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Some Strategies of Enhancing Airline Schedule Reliability and Airfield Operation Performance for Congested Airports

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Abstract

This study is based on the safe and efficiency purpose to develop and review appropriate measuring runway and apron capacity to meet the airline users and mixed traffic. This research mainly considers the key factors of airlines restrictions, aircraft size, turnaround times, and buffer times, and apron operation condition. The mathematical programming model is applied with to estimate the apron capacity of apron user policy and airline schedule reliability in hot summer peak hour for Taiwan Taoyuan international airport. The outcomes show that the policy of apron usage and schedule slot allocation will influence the airfield capacity and apron services. This study also finds three issues, which are the congestion problems of departure/arrival flights at the same time point for the neighbor aprons, the backward/forward shift length of time slot shifts at time points of current timetable, tower and airport operators need to set standard of shift backward/forward times to enhance the airfield operation efficiency. The regression estimator estimates the total minimum connection time of 20 flights at one peak hour must cost 409 minutes taxiing time. Average taxiing time of each flight cost 20.04 minutes, per flight adding one kilometer /hour of taxiing speed, the total minimum connection time can decrease 6 minutes. If the flights used the runway 5L to take off/land, the total minimum connection time in one hour can save 34 minutes.

Keywords: Airline schedule reliability, Airfield operation performance, Mathematical programming, Runway and apron capacity

1. Introduction

Flight delays frequently occur at congested airport, especially on runways, due to heavy flight demands and capacity shortages. The time slot issues of congested airports, worldwide, lack effective solutions. Therefore, air traffic control

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(ATC) units must assess their ability to handle these issues using a highly effective and systematized management approach. Related approaches to be considered include constructing new runways, improving the geometry arrangement of runways, taxiways, ATC facilities, and changing ATC procedure to modify the take-off/landing sequence. Such measure could appropriately increase airport capacity and decrease flight delays. However, these methods either involve significant expenditure or have an impact on the environment. Furthermore, these changes generally require a long time to implement. Therefore, in addition to long-term improvements, it is important to understand how to optimally utilize an airport's limited capacity for flight take-offs and landings in the short term in accordance with scheduled timetable allocation. Such optimal utilization is the most effective means of enhancing timetable management and should be the first priority for improving airport management to eliminate flight delays at the lowest possible cost. Practically, the timetable reflects the time sequence of the requirement of scheduled flights. This approach may not achieve optimal utilization and allocations of taking-off/landing flights to improve airport capacity. To avoid wastage of airfield facilities and resources, which would result in inefficiency utilization of capacity, the airfield capacity usage needs to be clarified and explored studies. The managing approaches of measuring aircraft taxiing time, taking-off/landing sequence and separation patterns, decision-making time of taxi in/taxi out, and flight pushback rules are developing to enhance airline schedules reliability and operation performance in the airfield.

The maximum number of aircraft operations accommodated by the gate-apron group component, the gate capacity always must be considered gate-apron aircraft parking arrangement, aircraft ground service and passenger loading characteristics, number and mix of the gates and stands by category, gate occupancy time per flight, and scheduling practices of the airlines. Therefore, this study will catch the apron of airline occupancy time type of aircraft, whether the flight is a turnaround, or through flight, the volume of deplaning and enplaning passengers per flight, the amount of baggage and mail per flight, the productivity of aircraft servicing operation and efficiency of apron personnel, and exclusive use of one airline or class of aircraft and availability to all users. The gate capacity can consider the factors to formulation such as the number of different gate can accommodate aircraft of different class, the mean each gate occupancy time of aircraft of different class, and fraction of aircraft different class demanding service. Aircraft delays of airside operations often occur at the bottleneck of the runway and apron. This study considers not only considers the time of landing/take-off flight distribution between the ramps, taxiways, and runways at the airfield but also the waiting time of landing/take-off flight connectivity between ramps, taxiways and runways. Adjusting crowded time points moving forward or backward reduces flight delays. This study wants to study the gate schedule timetable as not being an airfield delay constraint where the traffic flows freely, and assumes no technical flight delays. It discusses how to improve time points of flight distribution for timetable planning considering only connection time and airfield capacity problem between ramps, taxiways and runways.

all airlines and airports have increased their focus on energy conservation and carbon reduction in accordance with the environment regulations concerning aviation operations. Fuel costs have become the largest expense in operations, and decreasing fuel consumption not only reduces the impact of aircraft emissions, but also improves airlines' revenue. Meanwhile, with the trend of increasing demand with regard to Taiwanese aviation, Taiwan Taoyuan Airport (TPE) has limited airside capacity of north airside and south runway maintenance. Runways and aprons are the main bottlenecks of airfield capacity. Effectively managing aircraft taxiing time or flight pushback time to enhance airfield capacity and improve the efficient utilization of airport facilities has long been a congestion problem for airports and needs to be solved. Currently, both airports and airlines are devoted to being environmentally friendly through modifying procedure of airfield operations, energy saving and carbon reduction. Fuel costs have become the largest airline operating costs, if there can be lower aircraft waste time on the aprons, taxiways, and runway head, airlines will not only save more on fuel consumption but also reduce airports' environmental impact of carbon emissions. Therefore, the present study focuses on strengthening the efficiency and systematization of advanced traffic management systems and facilities in ATC units. An important timetable may consider the connection time and taking-off/landing sequence between runway and gates (aprons) whether convenience to the passengers, airport and airlines. Therefore, this study examines potential improvements to congestion capacity. Through reviews of airside operations at TPE, measures of airfield traffic management and procedures, timetable planning and strategies regarding management at TPE, and examining related topics of airside operations, this study seeks to develop a suitable model for further improvement strategies.

This study will analyze the relationship and issues between schedule timetables of the ramp and tower for ground traffic control to identify the time slot allocation problem. Scheduled timetables in varying time slot will be analyzed, and effective means of utilizing airport capacity will be examined. The mathematical programming model is applied to analyze the time slots of take-off and landing sequences. In fact, flight take-offs/landings of some timetables may not yet have reached optimal utilization, which worsens congestion problems. First, this study reviews the concept of apron and runway utilization at maximum available capacity and how to allocate the sequence to clarify and identify critical issues and influencing factors. Furthermore, domestic/international demand and special features of the local aviation environment will be considered while seeking strategies for better time slot management. Second, this study constructs a mathematical model to measure and analyze the defined maximum apron and runway capacity and the scheduled timetable delay to generate strategies of slot operation. The study considers the utilization constraints of maximum available runway and apron capacity to allocate the sequence slot and minimum connecting time between the runway and apron. This study also considers and the ground movement procedure of scheduled flights in airfield from take-off/landing to block out/ block in ramp parking. Third, given a specific flight timetable at peak hours for the congested TPE, this study utilizes the mathematical programming model to analyze the constraints of actual timetable demand, the separate time of flight take-off/landing, and the slot operation strategy to manage the scheduled timetable. This study also analyzes data on current ground movement procedure, runway occupancy time, taxi path, and apron use rules as well as the connections times between take-off/landing runway time, taxi time, and departing/arriving ramp time within the parameters of the mathematic model. The results estimate the minimum connection time between runway and apron for each flight. Furthermore, the results reveal the implications of the taxiing rules between the runway and apron, and the sequence and schedule strategies of time points. The sensitivity analysis will compare optimal/current timetable differences and strength to analyze and enhance the strategies of the airfield operation efficiency and airline schedule reliability.

