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The Research of Slots Allocation on Bridge Mode

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Abstract

Air transport worldwide is growing much more rapidly than the current airport systems' capacity. This creates somewhat of a crisis for modern commercial aviation. In order to reduce congestion and delays, slots and slots allocation concepts had been put on for many years, but as the most scarce resources, all airlines wish get much slots as possible, So bridge mode was applied by the most areas. We analyzed differences of the slots allocation between in the bridge mode and in the traditional mode, and studied the slots allocation algorithm considering the minimum total delay rate. This paper approved the slots allocation algorithm could reduce the total delay and increase the flights volume, and showed a practical significance.

***Keywords**: bridge mode, slots allocation, delay proportion*

1. Introduction

The sheer volume and sustained growth of flights have put an enormous strain on the air transportation system. which is evidenced by a worldwide increase in flight delays, airport congestion flights contradictions. so the high demand for air traffic control is put forward to ensure the safety and punctuality of flight from different perspectives which leads to the increasingly strong demand for reasonable air traffic flow management of flights. In China, more air routes are converged in some important navigation stations because of airspace restrictions and the lag infrastructure construction. With the growing air traffic flow, the contradictions between the available airspace resources and the aircraft flow in these convergent points are more and more prominent, which leads to the rising pressure of the air traffic safety. In order to ensure the flight safety of the convergent points, bridge mode was used by more air traffic control departments, that means that flight levels are assigned to those aircrafts into the convergent points from all directions, and flight levels in different directions are staggered each other, then different flight level numbers are allocated according to the air traffic flow in all directions. The bridge mode greatly enhances the safety level of the busy convergent points to the air traffic control department, but to entering flight in all directions, the slots allocation needs including height restrictions are brought out. Because of the restricted airspace in china, the traditional slots allocation method can not meet the needs of practical work, so the slots allocation method on bridge mode will be further researched.

2. Background and Literature Review

2.1 The Concept of the Term "slots" and Slots Allocation

Two consecutive operations on one airport runway, such as aircraft landings and takeoffs, require a minimum amount of time gap in between them. The time gap, which is

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imposed due to safety considerations, mainly depends on the type of aircraft involved in the two operations, meteorological conditions at the time operations take place, and the type of operations whether they are landings, takeoffs, a landing followed by a takeoff, or a takeoff followed by a landing[1].

The term, “slots” is frequently used to refer to slots pairs, which include a landing slots and a take-off slots. Naturally, an airline that wishes to offer a flight between a slots-constrained airport and another city’s airport frequently uses both a landing slots and a take-off slots, so that it can both deliver passengers to that city’s airport and receive passengers (bound for the slots-constrained airport or elsewhere) from the same airport. so the term [2], “slots” can be indicated by the beginning time, ending time and continuing time. Figure1, which follows provides an example of daily slots demand and allocations, time slots 1/1:00-1:040 dedicates that the beginning time is 1:00, and the ending time is 1:04, within the continuing 4 minutes period, the flight can take off or land.

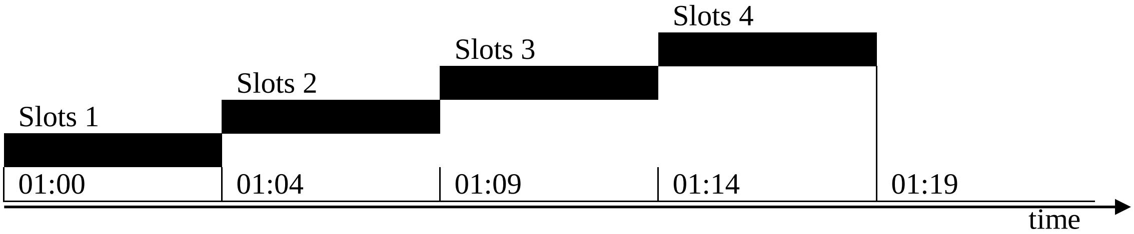

Figure 1. Schematic Diagram of Slots [3]

The slots allocation can be interpreted as a kind of special resource allocation according to a certain way or some kind of mechanism under the condition of meeting the airport capacity limits, and in different airlines and different levels of flight in order to optimum allocation of slots time. One result of slots allocation is shown as figure 2, in which A1 dedicates the first flight of airlines A, and so on.

