes, **IEEE Transactions on control systems technology, Vol. 5, No. 5**,.490-503.

ICAO (2000) Study looks at possible improvements to capacity management, **The Magazine of the International Civil Aviation Organization, Vol. 55, No. 9,** 19-21.

Li, S.L., Wong, J. T. (2000) An optimization model for flight technical delay analysis, **Academic Proceedings 15th R.O.C. Transportation Institute (Taiwan)**, 265-274.

Luo, Songjun and Yu, Gang (1997) On the airline schedule perturbation problem caused by the ground delay program. **Transportation Science, Vol. 31, No. 4,** 298-311.

Marchi, Richard (1996) New development in ATC technology and airport capacity. **Seminar on air hub development - challenges and strategies of modern airport. Taiwan**, 89-100.

Newell, G. F.(1979) Airport capacity and delays. **Transportation Science, Vol. 13, No. 3,** 201-241.

Rutner, S. M., Mundy, R. A., and Whitaker, Jonathan(1997) Alternatives for reducing delays at the United States' busiest airport, **Transportation Journal, Spring,**18-25.

Shaw, Stephen (1987) **Airline marketing and management,** Bath Press, 164-165.

Venkatakrishnan, C. S., Arnold Barnett, and Odoni,.A. R.(1993) Landing at airport: describing and increasing airport capacity. **Transportation Science, Vol. 27, No. 3,** 211-227.

Wong, J. T., Han, F. W. and Li, S.L.(1997) Runway capacity estimation for Sung Shan domestic airport, **Journal of the Chinese Institute of Transportation(Taiwan), Vol. 10, No. 4,** 113-126.