
Models Responding to Large-area Flight Delays in Aviation Production Engineering

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Abstract

Large-area flight delays have a serious impact on aviation safety and bring huge losses to airlines. Flight rescheduling is a classic aviation production engineering. Based on flight priority levels, models are built responding to large-area flight delays in this paper. The models adopt different rescheduling rules to flights in different status. Meanwhile they take the restraint of connection of flights and surplus flight time of IA flights (flights in the air) into account, which makes the model accord with practical situation. A case study is given which demonstrate the Effectiveness of the models. The models provide significant theoretical basis to airline flight rescheduling.

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Keywords: Aviation production engineering, Large-area flight delays, Flight rescheduling, Integer programming model

1. Introduction

Flight delays are caused by some unavoidable factors such as severe weather. They are called large-area flight delays when the delay degree reaches to a certain level measured by the number of delayed flights and the delay time. They disrupt the normality of scheduled flight seriously and have significant impact on aviation safety. The passengers are delayed and their trips are even cancelled. The airlines are confronted with huge losses, poor quality service and low credit. With the rapid development of domestic and international aviation industry and the expanded aircraft fleets of airlines, large-area flight delays have become one of the challenges that hinder the development of aviation industries. It becomes the urgent problem for airlines to reschedule flights when large-area flight delays happened.

Flight rescheduling is classic aviation production engineering. Flight interference is caused by numerous reasons in complicated situation, domestic and international scholars had never ceased their study in flight rescheduling in recent decades. Teodoric and Stojkovic put forward a dynamic programming model, which minimized the number of cancelled flights and delayed passengers [1]. Jarrah introduced two minimum cost flow models, adopting the shortest path for solution by considering flight delay and cancellation [2]. Yu brought forward a network flow model of two commodities, but at that time solution was not provided [3]. These network models are mainly suitable for small-scale flight rescheduling. Yan et al integrated flight delay and cancellation into one model and studied the problem of flight recovery by utilizing time-space network model [4-5]. Argüello and Bard et al studied the problem of flight recovery by using of time band network model, which converted aircraft routing problem into network flow model based on discrete time [6]. Thengvall et al introduced the concept of arc protection based on time band
network model and time band network model take the connection of flights into account well, however they do not take runway’s capacity for flight into consideration. Zhengping Ma et al provided an airport flight delay optimization model, which regards the taking off and the landing of flights as two closely related processes [8]. They tested, analyzed and processed possible delays happened within a few hours. Xiaohao Xu et al studied application of genetic algorithm in aircraft sequencing, building a mathematical model of multi-plane sequencing in multi-runway, whose objective was to minimize delay time [9]. For large-area flight delays, considering the economic cost and referencing immune response mechanism of biological immune system, Jinling Ji, Jianli Ding and Jianxiong Huang et al put forward a rapid recovery model [10]. They achieved B cell clone selection by compromise immune algorithm to optimize recovery and scheduling for flight delays, which had advantage over first-come-first-serve scheduling method.

The literature review shows that the previous studies of flight rescheduling mainly consider the flight cancellation and the minimization of flight delay time, and they scarcely research flight rescheduling responding to large-area flight delays and no scholar takes flight status into account. In this paper, based on flight rescheduling rules, flight rescheduling models responding to large-area flight delays are built.

2. Modeling

Each flight is in different status when large-area flight delay occurs, and corresponding rescheduling rules should be given according to their statuses when coping with real time flight delays.

Flights in the first status are flights whose passengers are boarding or have boarded, including WR flight (flight waiting for taking off on the runway), BD flight (boarded flight) and BG flight (flight whose passengers are boarding). WR flight is flight that plane has been pushed out and is waiting for taking off on the runway; BD flight is flight whose passengers have all boarded and the plane has not been pushed out and BG flight is flight whose passengers are boarding. For this class, as aircrew and planes have been dispatched and passengers are boarding, these flights are the top priority in flight release plan. Flights in the second status are IA flights (flights in the air), which have taken off but have not landed yet. Due to fuel limit, arrival time limit has to be taken into consideration when rescheduling flights.