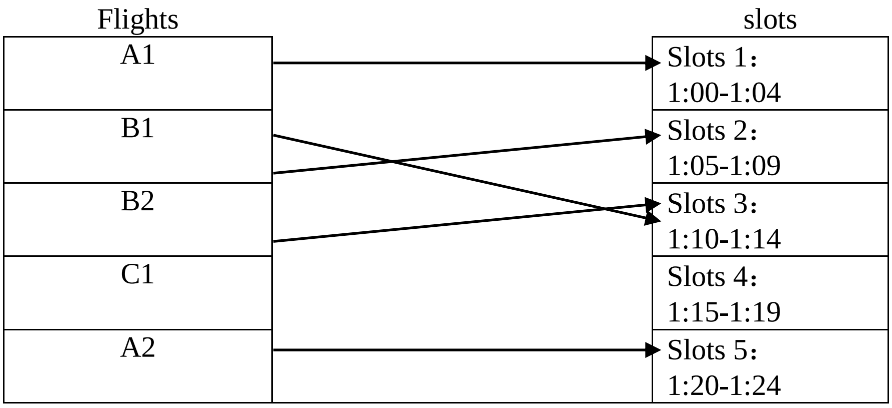

Figure 2. One Result of Slots Allocation

In the air transport, in the case of management of airports, the runways of an airport may be classified as a limited resource aeronautics and airport infrastructure that has supply and demand for their use. The use of runways of an airport is targeted by slots. Therefore, the process of allocating the aircrafts to the slots for landing or takeoff operations can be modeled as a “market”. For the arrival of a flight to occur at an airport, it should have a slots allocated at that airport.

States and other countries also have debated the best method of allocating and redistributing slots in recent years, including the extent to which sales or exchanges of these slots should be allowed.

As a kind of resource, Slots allocation depend on cooperation of Air Traffic Control

(ATC), airlines and airport managers, whereas the cooperation is based on Collaborative Decision Making (CDM). The CDM is a paradigm that tries to improve the exchange of information between the various parties involved at the airport such as Air Traffic Control (ATC), airlines and airport managers. The classical model of slots relocation and still in use by ATC is based on the paradigm of CDM, where airlines must provide reliable information in a timely manner to ATC, for a better outcome. [4]

Slots allocation is throughout the steps of CDM process. The first step is to allocate slots according to the flight schedule, then to substitute or cancel or compress slots, finally re-allocate the slots by integrating the airlines with Compression algorithm [5,6,7].

2.2 Literature Review

Slots holders have the right to schedule a landing or departure during a specific time period. Slots regulations first appeared in the United States in 1969, with the intent of reducing delays at five major metropolitan airports (O'Hare in Chicago, Reagan National in Washington, and LaGuardia, JFK, and Newark in the New York area), under what became known as the High Density Rule. Today, the High Density Rule applies only at Reagan National, though temporary slots controls still apply at all three New York airports[2].

Certain authors [8] focus on the most efficient mechanism for allocating landing slots, including whether auctions will produce a socially optimal result. Many slots holders in the United States and Europe have been "grandfathered" their slots based on past operations at particular airports, and then these slots are occasionally traded or sold with government approval. Policymakers have considered alternative allocation or resale mechanisms for these slots.

Other authors have examined whether there are private incentives to reduce airport congestion absent slots restrictions, and how the implementation of congestion taxes or slots restrictions may affect overall congestion levels and correspondingly consumer welfare (for example, Mayer and Sinai 2003; Morrison and Winston 2007).[9]

In addition, Gale and O'Brien (2013) have examined so-called "use-or-lose" provisions, which frequently apply to landing slots. They find that these provisions encourage capacity usage by a dominant firm that might otherwise restrict its own output, but they also encourage the dominant firm to acquire capacity from fringe firms, which has the effect of restricting overall industry output.[10]

3. The Slots Allocation on Bridge Mode

3.1 Introduction of Bridge Mode

More cars, road becomes blocked, so people invented the overpass. Plane is much, the air also becomes congested. In the field of air traffic management, "bridge" mode has been put forward for many years, which has played a significant role. The width of the flight route is fixed, the plane can't fly side by side, but can be "pyramid" flying on different level, so the entire route is like a "overpass air", but the number of layers of the overpass has a direct impact on air flight capacity.

"Minimum vertical interval (RVSM)" is a form of bridge mode which makes delays fundamental improvement.

the experience of the United States data also show that after the implementation of the "minimum vertical interval (RVSM)", the average fuel consumption by 1%; The European experience data demonstrated that at the same time, under the environment of RVSM operation, each flight to save fuel at least 80 kilograms (176 pounds), according to China Daily flights running about 4000 calculations, save fuel around 120000 tonnes a year, or about 720 million Yuan.

3.2 The Specificity of Slots Allocations on Bridge Mode

Compared with traditional mode, slots allocation on bridge mode will be more complex, which is mainly reflected in the following points:

（1）On bridge mode, every flight level is a traditional slots allocation model ,and a dimension is added to make slots allocation more three-dimensional. If only one flight level is available, the slots allocation between bridge mode and the traditional mode is similar.