2. Time slot sequence management between runway and aprons

Many researchers have (Cao, Kanafani,2000; Li 2003) proposed the time slot allocating management to decrease the congested airports. From the view of airport capacity management, a suitable allocating time slot not only satisfied airlines, but also decreased the congested flight and the cost of air traffic control. Therefore, how to effectively arrange current airfield capacity and avoid scheduled flight delay are the key issues. The climate and air traffic control facility capacity is main factors of the airport capacity. The flight take-off/landing must use the runway, taxiway and apron facilities. The airfield capacity at each time period always was decided by the influence of the climate, aircraft separation rule, flight speed, the geometry of runway and taxiway, apron push back, and the size of ramp stand even the controller factors. Therefore, airfield capacity is a variable at each time period. Meanwhile, a peak hour capacity is the supplied key issue (Cao, Kanafani,2000; Li,2001,2003). How to consider the related capacity factors to allocated slot sequence is important research trend. The queuing theory discusses the basic relationship between capacity and delay in order to understand air traffic management. A series of aircrafts in waiting queues between runway and apron 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 the delay is nonlinear, so when the ratio of the demand to capacity approaches to one, the time of delay increases rapidly. Therefore, some researchers (Marchi, 1996; Wong, Li 2002) 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 claim delays are a symptom of insufficient capacity, and the quantity of the capacity is better measured by the maximum throughput per time unit.

The gate capacity is measuring the maximum number of aircraft operations accommodated by the gate-apron group component. Generally, last researches will consider some factors such as gate-apron aircraft parking arrangement, aircraft ground service and passenger loading characteristics, number and mix of the gates and stands by category, gate occupancy time per flight, and scheduling practices of the airlines. Therefore, the measuring of gate occupancy time always depends on type of aircraft, the flight turnaround, or through flight, volume of deplaning and enplaning passengers per flight, amount of baggage and mail per flight, productivity of aircraft servicing operation and efficiency of apron personnel, and exclusive use of one airline or class of aircraft and availability to all airlines. Not only each gate available to all airlines to measuring the aircraft type, mix rates of demand traffic for different aircraft type and their average occupancy time, but also capacity estimation of each gate group depends the number of gate, main service time, and demand traffic mixes to computer the capacity of each gate group. The gate capacity can estimate.

Gilbo(1997) considered the interaction between arrivals and departures of aircraft, speculating that the ratio of arrivals and departures of aircraft will have significant impact on delays. Li (2001, 2003) expands the mutual flow interaction among arrival/departure sequence and arrival/departure separation and the limitation of the runway capacity. All above-mentioned factors have influence on the time an aircraft spending on the runway and thus the amount of arrival/departure aircrafts that a runway can handle. They not only try to apply the runway separation to estimate the optimal number of allocated slots and sequence of the runway capacity and measure and modify the scheduled timetable delay. However, all the waiting flights do not arrive/depart at the same time in every time interval, and the waiting time for each aircraft is not the same. Such a measuring method will cause errors. Therefore, there are rooms further to be studied, such as the more properly formulating the interacting behavior of the arrival/departure aircrafts between the runway and apron in the airfield delay problems.

Last years, study on issues between taxi time and fuel consumption in the airport ground movement (Khadilkar, Balakrishnan 2012; Burke,Stewart, Ravizza, Chen, Atkin 2013; Diana2013), not only discuss how to improve airport delays in order to enhance the utilization of airport capacity are often found in operations research literature on the queuing theory (Gilbo, 1997), also discuss the flight movement management(Roling and Hindawi,2008). Due to the impact of oil prices and environmental issues in recent years, reducing delays as well as fuel consumption has become increasingly important. Many notable researchers have been working on decreasing aircraft taxiing time and fuel consumption (Nikoleris, Gupta, and Kistler, 2011; Khadilkar and Bslakrishnan, 2012; Diana, 2013; Guo, Zhang, and Wang, 2014). Many researches examine not only how to reduce airport delays to enhance the airfield capacity but also management of aircraft taxiing. Many other studies focus on the control of taxiing in/taxiing out of apron (Gao, Zhang, and Wang, 2013; Zhao and Du, 2013; Liu, Chen, and Liu, 2014). Others still apply the dynamic optimality models to these problems (Wang, Han, and Chen, 2010; Balakrishna, Ganesan, and Sherry, 2010; Chen and Stewart, 2011; Koeners and Rademaker, 2011). For effective management of the airport airside operations, such as the sequence of aircraft landing/taking-off runway, taxiing time of aircraft on the taxiway, time management of flight push backs, research has been conducted on aircraft taxiway and runway schedules (Clare and Richards, 2011; Lee and Balakrishnan 2012); taxiway and runway control procedure (Yousaf, Zafar and Khan,2010); the optimization model of taxiing time (Jordan, Ishtkina, and Reynold ,2010 ; Li, Zhao, and Hao,2011; Liu, Wu, and Luo, 2011; Ravizza,Chen,Stewart, and et.2014); the dynamic model of aircraft taxiing routes (Wang, Han, and Chen,2010; Balakrishna, Ganesan, and Sherry, 2010; Chen and Stewart,2011; Koeners and Rademaker,2011); taxi-in/taxi-out of gate or apron (Gao, Zhang, and Wang,2013; Zhao and Du, 2013; Liu, Chen, and Liu, 2014); ground monitoring system data analysis, fuel consumption and decision-making of pushback research (Tang,2010;Burgain, Pinon, and Feron et. al,2012; Carpenter and Stroiney,2012; Zhao,2012 ; Burgain, Kim, and Feron,2014); and aircraft ground handling of fuel optimization and regression estimators(Nikoleris, Gupta, and Kistler,2011; Khadilkar and Bslakrishnan,2012;Diana,2013; Guo, Zhang, and Wang,2014).

These researches focus on taxiing time control for taxi-out and taxi-in to get the dynamic optimal situation for flight movement. However, A suitable timetable must satisfy the maximum flight demands and minimum flight connection. Basically, the flight sequence at a peak hour most reflects the service of apron and runway capacity and flight delays. Especially, the flight demands is near the saturated runway capacity. Therefore, a good timetable must consider all possible capacity to be effective utilization and planning. This paper considers the concept of aircraft taxiing speed for cargo/passenger flight take-off/landing slot to allocate and evaluate timetable planning. However, this study will exploit apron, taxiing and runway capacity, and aircraft movement speed to constructs a mathematical model, which discusses how to evaluate and measure the capacity to allocate flight sequence and evaluate timetable planning. It must not only consider the feature of flow, the sequence of composition between take-off and landing slot, but also discuss on how to evaluate the sequence performance as fig 1.

