Original Research Article

Departure Flight Delay Cost Study

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Abstract: The calculation aimed at the delay cost caused by the delay of departure flight is of certain referential importance in defining the cost of the delayed flight. This paper analyzes the aircraft departure process and the generation of flight delay costs and discusses the composition of flight delay costs in the departure process. the delayed departure flight is used as the research object, this paper analyzes the difference between the type of flight and the aircraft type takes the influences on the guest rates of the departure flight type into consideration and builds the calculation model of the delay cost of the departure flight; finally, the cost calculation formula of the departure delayed flight is given.

Keywords: Departure flight; Delay cost; Aircraft type; Flight type; Passenger load factor.

1. Introduction

With the gradual popularization and universalization of civil aviation passenger transportation, the volume of civil aviation passenger traffic and flights have increased significantly, only in 2019 the volume of civil aviation passenger traffic exceeded 600 million passengers, hub airports around the world and the air traffic control system is under enormous pressure; flight delays have also increased and caused huge losses, measured by Zhu Jiang and others. In 2018, the four major domestic airlines' delay costs increased by more than 72 billion yuan." In addition, the flight departure stage is the most sensitive stage for flight delays to occur; passengers, as the service objects of civil aviation, have the most direct perception of the actual departure time or departure time of flights, and excessive waiting or delay time will cause negative changes in passengers' emotions. Therefore, it is extremely important to study the delays of departing flights.

Many Chinese and foreign scholars have conducted a lot of research on the calculation problems related to flight delay costs. Zhao Wenzhi and others improved the delay cost model of domestic airlines by drawing on the cost analysis theory of ATA (Air Transport Association of America). Liu Yanhong and others analyzed the impacts caused by the economic losses of flight delays of different models; Yang Sai and others transformed the flight delay time into the passenger delay time and The cost of passenger delay time in ground waiting is investigated. Xia Zhenghong and others discuss the cost changes of onboard auxiliary power units and bridge equipment during ground waiting of delayed flights and establish a costing model for ground waiting of delayed flights, but do not explicitly consider the value of passenger time, fuel consumption of different aircraft types and ground service expenditures. Chen Minamata Xiu and others construct a model that considers the delay time of flights as the transcendental logarithmic cost function model is used as a variable to assess the total loss of flight delays of four major domestic airlines, but it does not consider enough the delay costs of passengers and the delay costs of flights in various stages of operation. Yang Xukai and others believe that better costing data can only be obtained by taking into account the delay costs of the airlines, passengers and other aspects of flight delays. In foreign countries, there are earlier studies on the cost of flight delay, Graham and others quantified the actual cost of one minute of delay on the ground and in the air of European airlines"; Muller and others assessed the cost of aircraft operating delays by taking aircraft air delays and ground delays as the object of their study; Hansen and others calculated the total delay cost by analyzing the total operating costs of airlines in each quarterly report; Aktirk and others developed a flight recovery optimization model by using cruise speed as a decision variable and introducing it into the cost coefficients for the first time.

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The above literature has described in detail the overall delay cost and the calculation model of delay cost (ground and air) in each stage of aircraft operation, and the delay cost is mainly borne by the airlines who directly bear the loss of the passenger group. Therefore, based on the research of the above scholars, this paper will differentiate the airline delay cost and passenger delay cost in flight delay based on the development of aviation logistics on the different types and models of flights, and introduce the impact of the model on the passenger rate to analyze and calculate the delay cost of departing flights. Finally, the article takes the flight operation data of Shuangliu Airport in a day in January 2018 with a high flight frequency period as an example to simulate the delay cost.

2. Definition of Flight Delay

At the end of the 1920s, the Warsaw Convention on International Civil Aviation Transportation mentioned the term "delay" for the first time, and then the Hague Protocol and Montreal Convention were signed successively to improve the norms of air transportation, but the meaning of delay or delayed flights and the determination standards are still not given in detail; with the development of the times, there are differences in the situation of civil aviation transportation in different countries, resulting in greater differences in the definition and determination standards of flight delay. With the development of time, there are differences in the situation of civil aviation transportation in different countries, resulting in the definition of flight delays and the criteria for determining flight delays are quite different.