（2）On the traditional slots allocation method, slots are suitable for all flights[11], but they are different on bridge mode, namely not all slots are applicable to all flights. In the practical work, some flight levels are not applicable to some aircrafts because of the effect of airspace environments, aircrafts performance and air-control protocols. and this kind of situation is more specially in the case of the limited airspace outside the air routes.

（3）Because the applicability of slots is different to aircrafts slots switch is more complicated. Not all aircrafts can switch slots, these aircrafts which can switch slotss must ensure that the switched slots are applicability each other.

（4）On bridge mode, it is possible that all slots are not applicable to an aircraft. if so, slots allocation will be resulted by the special coordination in air-control work. but this paper will not consider this case.

3.3 Slots Allocation Algorithm on Bridge Mode

The problem of slots allocation algorithm on bridge mode consists in the following elements:

St-time: starting time

End-time: ending time

K_t: time capacity in flight level t

A finite set of flights $F = \{1, \dots, f\}$, where f is flight sequence.

Then from staring time to ending time, the slots numbers in flight level t is :

$$N_{st} = \frac{Endtime - Sttime}{\frac{60}{K_t}}$$

Assuming $S_t = \{1, \dots, N_{st}\}$ is the slots set for flight level t ,then for any slots j , $j \in S_t$, its capacity is one flight. The starting time of slots j is defined I_{jt} , and the ending time is defined U_{jt} , then it can be written as:

$$I_{jt} = Sttime + (j-1) \times \frac{60}{K_t}, j \in \{2, \dots, N_{st}\}$$

$$U_{jt} = I_{j+1} - 1, \quad j \in \{1, \dots, N_{st} - 1\}$$

$$I_{1t} = Sttime, \quad U_N = Endtime$$

To any f , $f \in F$,the estimated time of over the restricted point is defined E_f ,and available flight level set is defined L_f. Flight f can be allocated to any slots j_t, $j_t \in R^f$, to all t, $t \in L_f$, R^f is the collections of $\{j_t : E_f \le U_{jt}\} \subseteq S_t$.

Flight f is allocated to slots j in flight level t ,the resulting is to lead to the delay, which is defined d_{fjt} :

$$d_{fjt} = \max\{E_f, I_{jt}\} - E_f, \quad \forall f \in F, \forall j \in S_t, \forall t \in L_f, j_t \in R^f$$

Assuming X_{fjt} is variable parameter, if flight f is allocated to slots j in flight level t, X_{fjt}=1，otherwise X_{fjt}=0。

According to the rule of first arrival first service, the time of over the restricted point E_f is arranged ascendingly to flight f , $f \in F$ ， and slots of flight is allocated successively, and every flight is allocated to the first available slots, then we can take initial solution, in which

$$j_t = \min\{d_{fjt} : E_f \le U_{jt}, \forall j \in S_t, \forall j_t \in R^f, \text{ and slot } j_t \text{ is not allocated}\}$$

Because the non-unique property of variable parameter t leads to the non-unique of j_t ,so we take the corresponding j_t initially

$$j_t = \min\{U_{jt} : E_f \le U_{jt}, \forall j \in S_t, \forall j_t \in R^f, \text{ and slot } j_t \text{ is not allocated}\}$$

Because the final allocation result is effected by the rule of slots allocation, so in general the rule is to minimize total delay time and total delay frequency. [12]

Having defined the problem, we wish under any criterion to allocate the slots in the airports. [13]

3.3.1 Minimizing total delay time: According to the rule of minimizing total delay time, the allocation formula X^F will meet the following constraints:

$$\min \sum_{f \in F} \sum_{j_t \in Rf} d_{fjt} x_{fjt} \qquad (3.1)$$

$$\sum_{f \in F : j_t \in R^f} x_{fjt} \le 1, \quad \forall j \in S_t, t \in L_f \qquad (3.2)$$

$$\sum_{j_t \in R^f} x_{fjt} = 1, \quad \forall f \in F \qquad (3.3)$$

$$x_{fjt} \ge 0, \quad \forall f \in F, \quad j_t \in R^f \qquad (3.4)$$

Formula(3.1) is the objective function; formula (3.2) dedicates that every slots only apply to one flight; formula (3.3)dedicates that every flight only is allocated to one slots; formula(3.4) ensures that it is a integer programming.

Specially, on bridge mode, to flight f , $f \in F, L_f$ maybe same. We assume the flight f_1 is allocated to the slots a_1 in the flight level t_1 ,and flight f_2 is allocated to the slots a_2 in the flight level t_2 ,then two flights must meet the following conditions when switching slots:

$$t_1 \in L_{f_2}, \text{ and } t_2 \in L_{f_1}$$

$$E_{f_1} \le U_{a_2 t_2}, \text{ and } E_{f_2} \le U_{a_1 t_1}$$

3.3.2 minimizing total delay frequency: In practical working, when calculating delay frequency, only the flights whose delay-time exceeds some certain standard are considered into those delay flights, and the standard is different according to departure airport.