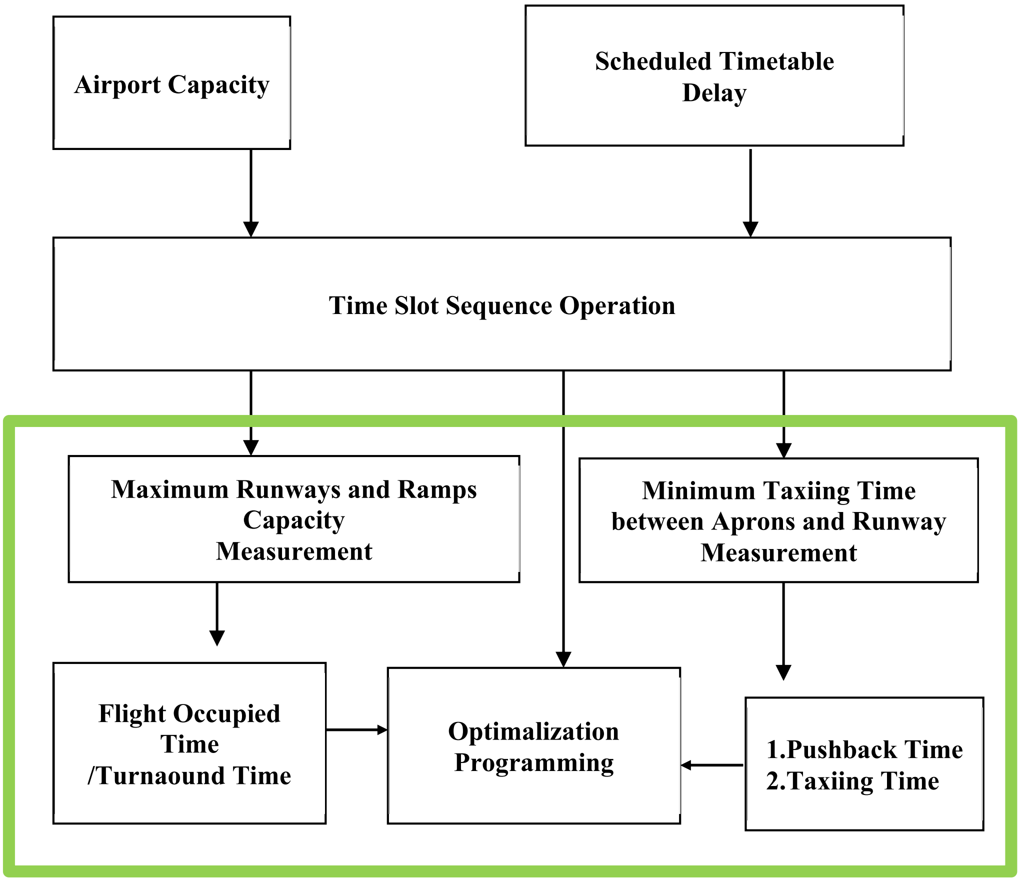

Fig 1 Relationship between flight schedules delay, apron capacity and runway capacity

3. Measuring the minimum connection time between apron and runway

3.1. Model limitation and assumption

Since the aircraft delays of airside operations are often happened at the bottleneck of the runway and apron. Therefore, this study must consider the time of landing/take-off flight distribution between the ramps, taxiways, and runways at the airfield and the landing/take-off flight connectivity between ramps, taxiways and runways to adjust crowded time-points move forward or backward to reduce flight delays problems expanded. This study defines the gate schedules timetable as not being a airfield delay constraint and that traffic flows freely and assumes no flight technical delays. There are only the connection time and airfield capacity problem between ramps, taxiways and runways to discuss how to improve the time-points of flight distribution for timetable planning.

Due to the runway is always a bottleneck for airport capacity, taxiways and gates will also directly influence the scheduled timetable in peak hour. This paper assumes that the maximum capacity is greater equal to the actual demand of departing/arrival, because there is hardly surplus slot in peak hours. The estimated parameters of the separation between departing and arrival flight are assumed under continuous and stable flight flow within one peak hour under good weather when control works are not under pressure. This paper assumes that every scheduled flight can normally operate at airport. There is no traffic handling delays, aircraft turnaround delays, aircraft technical delays, air traffic control and weather delays (Shaw, 1987) to cause flight delays. Only the schedule planning will cause scheduled timetable delays to happen. Owing to congesting air traffic at peak hour, the capacity at peak is theoretically closed to actual take-off/landing demand. Therefore assumes every airline all on time take-off/landing, the flight delay due to the planning issues of time slot. Meanwhile, the optimal slot sequence also will effectively expand the airport capacity.

This study constructs a mathematical programming model to modify an existing gate timetable to allow it to serve the minimum connected time of taxiing flights between the runway and apron. The notation and description of the parameters and variables is as follows:

3.2. Notation and descriptions

X_{ijk}^{a} : Whether arriving k type flights i scheduled flight can be assignment ramp j

X_{ijk}^{d} : Whether departing k flights i scheduled flight can be assignment ramp j

$R_iG_jT_k^{a}$: Optimal scheduled time of k airplane arrival assign the ramp stand j and runway sequence i th flight

$G_jR_iT_k^{d}$: Optimal scheduled time of k airplane from the ramp stand j departure to runway sequence i th flight

$R_iG_jT_k^{ar}$: Real time of the time point of touch-down on the runway for arrival k airplane arrival at the runway sequence i th flight to assign the ramp stand j

$G_jR_iWT_k^{a}$: Time of arrival k aircraft ramp stand j must be the waiting time for the runway separation of the runway sequence i th flight

$R_iG_jRT_k^{ar}$: Real time of taxiing time from the touch-down runway to the runway end for arrival k airplane arrival at the runway sequence i th flight to assign the ramp stand j

$R_iG_jTG_k^{ar}$: Real time of taxiing time from the runway end to taxi to the apron stand of objective apron for arrival k airplane arrival at the runway sequence i th flight to assign the apron stand j

$G_jR_iT_k^{dr}$: Real time from the apron stand j for departure k airplane at the runway sequence i th flight

$G_jR_iWT_k^{d}$: Time of departure k aircraft at apron stand j must be the waiting time for the runway separation of the runway sequence i th flight

$G_jR_iGT_k^{dr}$: Real time of taxiing time from the apron stand to taxi out apron to the taxiway for departure k airplane at the runway sequence i th flight from the apron stand j

$G_jR_iTR_k^{dr}$: Real time of taxiing time from the taxiway to the runway head for departure k airplane at the runway sequence i th flight from the apron stand j

$G_jR_iRHT_k^{dr}$: Real time of taxiing time from the runway head to take-off for departure k airplane at the runway sequence i th flight from the apron stand j

$G_jR_iWT_k^{d0}$: Current scheduled time of departure k aircraft at apron stand j must be the waiting time for the runway separation of the runway sequence i th flight

$R_iG_jT_k^{a0}$: Current scheduled time of arrival k airplane is assigned the apron stand j and runway sequence i th flight

$G_jR_iT_k^{d0}$: Current scheduled time of departure k airplane from the apron stand j to runway sequence i th flight

TOT_{jk}^{a} : Total number of arriving k aircraft at apron stand j

TOT_{jk}^{d} : Total number of departure k aircraft at apron stand j

T_{jk}^{s} Aircraft k schedule turnaround time constraints of each apron stand j

T^{o}_{jk} Aircraft k operation turnaround time constraints of each apron stand j

G^{0}_{jk} : Aircraft k constraints of each apron stand j capacity

RC^{0} : Runway capacity constraints at peak hour

3.3 Apron capacity estimator model formulation

An objective function maximizes the reach of one hour from the service capacity of each apron. The function 2 is total turnaround time for the total number of serving per hour arrival/take-off different type flight arrival on each apron stand should not exceed the time limit of Schedule turnaround time. Function 3 and 4 are the number constraints of arrival/departure different type flights for per apron stand Function 5 are the number constraints of arrival/departure different type flights for the runway. Function 6 and 7the total number of runway arrival and departure flights must meet the number of arrival and departure volumes for timetable demand. Function 8 s the 0-1 integer variables of different aircraft number of arrival and departure flight for each apron stand.

$$\text{MAX} \quad \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X^{a}_{ijk} + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X^{d}_{ijk} \tag{1}$$

$$\text{S.T.} \quad \sum_{i=1}^{n}\sum_{j-1}^{m} T^{o}_{ijk} \cdot X^{d}_{ijk} - T^{o}_{ijk} \cdot X^{a}_{ijk} \le T^{s}_{jk} \tag{2}$$

$$\sum_{i=1}^{n} X^{a}_{ijk} \le GC^{0}_{jk} \tag{3}$$

$$\sum_{i=1}^{n} X^{d}_{ijk} \le GC^{0}_{jk} \tag{4}$$

$$\sum_{k=1}^{l} X^{a}_{ijk} + X^{d}_{ijk} \ge RC^{0} \tag{5}$$

$$\sum_{k=1}^{l} X^{a}_{ijk} \ge X^{a0}_{ij} \tag{6}$$

$$\sum_{k=1}^{l} X^{d}_{ijk} \ge X^{d0}_{ij} \tag{7}$$

$$X^{a}_{ijk}, X^{d}_{ijk} \in 0-1 \ \textit{Integer} \tag{8}$$

3.4 Connection time estimator model formulation between runway and apron

The objective is making total connection time as short as possible. Function 9 indicates that the total connection time between apron arrival/departure at the airport and flight take-off/arrival must consider aircraft departure/arrival procedure at the airfield. The objective considers connection time between apron, taxiway and runway, which should improve the total connection time to minimize, and meet the international and domestic flight movement. Therefore, the total connection time for arrival/departure on international/domestic aprons and departing/arriving international/domestic flights must be smaller, and the flights of the airfield must operate more efficiently.