By analyzing the standard flight procedures for an aircraft performing a flight mission, it can be seen that its main components are the preparation of take-off preparation phase (closing the hatch), the departure phase (removing wheel gear, launching, driving, taxiing), takeoff phase (climbing, cruising, descending, approaching or waiting) and approach phase (approach landing, sliding in, blocking wheel gear, opening the hatch), and the main activities in a typical departure phase as shown in Figure. 1 refer to the following: the aircrew closes the hatch, the ground crew removes the wheel gear, the flight crew applies for a launching and driving instruction from the controller, and is allowed to operate the operation after the instruction is approved; the flight crew The crew applies to the controller for a taxi out instruction and waits at the specified position on the runway section according to the taxi route; the controller issues a takeoff permission instruction and the aircraft enters the runway to taxi for takeoff to the departure altitude; at the same time, the delayed flights are delayed for a longer period of time, for which the difference in time can be judged as delayed or not.

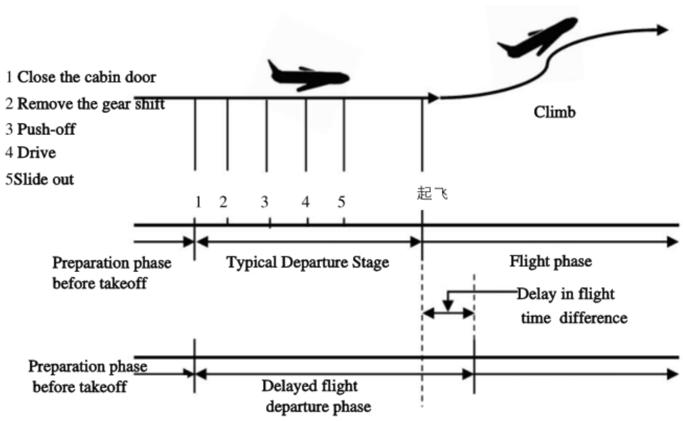

Figure 1 Typical departure stage and departure stage process of delayed flights.

In addition, scholars have done a lot of comparative analysis on the definition of flight delay in the literature related to flight delay, so this paper will not discuss too much about the definition of flight delay; Chapter 1, Article 3 of the 2016 Domestic Flight Regularity Management Provisions states that the definition of "flight delay" and "flight departure delay" is the same as the definition of "flight departure delay". The definition of "flight delay" and "flight departure delay" in Chapter 1, Article 3 of the 2016 Domestic Flight Normal

Management Regulations states that “flight delay” and “flight departure delay” are defined as “cases where the actual arrival time of flights is more than 15 minutes later than the planned arrival time” and “cases where the actual departure time of flights is more than 15 minutes later than the planned departure time”, which are combined with the relevant literature on flight delays. Combined with the relevant literature on flight delay, the statistical method of flight delay time is derived as follows: On the basis of the standard taxiing time T_s at the airport, if the difference between the planned departure time T_1 and the actual departure time T_0 is more than 15 min, assuming that the taxiing time is 30 min, the delay time of the departing flights will be $t = T_1 - T_0 = 30$.

3. Analysis of the Cost of Delayed Departures

The cost of delayed departure flights mainly refers to the additional costs that need to be paid during the delayed departure flights or the losses suffered by the flights that cannot operate normally. Article to departure flights as the object of study, through the previous analysis of departure flight delays can be seen: when the departure flight delays will hinder the normal departure procedures of the aircraft, the cost is the airline to resume the delayed flights to bear the cost; at the same time, the flight passengers will not be able to carry out the normal flight departure procedures, and stranded at the airport to produce passenger delay costs, resulting in the inability to carry out the normal trip and production activities, thus making the traveler unable to create value in the corresponding time, so the passenger delay cost can be quantified according to the value of time (Value of Travel Time, VTT) on the realization of the value of the traveler's time. In addition, due to the development of aviation logistics, the gradual establishment of cargo flight routes for transporting cargo and mail, the flight type is divided into cargo flights and passenger flights; therefore, the delay cost of passenger delay is not involved in the delay of cargo flights. Therefore, the expression of delay cost C_d^e of departure flights is shown in Eq.1:

$$C_d^e = \begin{cases} C_A + C_{P1}(\text{Erefers to passenger flights}) \\ C_A(\text{Erefers to cargo flights}) \end{cases} \quad \text{(Eq.1)}$$

Equation (1) where C_A denotes the cost of airline delays C_{p1} and denotes the cost of passenger delays.

