Hindawi
Mathematical Problems in Engineering
Volume 2020, Article ID 5757948, 12 pages
https://doi.org/10.1155/2020/5757948

Research Article

Study on the Optimization Method of Point Merge Procedure Based on Benefit in the Terminal Area

Yong Tian, Dawei Xing, Lili Wan, and Bojia Ye

College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

Correspondence should be addressed to Lili Wan; wanlili@nuaa.edu.cn

Received 29 May 2019; Revised 31 January 2020; Accepted 10 March 2020; Published 6 April 2020

Academic Editor: Alessandro Gasparetto

Copyright © 2020 Yong Tian et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

With the rapid development of the air transport industry, the problem of airspace congestion and flight delay in the terminal area (TMA) becomes more and more serious. In order to improve the efficiency of flight operations in TMA, point merge procedure had been devised. This paper takes the approach routes in TMA as the research object, taking into account such conditions as obstacle clearance, flight interval, and procedure area. Based on the flight time, fuel consumption, pollutant emission, and noise impact, an optimization model of point merge procedure is constructed. Genetic algorithm is used to optimize the structure of procedure. The Shanghai Hongqiao International Airport is selected for simulation verification, and the actual flow distribution of the airport is analyzed as an example. The results show that the average flight time was reduced by 0.26 min, the average fuel consumption was reduced by 1,240.64 kg, the average NO_x emissions were reduced by 1.09 kg, and the noise impact range was contracted by 55 km^2 after optimization. The point merge procedure optimization method can be expected to reduce the flight time, fuel consumption, and environmental impact of flights in TMA, so as to optimize the aircraft approach trajectory.

1. Introduction

With the rapid growth of the global economy, the air transport industry is developing rapidly. By the end of 2018, the total turnover of civil aviation transport in China reached 120.64 billion tons, with a year-on-year growth rate of 11.4%. Passenger transport volume reached 610 million, with a year-on-year growth rate of 10.9%. The volume of cargo and mail transportation reached 7.385 million tons with a year-on-year growth rate of 4.6% [1]. With the booming of the air transport industry, the number of flights has surged. As the connecting area between the air route and the airport, the terminal area (TMA) frequently suffers from flight congestion, which causes unnecessary holding in the air and ground delays and increases the operating cost. It also leads to the additional workload on controllers and pilots and endangers air traffic safety. In order to strengthen the flight control, developed countries in Europe and the United States are exploring some new operation modes.

The Point Merge System (PMS) is an approach proposed by the experimental center of EUROCONTROL for the convergence operation of traffic flow in TMA. It relies on the existing Precision Area Navigation (P-RNAV), to effectively strengthen the arrival flow flight management in TMA. Besides, it advances the further application of Area Navigation (RNAV) and Continuous Descent Approach (CDA) in TMA.

Nowadays, domestic and foreign researchers have carried out research on point merge procedure. The idea of point merge was originated from the early research on the separation between the sequencing and converging aircrafts. Eurocontrol (2006) formally put forward the concept of point merge and adopted a systematic method to integrate inbound flows [2]. The European air traffic control center (2007) determined to carry out trial operation of point merge [3]. After that, some airports started real-time data simulation and pilot application. Ivanescu et al. [4] simulated the land situation that the inbound flows in four directions converged on a single runway landing by using the real-time simulation trajectory. Then, the advantages of point merge procedure in terms of flight trajectory dispersion and instructions counts have been studied by Sahin

Meric and Usanmaz [5]. In addition, Liang [6–10] combined the point merge procedure with Air Traffic Control (ATC) automation to evaluate the potential operational benefits of procedure in terms of flight efficiency and runway throughput. As research continues, Hong et al. [11, 12] proposed a sorting algorithm based on mixed integer linear programming for the flight operation of point merge procedure. In China, relative studies started relatively late. The concept of point merge was introduced by Chu et al. [13]. Then, a CDA procedure based on point merge configuration was designed for Xiamen TMA [14]. Chao et al. [15] evaluated the static capacity and descending gradient of the point merge procedure. In addition, Qi et al. [16] introduced the point merge approach convergence method based on the tactical level of current communication, navigation, and surveillance technology. In terms of security, Zhao and Lei [17] proposed the design method of the protected area according to the characteristics of the fan-shaped area in point merge procedure. According to the operation characteristics of point merge procedure, Wang et al. [18] proposed a 4D trajectory prediction method for aircraft. Through a series of small-scale simulation tests, the feasibility, advantages, and limitations of point merge procedure were studied. However, in the process of design, systematic theory and quantitative analysis methods of indicators are not yet established. The designers mainly rely on their subjective experience for analysis, so the advantages and disadvantages of the design procedure cannot be quantified, which is not conducive to the improvement and optimization of the procedure.