Function 10 indicates that the optimal time-point of the gate for each arriving flight must be equal to the sum of the time point of the flight touching down on the runway, taxiing time from the runway touch-down to the runway end, taxiing time from the runway end to the objective apron, and time of entering the apron and taxiing to the apron stand before reaching the gate. Function 11 indicates that the optimal time point of the gate for each departing flight must be equal to subtracting the time point of departing flight take-off on the runway, taxiing time from runway head to take off, taxiing time from objective apron to the runway head, pushback time of the departing apron stand before gate and the waiting time of the apron stand or runway head. Function 4 indicates that the total waiting time at the gate for departing flights or the waiting at the runway head must be smaller than acceptable waiting time constraints. Function 13 indicates the total flights at each international (domestic) apron stand serving arriving flights. Function 14 indicates the total flights at each international (domestic) apron stand serving departing flights. Function 15 indicates that the modification time range between the optimal gate timetable and current gate timetable is equal to the total gate waiting time of all flights. Therefore, the total modified times of the gate timetable in unit hour must not exceed available total waiting time of all flights in unit hour. Function 16 represents the constraints of runway capacity in unit hour. Function 17 represents the aircraft type constraints of each apron stand capacity. Function 18 indicates that the optimal available time point variables must be 0-1 integer variables at each international (domestic) apron stand of arriving/departing flights must be larger than 0. Functions 19-20 indicate that the integer variables of optimal waiting time for arriving/departing flights at each international (domestic) apron stand or runway head must be larger than and equal to 0. Functions 21-22 indicate that the integer variables of available operational taxiing time for arriving/departing flights must be larger than and equal to 0.

$$\mathrm{MIN} \quad \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk}^{a} \cdot \left| R_i G_j T_k^{a} - R_i G_j T_k^{ar} \right| + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk}^{d} \cdot \left| G_j R_i T_k^{d} - G_j R_i T_k^{dr} \right| \tag{9}$$

$$S.T. \quad R_i G_j T_k^{a} + G_j R_i WT_k^{a} = R_i G_j T_k^{ar} + R_i G_j RT_k^{ar} + R_i G_j TG_k^{ar} \tag{10}$$

$$G_j R_i T_k^{d} + G_j R_i WT_k^{d} = G_j R_i T_k^{dr} - G_j R_i GT_k^{dr} - G_j R_i TR_k^{dr} - G_j R_i RHT_k^{dr} \tag{11}$$

$$G_j R_i WT_k^{d} \le G_j R_i WT_k^{d0} \tag{12}$$

$$\sum_{i=1}^{n} X_{ijk}^{a} = TOT_{ijk}^{a} \tag{13}$$

$$\sum_{i=1}^{n} X_{ijk}^{d} = TOT_{ijk}^{d} \tag{14}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk}^{a} \cdot \left| R_i G_j T_k^{a} - R_i G_j T_k^{a0} \right| + \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk}^{d} \cdot \left| G_j R_i T_k^{d} - G_j R_i T_k^{d0} \right| = \sum_{i=1}^{n} G_j R_i WT_k^{a} + G_j R_i WT_k^{d} \tag{15}$$

$$\sum_{i}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} X_{ijk}^{a} + X_{ijk}^{d} \le RC^{0} \tag{16}$$

$$\sum_{i}^{n} X_{ijk}^{a} + X_{ijk}^{d} \le G_{jk}^{0} \tag{17}$$

$$X_{ijk}^{a}, X_{ijk}^{d} \in 0-1 \ Integer \tag{18}$$

$$G_j R_i WT_k^{a} \in Positive\ Integer \tag{19}$$

$$G_j R_i WT_k^{d} \in Positive\ Integer \tag{20}$$

$$R_i G_j T_k^{a} \in Positive\ Integer \tag{21}$$

$$G_j R_i T_k^{d} \in Positive\ Integer \tag{22}$$

4. Model application

4.1 Data collection

This section arranges three parts, first part discusses current airfield layout and planned capacity also discusses current traffic combination of arrival/departure flights per hour, Second part discusses the result of optimal capacity and Third part sensitivity analysis of different landing/take-off combination. These parts can check the take-off/landing combination and airline using types (such as share, fixed) of apron stands under different timetable flight demand in peak hour how to make the strategies of improving apron capacity. There are north and south runway in Taiwan Taoyuan international airport. Because of only north runway served the cargos, this study only analyses north runway. This study will focus the north runway, taxiway and A1-A9, D1-D10 of passenger aprons and 501-518 cargo aprons such as Fig 2. The flight take-off /landing can use runway 5L or R32 take-off /landing. This section will use flight scheduled of north runway on November 17 to 23 one week 2013 and apply the above mathematical model. There are 254 cargo flights scheduled and 1552 passenger flights scheduled in one week in Taiwan Taoyuan international airport as Fig 3.

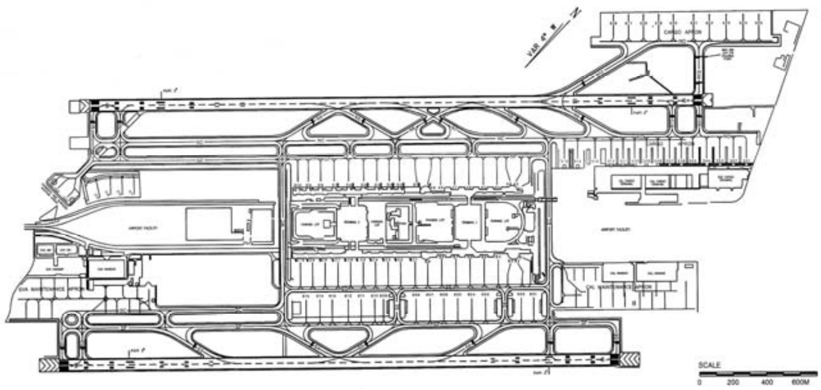

Fig 2 Airfield layout of Taiwan Taoyuan international airport

There are different sizes of cargo aprons to serve different aircraft at TPE airport and show in Table 2. The apron-gate turnaround time depends on the quantity of freight to be load/unload, and the aircraft's suitability and operation, usually expressed by position, number and size of doors, and load/unloading facilities and equipment. There are ten aprons of aircraft B748 to serve, eight aprons of aircraft B744 to serve, four aprons of aircraft MD11 to serve, and 3 aprons of aircraft A380 to serve. The turnaround time of different type aircraft is projected to be about 50-140 minutes depending on the layout of the unit load device. Table 2 also shows the turnaround time of B744 at TPS airport is larger than 88 minutes if the nose cargo door is used, 90 minutes if the side doors are used, and 50 minutes if both the nose and side doors are used. The cargo apron allocation flight is not congested under aircraft constraints such as Figure 3. The apron allocation per cargo flight in Taipei airport shows the 23 pm,20 pm, 5 am, 3 am, 7 am, 17 pm and 4 am per day are busy for cargo transportation in airfield. The number of aircraft occupy apron of the other time period per day are not over 4 aprons. The figure 3 shows that short haul and long haul routes are mainly service. The peak hours of week cargo flights are distributed 23 P.M.(59 flights), 20 P.M. (43 flights) and 7A.M(43 flights). The peak hour of week passenger flights are distributed 15 P.M.(114 flights), 12 A.M. (111 flights) and 14 P.M(109 flights)..Therefore, The peak hour of week flights are distributed 15 P.M.(127 flights), 12 A.M. (121 flights) and 7 A.M(121 flights). According to the air traffic data of Taiwan Taoyuan international airport 2013 November 17 to 23, This study making the Fig 4-6 shows that the current scheduled turnaround/operation turnaround distribution for arrival/departure cargo/ passenger flights at the cargo apron/ passenger aprons. The average delays of passenger flights are lower than cargo flights. Only the delay time of cargo apron 506, 508, and 522 and passenger apron A1 are very smallest.

