

The Application and Research of Flight Scheduling Strategies

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Abstract. The rapid development of the aviation industry has increased the complexity and importance of flight scheduling. This paper studies scheduling policies from both temporal and spatial perspectives. Three standard scheduling policies, First Come First Serve policy (FCFS), Small Job First policy (SJF), and Shortest Remaining Processing Time policy (SRPT), are introduced in a modularized form. In this paper, we explore the roles of the three policies in dealing with different scenarios in the airport scheduling process: FCFS prioritizes task arrival time for normal scheduling, SJF prioritizes task execution time for runway scheduling under the pressure of high throughput and SRPT prioritizes the remaining task execution time to cope with delays promptly. The dynamic system of flight scheduling should be able to cope with a variety of possible situations, combine various modules efficiently and improve them to solve the problems. The research in this paper can provide reference ideas for the design of subsequent dispatch models.

Keywords: Flight Scheduling, Airport Dispatch, First Come First Serve, Small Job First policy, Shortest Remaining Processing Time.

1. Introduction

Under the trend of economic globalization, trade and transactions among different countries and regions are becoming closer. Prosperous economic development has contributed to the continuous improvement of the living standards of people around the world. The importance of the aviation industry is also growing. A large-scale, well-established aviation industry not only provide travelers with more convenient and fast choices, but also facilitates the development of the cargo industry. According to the state of the industry report released in January 2023 by the Centre for Asia Pacific Aviation, more than 400 new airports have been built worldwide in the past decade. In 2023, global airport passenger throughput will reach 8.8 billion. This figure represents an increase of 2.8 billion compared to 2013, a year-on-year increase of almost 50%. Aviation is playing an increasingly important role.

With the booming of the aviation industry, airports, the cornerstone of its development, have also expanded in popularity to a larger and wider scale, spurred on by the industry's continuous growth. This is accompanied by an ever-increasing number of flights and an increasing size of airports. Larger airports have more complex structures and heavier scheduling loads. The efficiency of flight scheduling will directly impact the entire aviation system's operational effectiveness and passenger experience. This change has prompted experts and scholars within the industry to invest in extensive research to find efficient flight scheduling solutions.

Airport scheduling strategies focus on operational efficiency while keeping flights in and out of the airport in order. After decades of research, several algorithms have emerged. The most basic algorithm is First Come First Serve (FCFS) [1]. The traditional FCFS model was established by Neuman [2] et al. and Wu [3] et al. However, this model has the problems of being unable to handle multi-point constraints on the flight path and passing delays to subsequent flights in the queue when delays occur. Meyn [4] et al. proposed a new framework to solve the two problems in the traditional model in their results. Park [5] et al. combined the former's and Palopo's results [6] et al. analyzed the existing algorithms to make further improvements, and proposed a method to utilize the time slots between flights effectively. In addition, in order to find a more efficient solution for runway scheduling, Smeltink [7] et al. proposed a computational formula based on the mixed-integer linear programming (MILP) algorithm to solve the taxiing problem, and the MILP algorithm has been improved and generated new algorithms to solve the taxiing problem by Lee [8] et al. and Bosson [9]

et al. as well as Yang [10] et al. modified and generated new algorithms for application to runway scheduling. Later, Avella [11] et al and others proposed a new formulation of the runway scheduling problem based on mixed-integer programming, which continued to be improved and refined.

This paper aims to research different scheduling strategy modules to address various scenarios in the scheduling process. Part 2 of this paper will categorize airport scheduling in terms of time and space. Section 3 using departure flights as an example, introduces the three policies, their application scenarios, and the problems they can solve. Part 4 summarizes the paper.

2. Analysis of Perspectives on Flight Scheduling

Airport scheduling can be viewed from a time perspective as flight departure/landing scheduling, and from a spatial perspective as runway scheduling and ramp scheduling. The time perspective focuses on executing existing plans and ensuring overall efficiency, while the spatial perspective focuses on maintaining order and improving efficiency in the details.

2.1. Flight departure/landing time scheduling

Departure/landing scheduling is the coordination of when incoming flights land and when departing flights take off. Generally speaking, due to the airport's primary mission of serving passengers, this scheduling strategy is the primary consideration among all the scheduling strategies of the airport under normal circumstances to coordinate flights efficiently and on-time to ensure that passengers' schedules are not interrupted.