Flights in the third status are NB flights (flights whose passengers have not boarded). They have the following two conditions: the delayed NB flights and normal NB flights. The former is priority when rescheduling flights.

Besides flight status, flight priority level is also needed to be considered in flight rescheduling. It is a feature of flight, which represents the attention airlines highly focused on. For instance, flight with VIP (Very Important Person) is in a higher priority level than other flights and international long-distance flight is in a higher priority level than domestic flight.

According to flight status and priority levels, flights will be rescheduled step by step when large-area flight delay occurs. The first step is to reschedule flights in the first status and the rescheduling rules are as follows:

Rule (1): IR flight is prior to BD flight and BD flight is prior to BG flight;

Rule (2): High priority level flights will be rescheduled preferentially based on rule (1);

Rule (3): Flights with the same priority level will be rescheduled according to planned flight time. For the flights which have taken off, the planned flight time is planned landing time, and for those who haven’t taken off, the planned flight time is planned departure time.

The second step is to reschedule NB flights and IA flights, the rescheduling rules are as follows:

Rule (4): High priority level flights will be rescheduled preferentially;

Rule (5): Flights with the same priority level will be rescheduled according to planned flight time.

Rule (6): Flights in the same flight string conform to continuity, namely meet the requirements of flight transit time, where the flight string is set of flights assigned to the same aircraft according to flight plan.

Rule (7): IA flights should conform to restraint of surplus flight time which is the left time for the aircraft to finish the current flight according to the remaining oil.

\[ F : \text{ Set of flights.} \]

\[ F_k : \text{ Set of LD flights for } k = 1; \text{ Set of NT flights (flights which have not taken off) for } k = 2; \text{ Set of IA flights for } k = 3; \text{ Set of BG flights for } k = 4; \text{ Set of BD flights for } k = 5; \text{ Set of WR flights for } k = 6. \text{ Obviously, we} \]
have \( F = F_1 \cup F_2 \cup F_3 \) and \( F_4 \cup F_5 \cup F_6 \subset F_2 \).

- \( L_i \): Flight string \( i \).
- \( l_y \): Flight \( j \) in flight string \( i \).
- \( Dp_y \): Airport of departure.
- \( Ap_y \): Airport of destination.
- \( TA_y \): The latest landing time for IA flight \( l_y \) in \( F_3 \).
- \( D_y \): The planned departure time for flight \( l_y \) in \( F_2 \) and the actual departure time for flight \( l_y \) in \( F_1 \) or \( F_3 \).
- \( A_y \): The planned landing time for flight \( l_y \) in \( F_2 \) and the actual landing time for flight \( l_y \) in \( F_1 \) or \( F_3 \).
- \( t_y \): The planned flight time of the flight \( l_y \) which is the difference between the planned landing time and the planned departure time.
- \( P_y \): The priority level of flight \( l_y \). The smaller the value, the higher the priority level is.
- \( G_y \): The standard transit time of flight \( l_y \) at its destination airport \( Ap_y \).
- \( M \): A number that is large enough so that the second part of the objective functions is prior to be achieved.
- \( En_r[t_1,t_2] \): The runway’s capacity for departure and landing flights at airport \( r \) in time interval \([t_1,t_2]\). For example, if \( En_r[7:00,8:00]=10 \), then airport \( r \) may guarantee departure and landing of 10 flights in time interval 7:00-8:00.

Assumption: The rescheduled flight times are evenly distributed in the time interval \([t_1,t_2]\).

According to the assumption, the time interval \([t_1,t_2]\) is divided into \( En_r[t_1,t_2] \) sections evenly. Then we can get a time scale axis for each airport and every time scale will be assigned to a rescheduled flight. Let \( T_r \) be the set of time scale.

- \( \hat{D}_y \): The rescheduled departure time of flight \( l_y \) in \( F_4 \cup F_5 \cup F_6 \).
- \( \hat{A}_y \): The rescheduled landing time of flight \( l_y \) in \( F_4 \cup F_5 \cup F_6 \).