Table 1 Maximum aircraft operation of cargo apron at TPE airport

Apron name	Amount	Maximum aircraft type	Schedule turnaround time (minutes)	Operation turnaround time (minutes)
501-505, 509,511,514	8	B744	220	224
506,508,510,512	4	MD11	271	273
507,513,515-521,525	10	B748	198	184
522-524	3	A380	503	520
A1	1	A300	81	86
A3	1	A330	75	87
A2,A4-A9,D1,D2,D4,D5,D7-D10	16	B744	76	79
D3	1	B763	74	74
D6	1	A380	74	74

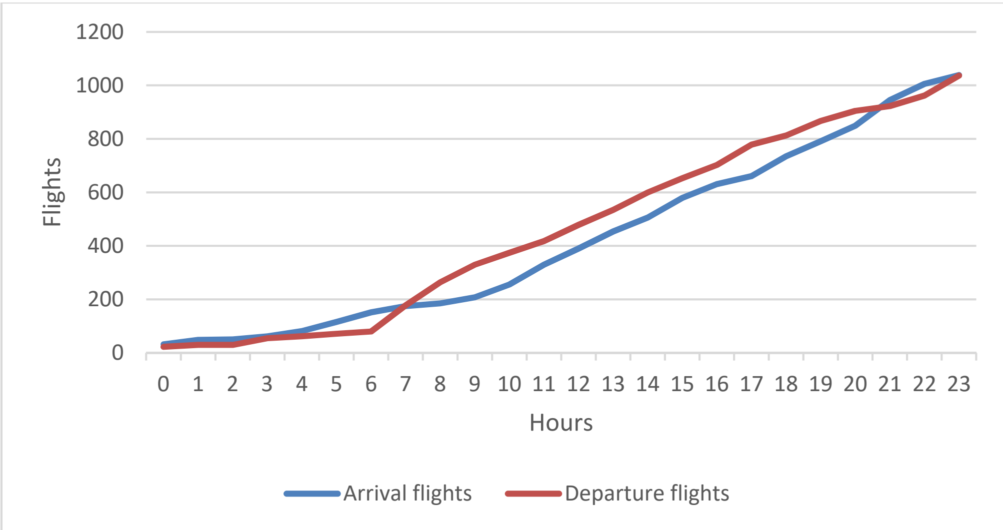

Fig 3 Number of passenger/cargo flights per week at TPE airport

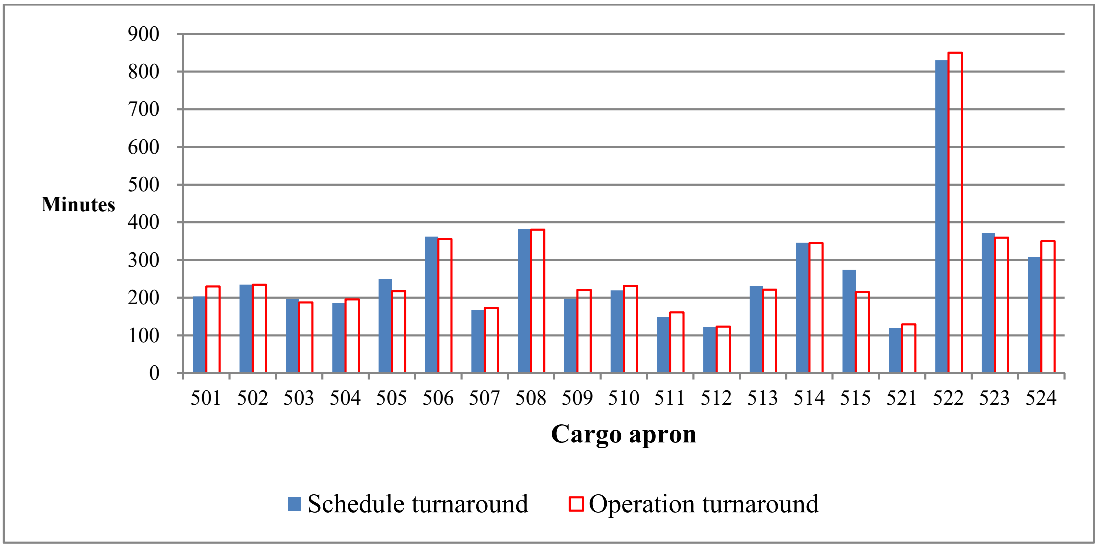

Fig 4 Average schedule/operation turnaround time of arrival flights at each cargo apron

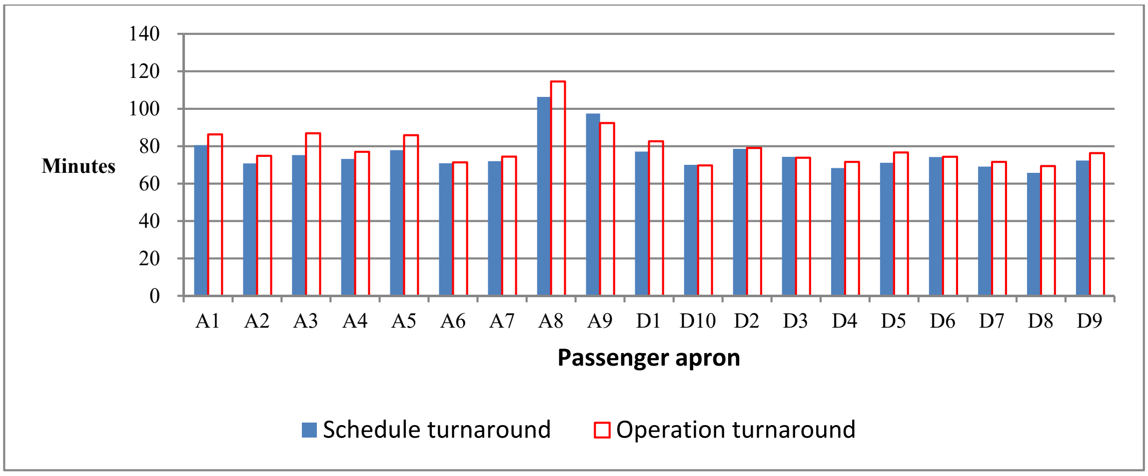

Fig 5 Average schedule/operation turnaround time of arrival flights at each passenger apron