3.1 Cost of Airline Delays

According to Air China's operating costs for fiscal year 2019, as shown in Figure 2, operating costs mainly include aviation fuel costs, landing and take-off and parking expenses, depreciation and leasing costs, aircraft maintenance, repair and overhaul costs, employee compensation costs, airline catering costs, Civil Aviation Development Fund (CADF), other main operating costs, and other operating costs.

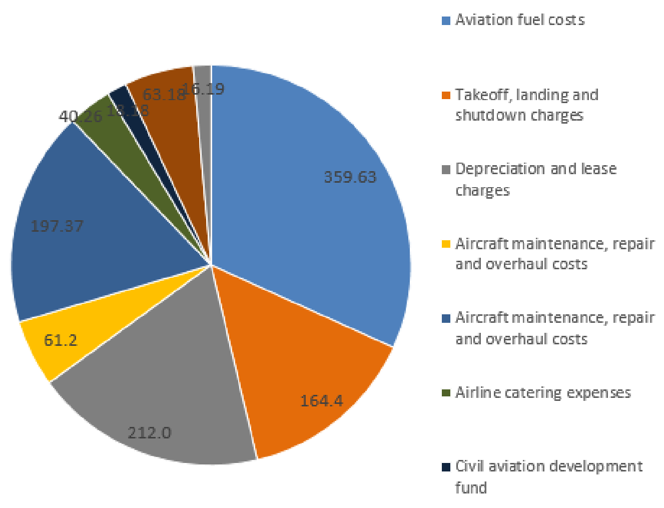

Figure 2 Air china fly 2019 operating cost distribution statistics.

As a result, airlines incur direct economic losses due to additional fuel consumption by aircraft, airport service costs and crew costs during departure delays, and delayed flights result in passengers being stranded and unable to make their normal journeys. According to the “Flight Normalization Regulations”, airlines will pay for passenger compensation costs, which also involves the costs of aircraft, airport, passenger crews and ground crews; the costs incurred by airlines during departure delays are mainly fuel costs and non-fuel costs (additional crew costs, maintenance costs, passenger compensation costs and other fixed costs (aircraft depreciation, leasing, and additional airport services, etc.), as shown in Eq.2:

$$C_A = C_f + C_0 \tag{Eq.2}$$

In Equation (2): C_A is fuel cost, C_0 is non-fuel cost

3.2 Cost of Passenger Delays

According to the different purposes of travelers, the passenger groups are divided into two categories: productive business traveler groups (e.g., business trips, work, etc.) and consumptive leisure traveler groups (e.g., pleasure trips, family visits, etc.) The time value of travelers is different from that of business travelers, which in turn generates different time values. For the quantification of time value, there are mainly the income method, the production method and the willingness-to-pay method, among which the income method can quantify the time value of travelers more directly.

Among them, the business traveler group can create production value for enterprise units and society, which will promote the development of social economy and improve the gross national product (Gross National Product, GDP), can be used per capital GDP and employee production work time w to calculate the business traveler's unit cost of time; leisure traveler group is in the rest or non-work period of recreational activities, mainly consuming personal accumulated economic income. It mainly consumes the economic income accumulated by individuals, so it is calculated using the relationship between per capital income (Per Capital Income, PCI) and productive working time w . Therefore, the time cost of a single traveler, V_P, is quantitatively calculated as shown in Eq.3:

$$V_p = \begin{cases} \dfrac{\overline{GDP}}{h} & p = b \\ \dfrac{PCI}{h} & p = l \end{cases} \tag{Eq.3}$$

In equation (3): V_p denotes the time-value cost of traveler type p, b is business traveler, 1 is leisure traveler, and h is working time (assuming a total of 365 days in a year, excluding national holidays such as weekends, National Day and Chinese New Year, and based on an 8-hour working day, h is about 120,000 min); in 2018 $\overline{GDP}$ = 64,520.7 yuan, PCI = 28,000 yuan.

4. Research on the Calculation of Flight Delay Costs

4.1 Airline Costs

The airlines mainly include two parts, fuel cost and non-fuel cost, in the process of delayed departing flights.