Then we build the following mathematical programming model.

\[
\begin{align*}
\text{(P1)} & \quad \max \sum_{r \in T_r} (u_{ijkl} - M \times \hat{D}_y) \\
& \quad (\hat{D}_y - \hat{D}_{kl})(u_{ijkl} - 0.5) > 0, Dp_y = Dp_{kl}, i \neq k, l_y \in F_4, l_{kl} \in F_4, m > n \quad (1) \\
& \quad (\hat{D}_y - \hat{D}_{kl})(u_{ijkl} - 0.5) > 0, Dp_y = Dp_{kl}, P_y > P_{kl}, i \neq k, l_y \in F_4, l_{kl} \in F_4, m = n \quad (2) \\
& \quad (\hat{D}_y - \hat{D}_{kl})(D_y - D_{kl})(u_{ijkl} - 0.5) > 0, Dp_y = Dp_{kl}, P_y = P_{kl}, i \neq k, l_y \in F_4, l_{kl} \in F_4, m = n \quad (3) \\
& \quad \hat{D}_y \geq D_y \quad (4) \\
& \quad \hat{D}_y \in T_r, l_y, l_{kl} \in F_4 \cup F_5 \cup F_6; u_{ijkl}, v_y \text{ are all 0-1 variables} \quad (5)
\end{align*}
\]

The objective function of programming (P1) ensure the flight rescheduling conform to rules (1) to (3) and make the rescheduled departure time be as early as possible for every flight. Inequations (2) to (4) ensure the objective function conform to rules (1) to (3). Inequation (5) ensures that the flight cannot take off before schedule. Inequation (6) is limit of some variables.

Based on programming (P1), \( \hat{D}_y \) are calculated for flight \( l_y \) in \( F_4 \cup F_5 \cup F_6 \). We assign the values of \( \hat{D}_y \) to \( D_y \) and let \( \hat{D}_y = \{\hat{D}_y\}, F_3' = F_4 \cup F_5 \cup F_6 \). Then we can reschedule the remaining flights by programming (P2).
The objective function (7) of programming (P2) ensure the flight rescheduling conform to rules (4) to (7) and make the rescheduled departure time be as early as possible for every flight. Inequations (8) to (11) ensure the objective function conform to rule (4). Inequations (12) to (15) ensure the objective function conform to rule (5). Inequation (16) ensures that the flight cannot take off before schedule. Inequations (17) and (18) ensure the objective function conform to rule (7). Inequations (19) to (21) ensure the objective function conform to rule (6). Inequation (22) is limit of some variables.

3. Case study

In this section a case study is given with taking 1000 flights of some airline company for examples and only 60 flights of them are illustrate in table 1 for lack of space.

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Annotation: Fi is the flight i of some airline company. Pi is the priority order of the flight i. Dpi is the airport where the flight i taking off. Di-Plan is the planned time for the flight i to take off. APi is the airport where the flight i landing on. Di-Real is the real historical time for the flight i to take off. Ti-Rdelay is the real delay time of the flight i. Di-Adjusted is the rescheduled time computed by the models for the flight i to take off. Ti-Adelay is the computed delay time of the rescheduled flight i.

They are outgoing flights in some airport (airport A) needed to take off in the next three hours. The runway’s capacity for departure flights at the airport in time interval is 32. The runway’s capacity for departure flights at the airport in time interval is 13. The runway’s capacity for departure flights at the airport in time interval is 15. The flights 1 to 60 were rescheduled by the models and the result is shown in table 2.

Table 2: Rescheduled flights

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<td>0:41</td>
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With the comparison in table 3, we find the computed time is better than the real historical time for flights of the first 10 priority. Each computed delay time is 20 minutes less than the real one on average.

Table 3: Comparison between the real delay time and the computed delay time

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<th>Fi</th>
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<th>41</th>
<th>55</th>
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</table>
4. Conclusion

Large-area flight delays have a serious impact on aviation safety and may bring huge losses to airlines. Based on different flight status, two nonlinear mixed integer programming models in aviation production engineering are built. In this paper, the rescheduling rules come from practical project, and the models are suitable for guidance of airlines operation control department. A case study is given which demonstrate the Effectiveness of the models. While there are also limitations in this paper, for models are built under the hypothesis that the rescheduled flights time are distributed evenly in the time scale axis, and we do not take crew and passengers into account, which needs further improvement in the future research.

References