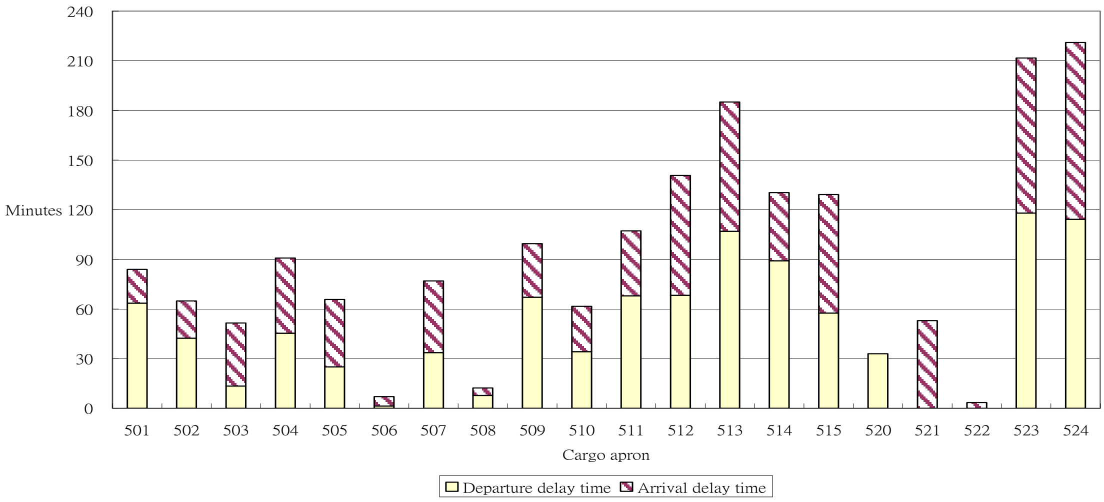

Fig 6 Average delay distribution for one week departure/arrival flights at each cargo apron

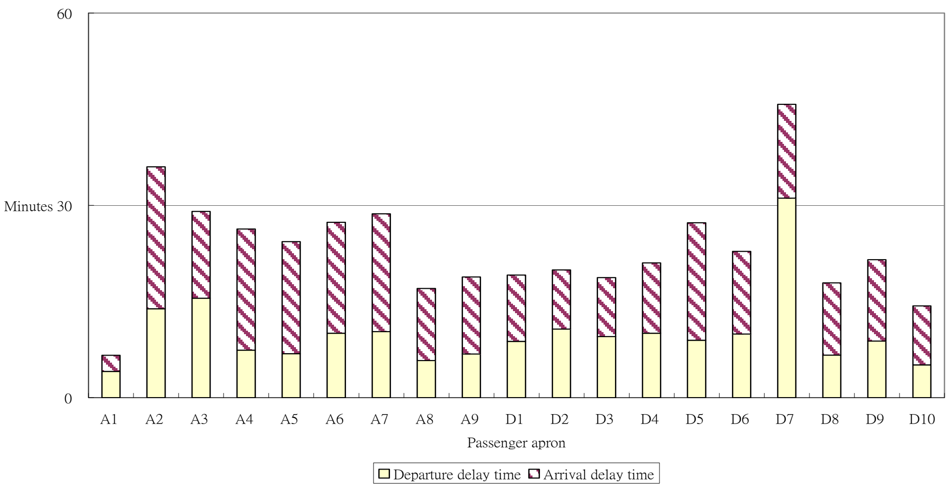

Fig 7 Average delay distribution for one week departure/arrival flights at each passenger apron

The apron capacity estimation and analysis show Table 3 that the policy of stand usage will influence the apron capacity and if the aircraft passenger/cargo B744 aprons are very busy and longer occupy apron time, If all flights concentrate at peak hours, there are also apron stands congested.

Table 3 Apron capacity estimation

Aircraft type	Apron group	Number of Apron	Mix (%)	Demand (aircraft/hr)	Capacity (aircraft/hr)
B744	501-505,509,511,514	8	13.34%	0.273	0.268
MD11	506,508,510,512	4	5.30%	0.278	0.276
B748	507,513,515-521,525	10	5.25%	0.962	1.035
A380	522-524	3	1.35%	0.442	0.427
A300	A1	1	2.50%	0.494	0.465
A330	A3	1	3.23%	0.413	0.356
B744	A2,A4-A9,D1,D2,D4,D5,D7-D10	16	60.12%	0.350	0.337
B763	D3	1	4.58%	0.295	0.295
A380	D6	1	4.34%	0.311	0.311

4.2 ***The result of optimal model***

Owing to the number of variance between cargo and passenger in different hours, this study specially chooses the more number of flights in peak hour. This model measures each flights taxing time and need waiting time between gate and runway to pursuit the minimum connection time. The model also measures the total waiting time of all flights not only can modify current scheduled timetable available improving window time and range, and in advance provides the optimizing timetables of prototype in peak hours. This study use Lingo software to solve the optimization problem. This study use the airlines' turnaround time of different air routes, the combination of arrival/departure flights per hour, and the occupancy time of arrival/departure flights per hour at TPE airport and are applied to the optimal capacity of runway and apron models. This study also use Lindo package software to solving optimal question.

In order to analyse the flight movement in peak hour, this study collects 20 scheduled flights assigned north runway 20 pm on Thursday. The scheduled flights combine 8 arrival passenger flights, 4 arrival cargo flights, 5 departure passenger flights, and 3 cargo flights. This study assumed the flight push back from apron stand of gate to taxiway cost 1.5 minutes, and the taxing time of the flight from taxiway enter the apron stand of gate to taxi cost 1 minutes. There are 5L and 23R runways to take-off/landing of north runway of Taiwan Taoyuan international airport. Currently, air traffic controllers of Taiwan Taoyuan international airport are usually prefer to use runway 5L to take-off/landing. Therefore, this study also does the sensitivity analysis to discuss the connection performance between apron and runway by taxing time of speed type and different runway procedure of take-off/landing. The study according to above Figure 2 collects geography location and coordinate system of runway 5L and 23R, N1,N11,NP,NC,…etc taxiing way, and cargo/passenger apron. The study also assumes taxiing speed as four types of 35 kilometres /hours, 30 kilometres /hours, 25 kilometres/hours and 20 kilometres/hours to analyse different taxiing speed to cost taxiing time. The optimization results of the flights shows as the Fig 8 and Table 1.

The current cargo/passenger timetables are busy at some time points cause cluster delay at the runway, also cause flight fuel costing of practical airfield operation problems. The figure 11 shows the gate time point of flights optimal scheduled with higher taxing speed are closed to the time point of the current scheduled. When 20 aircrafts are assigned to taxi the runway 23R take-off/landing procedure, and the time point variances between optimal scheduled and current scheduled are obviously expanding more than the runway 5L take-off/landing procedure. Specially, the gate time point of the arrival/departure cargo apron flights are variance more than the gate time point of the arrival/departure passenger apron.

The table 4 shows The Minimum connection time between apron and runway show that, no matter use runway 5L or 23R take-off/landing procedure, the flight taxing speed faster, the connection time between apron and runway shorter. There are very significantly that the waiting time of departure flights are longer than the waiting time of arrival flights when flight taxing speed faster, but the departure waiting time are no more longer than arrival waiting time when flight taxing speed slower. Flight taxing speed to minimum connection time are very important impact. Meanwhile, the waiting time of departure/arrival cargo flights are also more than all flights influenced by flight taxing speed. The table 4 shows that runway 5L take-off/landing procedure not only can save more connection time and waiting time of flights than runway 23R take-off/landing procedure, but also can save more connection time and waiting time of cargo flights than runway 23R take-off/landing procedure.