In this type of scheduling process, as the airport pre-schedules daily flights from different routes, there is usually a pre-determined timetable for the tower to refer to during the scheduling process. This pre-determined scheduling scenario usually ignores special circumstances and their impacts to achieve the most efficient scheduling possible under ideal conditions. These ideal scenarios are usually based on fixed check-in/check-out times and no delays caused by special circumstances such as accidents or the absence of bad weather. However, these special circumstances cannot be avoided during actual execution. Therefore, in practical scheduling, the predefined scheduling plan is often subject to the real-time situation and cannot be strictly enforced. Despite this, airport scheduling still generally follows the guidance of the pre-determined plan in the execution process, because it is this pre-determined plan that determines the travel arrangements of passengers.

2.2. Runway scheduling

Runway scheduling is coordinating when and which runway is occupied by incoming and outgoing flights. The runway, as the main place for flights to and from the airport, its utilization maps the size of the airport's throughput, and to a certain extent, reflects the efficiency of flight scheduling. Efficient scheduling program not only helps the airport to save operating costs, but also ensures that flights can take off as early as possible.

Due to the existence of many factors that cause the fluctuation of flight arrival and departure times in real conditions, to ensure that flights that meet the takeoff or landing conditions are on time as much as possible, runway scheduling often pursues a high utilization rate in the actual scheduling process. In this way, flights that do not meet the conditions for takeoff or landing can be avoided from occupying the runway and causing delays to subsequent flights.

2.3. Apron scheduling

Apron scheduling is the coordination of parking spaces occupied by arriving/departing flights. In large airports, apron scheduling can significantly impact the overall efficiency of arrival and departure.

Different airports may have multiple terminals and very differently located boarding gates due to different planning and construction. These factors impact the time it takes for an aircraft to be ready for takeoff or to get into the departure queue. Therefore, efficient apron scheduling is important for overall efficiency and safety.

The three major types of scheduling above determine the final scheduling results from different perspectives of time and space, which influence the efficiency of flights entering and leaving the airport. Especially the previous two types of strategies have a significant impact on the overall effect of airport flight scheduling, and these two types of scheduling strategies are the main targets of all scheduling policies. The following section will take flight departure as an example and introduce the three policies from the perspective of flight departure time scheduling and runway scheduling.

3. The Application of Three Policies in Flight Departure Scheduling

In order to measure the efficiency of the scheduling strategy (e.g., task arrival rate, waiting time, and execution time) for the task "Flight Departure", the task is divided into two major phases based on whether the task starts executing or not to facilitate the subsequent analysis. The two phases include "task loading" (the waiting time after task arrival) and "task execution".

The task load time covers the time from the opening of check-in to completing boarding for a flight. The airport allocates the task loading time to avoid congestion at the terminals and to assure an orderly and efficient check-in service. Generally speaking, loading times are similar between flights departing from the same airport in the same time period. This means that the arrival rate of tasks within the same time period is relatively stable and will not fluctuate too much. For the airport's daily flight departures, it also helps to ensure that task arrival rates are predictable to help the airport plan ahead for scheduling.

Task execution time, in the context of "scheduling the departure of a flight", can be defined as the time taken from the end of boarding to the actual departure of the flight from the runway. Unlike task loading time, task execution time is significantly different due to several non-negligible factors - the time it takes to load fuel, luggage, and conduct takeoff inspections varies greatly depending on the distance to be flown and the type of aircraft to be carried. For example, short-haul, regional flights are usually operated by narrow-body aircraft with a capacity of around 100 passengers. These flights are fueled only for short distances, usually carry less luggage, and have shorter takeoff inspection times. In contrast, long-haul and mainline flights are generally operated by larger aircraft due to the large number of passengers and longer flight distances. Mainline flights usually carry more passengers and luggage; longer routes mean more fuel consumption and more complicated takeoff inspections. For these reasons, mission execution time varies greatly from flight to flight. For flights in normal condition, this task execution time is predictable.

3.1. First Come First Serve

First Come First Serve policy (FCFS) is a policy that determines the order of execution by prioritizing the arrival time of tasks, in which the tasks that are loaded into the queue first will be executed first.

In the daily scheduling of airport flight departures under real conditions, the number of flights affected by delays is normally only a small percentage of the total number of departures. This means that the airport's pre-schedule is accurate and efficient in terms of overall sequencing, and the order in which most of the flights enter the queue and execute is also determined by the pre-schedule. As a result, FCFS has become the primary method of scheduling departure times at airports. This method gives flights with earlier scheduled departure times a higher priority. This priority is applied throughout the entire scheduling process, including the loading and execution of tasks. FCFS is the most basic and effective scheduling method to ensure the basic order of departure scheduling, which keeps the majority of flights on time and schedule.