4.1.1 Fuel Cost

For the fuel cost part, mainly the aircraft in the delay process needs to consume additional fuel to maintain the operation of basic equipment on board the aircraft or to provide basic services for passengers, this cost is affected by the time and unit time fuel consumption rate. The thrust required to keep the aircraft in operation varies by model, and the fuel consumption f_c and fuel cost c_f of aircraft engines are shown in Eq.4 and Eq.5:

$$C_f = f_p \bullet f_c \tag{Eq.4}$$

$$F = f_r^a \bullet \mathrm{t} \tag{Eq.5}$$

Where f_r^a is the fuel consumption rate per unit of time for flight aircraft type a, t is the delay time of the departing flight, and f_p is the unit price of fuel (before the price adjustment in May 2020, the comprehensive procurement cost of aviation kerosene was 3.029RMB/kg).

Based on the estimated statistical data of taxiing fuel consumption of different aircraft models, and combining the relationship between the fuel consumption of aircraft to generate thrust and fuel flow rate (taxiing thrust coefficient is 8%, stationary waiting 3%) , the fuel consumption per unit time and fuel unit time cost of each aircraft model during the departure delay are calculated as shown in Table 1.

Table 1 Fuel consumption per unit time for each aircraft type in taxiing phase and waiting phase for departure delay fuel consumption and unit time cost of fuel for departure delays.

Models	Fuel consumption per unit time during taxiing phase(kg/min)	Departure delay waiting stage fuel consumption per unit time consumption(kg/min)	Delayed Departure Flights Unit time cost of fuel(RMB/min)
System 320	11.5	4.93	14.93
System 330	25	10.71	32.44
System 340	25	10.71	32.44
System 737	11.35	4.86	14.72
System 747	45.4	19.46	58.94
System 757	18	7.71	23.35
System 767	22	9.43	28.56
System 777	35	15	45.44
M90 and other light machine series	16	6.86	20.78

Note: *A certain series of models includes its similar series of models, e.g. 320 series models include A320, A321, A319, etc.*

4.1.2 Non-Fuel Costs

The non-fuel unit time cost of aircraft mainly includes the unit time cost paid by aircraft maintenance and operation during the departure delay phase C_a and is affected by the aircraft type and combined with the commonly used classification method of the strong and weak aircraft types of wake turbulence, the non-fuel unit time cost is as shown in Table 2, so other aspects of the cost C_0. This is shown in the Eq.6.

$$C_0 = C_a \bullet t \qquad \text{(Eq.6)}$$

In Eq.6 where C_a is the non-fuel unit time cost of flight type a.

Table 2 Fuel consumption per unit time for each aircraft type in taxiing phase and waiting phase for departure delay fuel consumption and unit time cost of fuel for departure delays.

Wake classification	Heavy Model	Middle Model	Light Model
Model	B767、B777、B747、A300、A310、A330、A340、A380	B737、B757、A318、A319、A320、MD82、MD90、ERJ145/190、ARJ21	Y-5、Y-12、TB20/200
Ca(RMB/min)	148.7	8.4	5.6

4.2 Cost of Passenger Delays

After the previous analysis of a single passenger time cost calculation, and for a passenger delay flight, due to its model of passenger capacity, cockpit layout is different, will cause passengers to ride the advantages and disadvantages of comfort and fare differentiation, which in turn affects the implementation of the flight model of the passenger capacity and the passenger occupancy rate of the change of the gateway, the passenger occupancy rate of each model as shown in the table (the article only consider the impact of the different models, and therefore the brand effect of the airline); in addition to a flight airline in business passengers and leisure passengers distribution ratio is different, the number of these two types of passengers is also different, according to the 2004-2009 civil aviation business passengers and leisure passengers share of statistics. (The impact of the airline brand effect is not considered); In addition, a flight flight aviation in business passengers and leisure passengers distribution ratio is different, the number of these two types of passengers is also different, according to the 2004-2009 civil aviation business travelers and leisure travelers accounted for the proportion of the statistical value of the country, regression prediction, can be obtained in 2018, business and leisure travelers accounted for the proportion of the data were about 37% and 63%; a passenger cost C_P of a departure delayed flight is calculated as shown in Eq.7:

$$C_P = n_a \bullet w_n^a \bullet r_b \bullet V_b \bullet t + W_n^a \bullet r_l \bullet V_1 \bullet t \quad \text{(Eq.6)}$$

In Eq.7, n denotes the number of passengers carried by aircraft type a and is divided by the number of passengers carried by the aircraft as shown in Table 4, w_n denotes the occupancy rate of the flight type, r_b denotes the percentage of business travelers on the flight, r_l and denotes the percentage of leisure travelers on the flight.