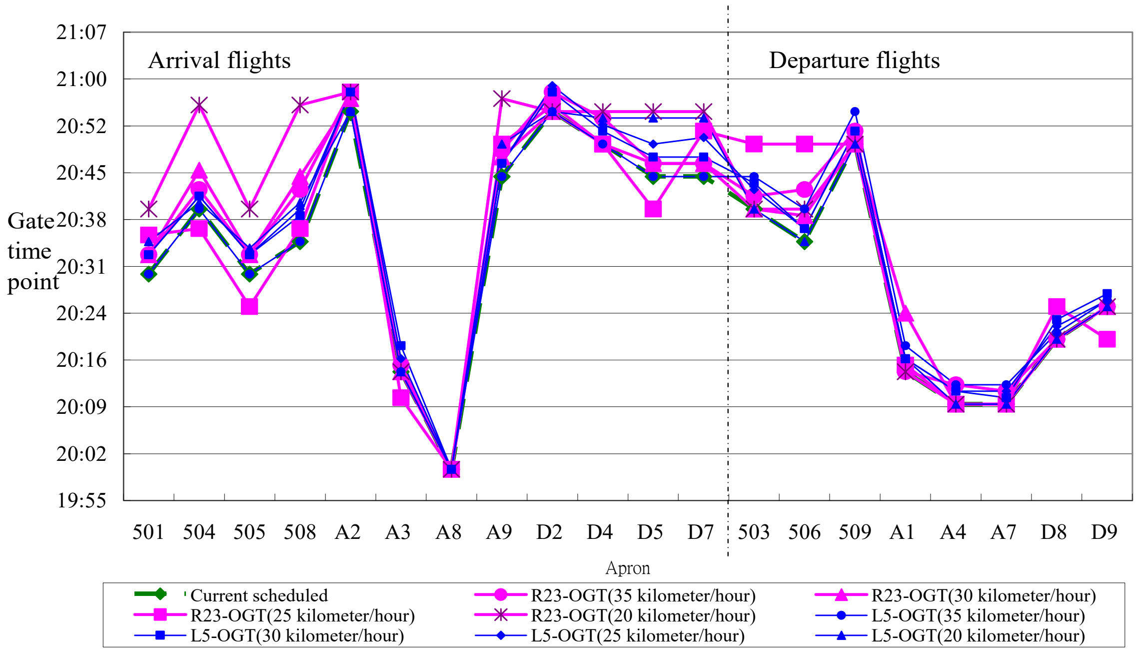

Fig 8 Time point of gate flight optimal scheduled with different taxing speed and runway

Table 4 Performance of four speed types for flights movement in airfield with 5L/23R take-off/landing procedure

Take-off/ landing	Minimum connection time between apron and runway (MinCT)	Flight taxiing speed (kilometer /hour) (FTS)	Total waiting time (TWT)	Average waiting time for departure flights (AWTDF)	Average waiting time for arrival flights (AWTAT)	Average waiting time for departure cargo flights (AWTDCF)	Average waiting time for arrival cargo flights (AWTACF)	The variance time for current Scheduled timetable (VTST)
Runway 5L	174	35	27	3.375	0	5	0	27
	174	30	50	2.25	3	2.67	3	50
	219	25	54	2	3	2.33	3.25	54
	257	20	46	0.375	4	0	4	45
Runway 23R	197	35	54	2.125	3.083	4	4.25	54
	219	30	44	1.625	2.583	1.33	5.5	44
	249	25	73	6.625	5	0.667	9.5	73
	294	20	102	0.625	8.083	1.667	14.25	102

4.3 Timetable scheduled issues and discuss

According to the optimal results of time point at 20:00 peak-hour which flights with different speed take-off/landing between the L5, R23 runway and apron location show as Table 5. The timetable characteristics of time point for using different L5 and R23 runway and taxi-in/taxi-out different aprons procedures, when the flights between runway and apron speed faster, their timetable variances of time points are smaller, when the flights between runway and apron speed more slow, their timetable variances of time points are larger. There the separation of time points for current timetable seems to be closed in the after half hour.

This study also computer the difference between the current timetable and optimal flights with different speed take-off/landing between the L5, R23 runway and apron location show as Table 6. Similarly, the average shift time of current timetable for L5 procedure is less than average shift time of current timetable for R23 procedure. Thus, the time point of 20:30, 20:35, 20:40 and 20:45 of eight optimal timetables are difficult the same as time point of current timetable. Owing to the timetable of current timetable lack considering the flight operation time between apron and runway, this planning will cause apron delay or bottleneck on the airfield. In addition, the time point of 20:45 are very heavy flight scheduled are easy to congest on the airfield. The separation time of time point at 20:30, 20:35, 20:40 are very short and cargo apron also very closed, and the flights are more one to be easily congested on the airfield. These issues are very clearly and should to reschedule the time point of cargo flights.

Table 5 Optimal timetable of peak-hour flights with different speed (kilometer/hour) take-off/landing between the L5, R23 runway and apron location

Take-off /landing	Apron location	Current scheduled	R23(35)	R23(30)	R23(25)	R23(20)	L5(35)	L5(30)	L5(25)	L5(20)
A	A8	20:00	20:00	20:00	20:00	20:00	20:00	20:00	20:00	20:00
D	A7	20:10	20:12	20:10	20:10	20:10	20:13	20:11	20:12	20:10
D	A4	20:10	20:13	20:10	20:10	20:10	20:13	20:12	20:12	20:10
A	A3	20:15	20:16	20:15	20:11	20:15	20:15	20:19	20:17	20:15
D	A1	20:15	20:15	20:24	20:16	20:15	20:19	20:17	20:17	20:17
D	D8	20:20	20:20	20:20	20:25	20:20	20:21	20:23	20:22	20:20
D	D9	20:25	20:25	20:25	20:20	20:25	20:26	20:27	20:26	20:25
A	505	20:30	20:33	20:33	20:25	20:40	20:30	20:33	20:33	20:34
A	501	20:30	20:33	20:33	20:36	20:40	20:30	20:33	20:33	20:35
A	508	20:35	20:43	20:45	20:37	20:56	20:35	20:39	20:40	20:41
D	506	20:35	20:43	20:39	20:50	20:40	20:40	20:37	20:37	20:35
A	504	20:40	20:43	20:46	20:37	20:56	20:40	20:42	20:42	20:41
D	503	20:40	20:42	20:40	20:50	20:40	20:45	20:44	20:43	20:40
A	D5	20:45	20:47	20:47	20:40	20:55	20:45	20:48	20:50	20:54
A	A9	20:45	20:49	20:48	20:50	20:57	20:45	20:47	20:47	20:50
A	D7	20:45	20:47	20:47	20:52	20:55	20:45	20:48	20:51	20:54
A	D4	20:50	20:54	20:50	20:50	20:55	20:50	20:52	20:53	20:54
D	509	20:50	20:52	20:50	20:50	20:50	20:55	20:52	20:52	20:50
A	D2	20:55	20:58	20:55	20:56	20:55	20:55	20:58	20:59	20:55
A	A2	20:55	20:58	20:57	20:58	20:58	20:55	20:58	20:58	20:55
Timetable average(1)		32.5000	35.1500	34.7000	34.1500	37.6000	33.8500	35.0000	35.2000	34.7500
Timetable standard error(2)		16.4237	17.4183	16.8276	18.1232	19.5809	16.2619	16.8492	17.2797	17.7018
(1)/(2)		1.98	2.02	2.06	1.88	1.92	2.08	2.08	2.04	1.96

A: arriving flight ; D: departing flight

Table 6 Optimal shift of apron time point of peak hour flight timetable with different speed take-off/landing (kilometer/hour) between the L5, R23 runway and apron location