Assuming the delay-time standard of flight f in airport is B_f , and the status whose the flight is delayed is h_f [14],

Then

$$hf = \begin{Bmatrix} 1, d_{fjt} - B_f \geq 0 \\ 0, d_{fjt} - B_f < 0 \end{Bmatrix}$$

Allocation program X^F will meet the following constraints:

$$\min \sum_{f \in F} \sum_{j_t \in R^f} h_f x_{fjt} \quad (3.5)$$

$$\sum_{f \in F: j_t \in R^f} x_{fjt} \leq 1, \quad \forall j \in S_t, t \in L_f \quad (3.6)$$

$$\sum_{j_t \in R^f} x_{fjt} = 1, \quad \forall f \in F \quad (3.7)$$

$$x_{fjt} \geq 0, \quad \forall f \in F, \quad j_t \in R^f \quad (3.8)$$

When allocating slots according to other rules, we need adjust the objective function, but the problem will not be repeated in this paper。

4. The Slots Allocation Algorithm Example on Bridge Mode

This paper will take an example to illustrate slots allocation algorithm of minimizing the total delay times on bridge mode. Taking a direction from East-china region to Zhengzhou for example, because of the effect of convergent points in Zhoukou, flights from shanghai to Zhoukou via Fuyang only can use flight level s0780 or s0920m from 0900 to 0940.and the capactiy in flight level S0780 is 8 sorties in this period, and is 5 sorties in flight level s0920.Considering the practical airspace conditions, the flights from shanghai airports to Zhengzhou airports may use flight levels s0780 or s0920,but because of fly instances and air-control Co-ordinations, the flights from Hangzhou and Nanjing to Zhengzhou only can use flight levels s0780.The information about these flights is shown in figure4.1:

Table 1. Flight Information

flight sequence $f \in F$	departure airports	estimated flight over E_f
f_1	ZSSS	09:02
f_2	ZSPD	09:04
f_3	ZSPD	09:06
f_4	ZSSS	09:08
f_5	ZSPD	09:12
f_6	ZSHZ	09:13
f_7	ZSNJ	09:14
f_8	ZSHZ	09:18
f_9	ZSNJ	09:22

In the limited times, the slots set in flight levels S0780 and S0920 are respectively:

L_{0780}={[0900，0904]、[0905，0909]、[0910，0914]、[0915，0919]、[0920，0924]、[0925，0929]、[0930，0934]、[0935，0939]}；

L_{0920}={[0900，0907]、[0908，0915]、[0916，0923]、[0924，0931]、[0932，0939]}。

According to the rules of FAFS and minimizing delay-time, the results is shown in figure4.2

Table 2. The Calculation Result

Flight ID	First arrival Fist service			minimizing delay-time		
	slots	Allocation E_f	delay time	slots	Allocation E_f	delay-time
f_1	[0900，0904]	0902	0	[0900，0904]	0902	0
f_2	[0900，0907]	0904	0	[0900，0907]	0904	0
f_3	[0905，0909]	0906	0	[0905，0909]	0906	0
f_4	[0908，0915]	0908	0	[0908，0915]	0908	0
f_5	[0910，0914]	0912	0	[0916，0923]	0916	4
f_6	[0915，0919]	0915	2	[0910，0914]	0913	0
f_7	[0920，0924]	0920	6	[0915，0919]	0915	1
f_8	[0925，0929]	0925	7	[0920，0924]	0920	2
f_9	[0930，0935]	0930	8	[0925，0929]	0925	3
Total delay-time	-----	-----	23	-----	-----	10

We can see in Table 2 the total delay time was reduced by 13 minutes.

5. Conclusion

Airlines that use a slots-constrained airport must determine which city pairs to serve and how many flights to offer on those city-pair routes, subject to a total capacity constraint that is represented by the number of slots that they hold. As airlines consolidate through mergers and alliances, and with airlines directly selling and exchanging airport landing slots, an important policy and economic question has emerged regarding the competitive effects of changes in the concentration of slots ownership and control.

The slots allocation algorithm has been more mature, the process usually is to determine the slots time-> make sure the objective function-> initialization-> optimization the objective function through the slots time switching.

According to the difference of the objective function and the rules of the slots time switching, the result shows obviously different. at present in our country ,the bridge mode is used in more areas. The algorithm of slots time allocation in this paper will help reduce the total delay-time, and improve the normal level of the flights, and has a certain sense of practical application.

Future work will modify the slots allocation algorithm in such a way that it can include more functions and performance measures for airport managers in order to make it unmanageable. The aircraft allocation effects can be analyzed under different scenarios and type of manipulation that may incur in the market can be studied and used taking advantage of real-world data[15].

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