This paper focuses on the approach route. It plans the approach route considering efficiency during aircraft operation. Then, it takes flight time, fuel consumption, pollutant emission, and noise impact as optimization objectives on the basis of point merge structure to build an optimization design model of point merge procedure and optimizes aircraft approach trajectory in TMA. The main contributions of the paper can be summarized as follows:

(1) We propose the point merge procedure optimization method for optimizing aircraft approach trajectory in TMA
(2) The empirical results show that the method can successfully reduce the flight time, fuel consumption, and environmental impact of flights in TMA
(3) We performed the flow pressure operation during peak hours to verify the effectiveness of the method

The rest of this paper is organized as follows. The second part introduces the framework of point merge procedure from three aspects: principle, configuration, and specification. In the third part, four indexes and constraints of flight time, fuel consumption, pollutant emission, and noise impact are set, and an optimization model of point merge procedure is established. The fourth part uses genetic algorithm (GA) to solve the optimization model. The fifth part takes the Shanghai Hongqiao International Airport as an example for simulation analysis. Finally, the sixth part presents the conclusion and prospections.

2. Framework of Point Merge Procedure

At present, radar vectoring is the main means of flight control in TMA. In radar vectoring, there are many problems in radar guidance, such as large amount of control work, difficulty in vertical profile prediction, and large trajectory dispersion. In this section, we present the framework of point merge procedure.

Point merge procedure combines the advantages of RNAV procedure and continuous descent technology. It adopts the closed loop command of "direct to" the merge point and changes the open-loop heading guidance mode of radar vectoring. The structure of the point merge procedure is shown in Figure 1. The point merge procedure may be defined as an RNAV STAR, transition or initial approach procedure, or a portion thereof and is characterized by the features as follows [19]:

(1) A single point, denoted as "merge point," is used for traffic integration.
(2) Predefined legs, denoted as "sequencing legs," isodistant from the merge point, are dedicated to path stretching/shortening for each inbound flow. These legs shall be separated by design vertically, laterally, or both.

As shown in Figure 2, the combination of merge point with geometric convergence and sequence legs with path stretching ability makes the point merge procedure more flexible. Without the support of additional tools, the special path structure of point merge provides the controller with a structured and intuitive method to establish and maintain aircraft flight sequences.

3. Optimization Model of Point Merge Procedure

3.1. Model Assumptions. For standardizing the optimization process of arrival route in TMA and facilitating the description of the problem, the following assumptions are made for the model:

(1) Except for restricted airspace, TMA can be used everywhere, and all approaching aircraft can land safely without deviating or diverting.
(2) Aircraft use PBN technology, and navigation deviation is not included. The aircraft can fly along any desired trajectory.
(3) The impact of departure flight on arrival flight is not considered.
(4) Good meteorological conditions exist in TMA, and there is no weather condition affecting the safe operation of the aircraft.

3.2. Parameter Setting. Based on the basic principles of flight procedure design, this paper analyzes the affecting factors of point merge procedure design and studies the method of point merge procedure. Setting parameters are set as follows.

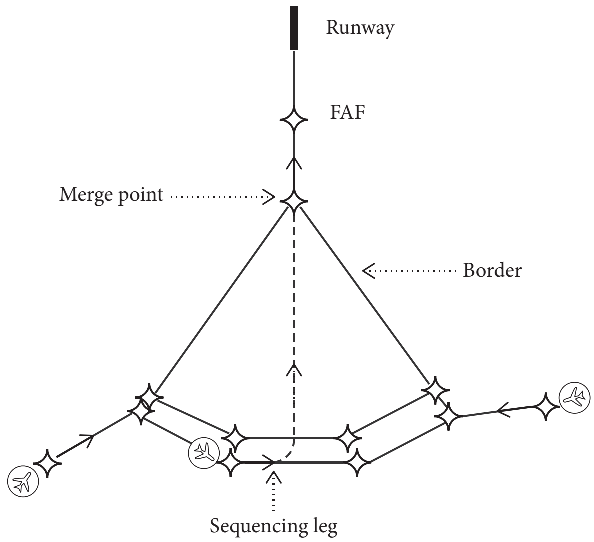

Figure 1: Structure of the point merge procedure.

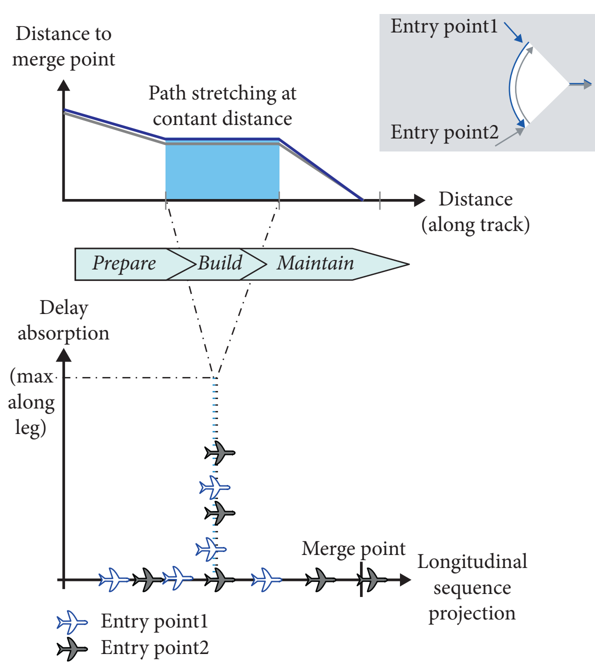

Figure 2: Profile of point merge procedure.