Take-off /landing	Apron location	Current scheduled	R23(35)	R23(30)	R23(25)	R23(20)	L5(35)	L5(30)	L5(25)	L5(20)
A	A8	20:00	0	0	0	0	0	0	0	0
D	A7	20:10	2	0	0	0	3	1	2	0
D	A4	20:10	3	0	0	0	3	2	2	0
A	A3	20:15	1	0	-4	0	0	4	2	0
D	A1	20:15	0	9	1	0	4	2	2	2
D	D8	20:20	0	0	5	0	1	3	2	0
D	D9	20:25	0	0	-5	0	1	2	1	0
A	505	20:30	3	3	-5	10	0	3	3	4
A	501	20:30	3	3	6	10	0	3	3	5
A	508	20:35	8	10	2	21	0	4	5	6
D	506	20:35	8	4	15	5	5	2	2	0
A	504	20:40	3	6	-3	16	0	2	2	1
D	503	20:40	2	0	10	0	5	4	3	0
A	D5	20:45	2	2	-5	10	0	3	5	9
A	A9	20:45	4	3	5	12	0	2	2	5
A	D7	20:45	2	2	7	10	0	3	6	9
A	D4	20:50	4	0	0	5	0	2	3	4
D	509	20:50	2	0	0	0	5	2	2	0
A	D2	20:55	3	0	1	0	0	3	4	0
A	A2	20:55	3	2	3	3	0	3	3	0
The average shift time(1)			2.6500	2.2000	3.8500	5.1000	1.3500	2.5000	2.7000	2.2500
The shift time of standard error(2)			2.2308	3.0366	3.8289	6.4064	1.9808	1.0000	1.4179	3.1098
(1)/(2)			1.19	0.72	1.01	0.80	0.68	2.50	1.90	0.72

4.4 Correlation coefficient analysis of influence variables of the minimum connection time

Thus, the sensitivity analysis of table 1 of optimization model outcome shows the flight taxiing speed and time influence the connection time of flights between apron and runway. This study in advance is applied the correlation coefficient to analyze the key variables of influence minimum connection time of flights between apron and runway for runway 5L/23R take-off/landing at peak hour, The tables 7 shows that the flight taxiing speed, the total waiting time, the average waiting time for arrival flights, the average waiting time for departure cargo flights, the average waiting time for arrival cargo flights, and the variance times for current scheduled timetable are high significant correlation with the variables of the minimum connection time of flights between apron and runway. The shorter flight taxiing speed or the shorter average waiting time for departure cargo flights, but the longer flight connection time. Only the variables of average waiting time for departure flights, whether if used runway 23R take-off/landing, and whether if use runway 5L take-off/landing are not significant, that mean the samples too few not to separate runway 23R/5L take-off/landing, but the connection time of runway 5L procedure of take-off/landing is shorter than the connection time of runway 5L procedure of take-off/landing.

Table 7 Correlation coefficient of influence variables of minimum connection time for runway 5L/23R take-off/landing at peak hour

Correlation coefficient	MinCT	FTS	TWT	AWTDF	AWTAF	AWTDCF	AWTACF	VTST
MinCT	1	-.874(**)	.785(*)	-.197	.875(**)	-.725(*)	.848(**)	.777(*)
FTS	-.874(**)	1	-.622	.267	-.763(*)	.823(*)	-.623	-.613
TWT	.785(*)	-.622	1	-.020	.961(**)	-.403	.956(**)	1.000(**)
AWTDF	-.197	.267	-.020	1	-.161	.075	.011	-.014
AWTAF	.875(**)	-.763(*)	.961(**)	-.161	1	-.590	.943(**)	.957(**)
AWTDCF	-.725(*)	.823(*)	-.403	.075	-.590	1	-.512	-.394
AWTACF	.848(**)	-.623	.956(**)	.011	.943(**)	-.512	1	.955(**)
VTST	.777(*)	-.613	1.000(**)	-.014	.957(**)	-.394	.955(**)	1
Runway 23R	.429	.000	.571	.204	.507	-.187	.700	.575
Runway 5L	-.429	.000	-.571	-.204	-.507	.187	-.700	-.575

* means $\alpha = 0.05$ very significant,** means $\alpha = 0.01$ very high significant

4.5 Regression analysis of the minimum connection time at peak hours

This study in advance is applied the regression analysis to estimate the minimum connection time for runway 5L/23R take-off/landing at peak hour. The variables of minimum connection time of flights between apron and runway are high significant correlation with flight taxiing speed, the total waiting time, the average waiting time for arrival flights, the average waiting time for departure cargo flights, the average waiting time for arrival cargo flights, and the variance times for current scheduled timetable. In order to avoid the collinear problem, this study only used the variables of the flight taxiing speed, whether if use runway 5L take-off/landing to estimate the minimum connection time of flights between apron and runway at one peak hour. The function 24 is passed the test and good fitness. This function shows that the total minimum connection time of 20 flights at one peak hour must cost 409 minutes taxiing time. Average taxiing time of each flight cost 20.04 minutes, per flight adding one kilometer /hour of taxiing speed, the total minimum connection time can decrease 6 minutes. If the flights used the runway 5L to take off/land, the total minimum connection time in one hour can save 34 minutes. This means the air traffic controllers of Taiwan Taoyuan international airport are usually prefer to use runway 5L to take-off/land is good strategies for airfield operation of taxiing time.

$$MINCT = 408.875 - 6.150FTS - 33.750L5 \qquad F = 45.191 \; R^2 = 0.948 \;\; N = 8$$
$$(t = 19.829) \; (-8.534) \;\; (-4.189) \tag{24}$$

MINCT : The minimum total connection time of flights between apron and runway at one peak hour
FTS : The flight taxiing speed (kilometer /hour)
The flights whether if use 5L take-off/landing procedure

5. Conclusion

This study measures each flights taxing time and need waiting time between gate and runway to pursuit the minimum connection time. The optimal model measures the total waiting time of all flights not only can modify current scheduled timetable available improving window time and waiting(delay) time, and in advance provides the optimizing timetables of prototype in peak hours. The major findings from this study can be briefly stated as follows:

First, the apron capacity of stand user policy and aircraft size will influence the apron capacity. The outcomes show that the policy of stand usage will influence the apron capacity and all arrival flight at the peak hours using the same apron, there will be congested on the bigger aprons, the remote cargo aprons are not congesting problem. Meanwhile, If all flights concentrate at peak hours, there will also cause congesting apron stands. This study can be developed an estimator of the apron capacity to improve the policies of stand usage and apron services to keep traffic densities at management level.

Second, the optimal model not only can be applied to modify cargo or passenger timetable, but also will check the timetable delay and estimate the airfield performance of aircraft movement in different flight traffic combination. The current cargo/passenger timetables are busy at some time points such as 20:30, 20:35, 20:40 and 20:45 will cause the bottleneck at the airfield, also higher flight fuel cost of practical airfield operations. This study also finds three issues, which are the congestion problems of departure/arrival flights at the same time point for the neighbor aprons, the backward/forward shift length of time slot shifts at time points of current timetable, tower and airport operators need to set standard of shift backward/forward times to enhance the airfield operation efficiency.

Third, this study also proposes the key variables of the performance for minimum connection time between apron and runway, such as the flight taxiing speed (kilometer /hour), total waiting time, the average waiting time for departure flights, the average waiting time for arrival flights, the average waiting time for departure cargo flights, and the average waiting time for arrival cargo flights.

Fourth, there are very significantly the departure waiting time are longer than passenger and cargo arrival waiting time when flight taxing speed faster, but the passenger and cargo departure waiting time are no more longer than arrival waiting time when flight taxing speed slower. Meanwhile, the variables of flight taxing speed to total connection time are very important impact, it pays to catch real data to make an estimator forecast. The waiting time of departure cargo and departure passenger are also influence by flight taxing speed.

Fifth, the regression estimator estimates the total minimum connection time of 20 flights at one peak hour must cost 409 minutes taxiing time. Average taxiing time of each flight cost 20.04 minutes, per flight adding one kilometer /hour of taxiing speed, the total minimum connection time can decrease 6 minutes. If the flights used the runway 5L to take off/land, the total minimum connection time in one hour can save 34 minutes.

Finally, this study provides the optimal model to discuss timetable rescheduling in peak hour. The outcome indicates to how to modify the arrival/departure scheduled flight and enhance the flight movement operation in airfield. In the future can improve strategies of air traffic management and flight fuel saving.

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