Table 4 Aircraft capacity.

Aircraft	Model
Small craft(n ≤ 100 seats)	ARJ21(90 seats)、CRJ-700(70 seats)、CRJ-900(90 seats）
Middle craft(100 seats ≤ n2 ≤ 00 seats)	A320(150 seats)、A321(185 seats)、A319(124 seats)、B737(180 seats)、ERJ190(114 seats)
Large craft(n＞200 seats)	B777(451 seats)、B787(290 seats)、A330(335 seats)、A350(412 seats)、B757(243 seats)、B747(416 seats)、B787(290 seats)

Note: *The above models are the typical number of seats, and in accordance with the 2-level cockpit division statistics; the above models in accordance with the model series of the largest typical passenger capacity statistics, for example, the B737 series in the 2-level cockpit in the various models of the typical amount of seats were: 104, 146, 110, 126, 162, 180, so to determine that the B737 for the 180-seat; some of the large airliners cockpit distribution of the three levels, such as the B744, so the number of its cockpit in accordance with the number of 3 levels of statistics for the number of 416 seats.*

5. Data Calculation

Taking the departing flights of Chengdu Shuangliu Airport as the research object, the existing data of 10 flights at a peak hour on a certain day in January 2018 were selected for the algorithm, as shown in Table 5.

Table 5 Calculation of delay costs for departing flights by aircraft type.

Flight number	Airport of departure	Plan departure time	Actual departure time	Flight Type	Departure delay time(min)	Machine type	Flight delay costs(yuan)	Passenger delay cost(yuan)	Cost of delayed departures (yuan)	Unit time cost (yuan/min)
F1	ZUU	3:45	6:17	Freight transport	122	73F	2820.64	0	2820.64	23.12
F2	ZUU	7:30	9:13	Passenger transport	73	738	1687.76	3459.70	5447.46.19	74.62
F3	ZUU	7:35	8:35	Passenger transport	30	320	699.9	1281.65	81.55	66.05
F4	ZUU	7:35	9:03	Passenger transport	58	319	1353.14	2048.36	34014.50	58.65
F5	ZUU	7:40	8:34	Passenger transport	24	320	559.92	1025.32	1585.24	66.05
F6	ZUU	7:45	8:32	Passenger transport	17	320	396.61	726.27	1122.88	66.05
F7	ZUU	7:45	9:39	Passenger transport	84	737	1942.08	4326.26	6268.30	74.62
F8	ZUU	8:00	9:10	Passenger transport	40	333	7245.6	3663.50	10909.10	272.73
F9	ZUU	8:00	9:43	Passenger transport	73	320	1703.09	3118.69	4821.78	66.05
F10	ZUU	8:00	8:55	Passenger transport	20	320	466.6	854.43	1321.03	66.05

Calculations show that the cost of delaying passenger and cargo flights varies greatly, and there is a clear difference between the cost of fuel and the cost of delaying passengers between different types of aircraft, but it is still mainly affected by the length of the delay.

6. Summary

This paper firstly explains the definition of flight delay, then analyzes and discusses the delay of departure flights and the cost of departure flight delay, and divides the cost of departure flight delay into the delay cost of airlines and the delay cost of passengers, and puts forward the calculation of the difference between cargo and passenger of the flight type; secondly, according to the difference of the aircraft type, the differentiated calculation of the delay cost of the airlines and the passengers and the introduction of the impact of the aircraft type on the passenger rate; finally, the data of delayed departure flights at Chengdu Shuangliu Airport is used for the calculation. Finally, the data of delayed flights departing from Chengdu Shuangliu Airport are selected for calculation, and the results show that this paper can calculate the delay cost more accurately, which provides a reference for the calculation of flight delay cost; however, how to calculate the delay cost more accurately, it is still necessary to collect the relevant data in more detail and calculate the program for more systematic design.

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