The more rigid limitations of the FCFS strategy become obvious when delays or other unforeseen circumstances prevent the planned schedule from being realized due to unavoidable factors. If other algorithms are not introduced to cope with the situation and continue to execute the preset schedule, the subsequent flights in the queue will be delayed one after another. As a result, it is necessary to introduce other algorithms to solve this kind of problem in the actual scheduling process.

3.2. Small Job First

Small Job First policy (SJF), is a policy that prioritizes the execution order based on the execution time of the tasks. In this policy, regardless of the order of arrival of the tasks in the queue to be executed, the task that takes less time to execute will always be executed first.

In the practical flight scheduling process, the number of runways, as the actual place to undertake the "airplane takeoff" task, is always limited. Therefore, when airports are facing high throughput pressure, in order to avoid long runway occupation by long execution time tasks and to ensure the on-time performance of most of the flights, the demand of scheduling strategy is shifted to the rapid processing of a large number of routes. Thus, the SJF strategy is used in the scheduling process due to its attribute of low average waiting time.

Due to the natural negligence towards long tasks of SJF policy, a full-scale application will inevitably lead to long delays for tasks with long execution times. It is equally important for airports to consider different flights with long and short execution times in a balanced way, so SJF is suitable for partial application. This can be achieved by loading some of the short execution time tasks into some runways and scheduling them with SJF strategy, while executing the existing schedules on the other runways with FCFS policy in order to ensure the on-time performance of the long execution time flights. A typical example is Hartsfield-Jackson Atlanta International Airport (KATL). As a high-volume international air transportation hub, KATL carried nearly 2,500 passenger flights on July 18, 2024, as well as approximately 300 cargo flights. During peak periods, passenger flights take about 2 minutes each to depart, while cargo flights depart at a rate of about 5 minutes each. Through the partial deployment of SJF, passenger flights with shorter execution times are prioritized to ensure efficient departures at the airport.

In general, SJF is utilized in airport scheduling applications, which need to consider both the spatial perspective of runway scheduling and the time perspective of departure time scheduling. As a solution for high load conditions, SJF is undoubtedly effective.

3.3. Shortest Remaining Processing Time

The shortest Remaining Processing Time policy (SRPT) is a policy that prioritizes the execution order over the remaining task execution time. Unlike FCFS and SJF, SRPT is a preemptive policy: the task's remaining processing time affects the existing queue order in real time. Tasks with less remaining execution time are always given higher priority.

There are always delayed or even canceled flights in the real airport scheduling process. The circumstances that lead to delays or cancellations are complex and varied: previous flights do not arrive on time or the weather conditions are not suitable for departure. Though the percentage of delayed or canceled flights is usually small, if they are not handled and still dispatched according to the original queue, the subsequent flights may be affected in a wide range. In the face of delays, SRPT policy, due to its preemptive nature, can respond in a timely and efficient manner when dealing with abnormal situations.

For an airport under normal operation, especially during the daytime, runway utilization should be maintained at a high level to ensure that flights are scheduled to depart at the right time. When the utilization drops abnormally, it means that the pre-defined schedule is failed. In order to maintain the runway utilization, the scheduling strategy will be temporarily shifted from FCFS to SRPT by comparing the schedules and prioritizing the tasks with a short remaining execution time. This will shift flights that are already ready or can be ready for takeoff earlier. The SRPT will be continued until the delayed flights get the right conditions for departure. Due to the existence of the schedule, the advanced flights are usually located in the immediate vicinity of the delayed flights, which ensures the punctuation of latter flights and guarantees that the remaining part of the schedule will be executed.

SRPT takes the perspective of runway scheduling as an entry point to address the subsequent impacts of delays by improving runway utilization, thus guaranteeing on-time flight. It is an essential part of the dynamic management of airports.

4. Conclusion

This essay presents a perspective analysis of flight scheduling from a temporal as well as a spatial point of view. It introduces the problems solved by the three policies in flight scheduling and how they are applied in a modularized form. For flight scheduling, which is a complex task as a whole, efficient and on-time dispatching methods is only one of the requirements. A good scheduling strategy should consider the optimal solution of scheduling cost to guarantee safety. Through the introduction and discussion of modularization, this essay provides reference ideas for the design of subsequent scheduling systems. The dynamic system of flight scheduling should be able to cope with a variety of possible situations, combine various modules efficiently and improve them to solve the problems. It is believed that more advanced algorithms will be developed and applied to flight scheduling models in the future.

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