3.2.1. Selection of Merge Point. On the extended center-line of runway in TMA, within the range of 15 km to 40 km from the runway threshold, the traffic flow begins to converge and integrate, and the fix located on the extended center-line of the runway serves as the merge point of procedure. The altitude of merge point is generally within the range of 2,000 ft to 4,000 ft.

3.2.2. Sequencing Leg Setting. The sequencing leg is set with the merge point as the center of the circle, and the number of sequencing legs is usually determined according to the number of approach routes. When the routes with low flight flow are roughly the same, the same sequencing leg can be assigned to them. The horizontal interval between the two sequencing legs is set as 4 km. Each sequencing leg occupies a flight level, respectively. The vertical separation between every two flight levels is 300 m, and the inner side is high and the outer side is low. The altitude range of the outer sequencing leg is generally from 8,000 ft to 12,000 ft, avoiding the use of the transition level.

3.2.3. Angle Setting. Angle contains the convergence angle and offset angle; the convergence angle is the angle contained by the merge point as the center of the circle and the sequencing leg as the radian. The bigger the convergence angle, the longer the sequencing leg and the greater the amount of horizontal space program. Its range is commonly from 30° to 120°. The offset angle is based on the runway extension line, and its value indicates the angle from the extension line. When the offset angle equals 0, convergence angle bisector and extended center-line of runway overlap. The range is usually from −90° to 90° (the left is positive, right is negative).

3.3. Characteristic Indicators and Constraints. In the process of procedure optimization, relevant indexes should be set to guarantee the operation efficiency and to promote the optimization and rationality of procedure structure.

3.3.1. Flight Time. The flight time is calculated as

$$T = \frac{1}{n}\sum_{i=1}^{n} t_i, \tag{1}$$

where T represents the average flight time and t_i is the sailing time of flight i.

3.3.2. Fuel Consumption. Fuel consumption is calculated as

$$F = \frac{1}{n}\sum_{i=1}^{n} f_i \cdot N_i \cdot t_i, \tag{2}$$

where F stands for average fuel consumption; f_i is the fuel flow rate of flight i; and N_i is the number of engines i.

3.3.3. Pollutant Emission. Pollutant emission can be calculated as

$$E = \frac{1}{n}\sum_{i} N_i f_i \mathrm{EI}^i t_i. \tag{3}$$

NO_x, one of the largest emission in aviation, was selected for evaluation. Here, E is the average emission of pollutant NO_x and EI^i is the emission index of pollutant NO_x of flight i.

3.3.4. Noise Influence. Noise influence can be calculated as

$$\begin{aligned} Q(L) &= \sum_{(x,y)\in TS} \left[S(x,y) \,\middle|\, L_{WECPN} > L \right], \\ L_{\mathrm{WECPN}} &= \overline{L_{\mathrm{EPN}}} + 10 \cdot \lg\left(N_1 + 3N_2 + 10N_3\right) - 39.4, \end{aligned} \tag{4}$$

where L_{WECPN} is the daily Weighted Equivalent Continuous Perceived Noise Level (WECPNL) of the procedure and N_1, N_2, and N_3 are the number of flights during daytime, evening, and night. The specific number is determined by referring to the actual situation of the airport. Generally speaking, daytime is from 7:00 to 19:00, evening from 19:00 to 22:00, and night from 22:00 to 7:00. $S(x, y)$ is the area of the observed zone of which the center coordinate is (x, y). $\forall (x, y) \in TS$, where TS is the range of noise evaluation in TMA. In terms of noise, the Federal Aviation Administration (FAA) stipulates 65 dB DNL as the threshold of compatibility between aviation noise and residential land. Therefore, 65 dB is selected.

In order to ensure that the optimized procedure meets the actual requirements, relevant constraints on procedure operation and structure distribution are established as follows:

(1) Constraint on obstacle clearance:

$$H \geq H_{\text{OCA}}, \tag{5}$$

where H is the altitude of the route and H_{OCA} is the minimum safe altitude in the obstacle clearance zone.

(2) Constraint on separation:

$$\begin{aligned} C &= \sum_{i=1}^{n} c_i = 0, \\ c_i &= \begin{cases} 0, & d_{ij} \geq W_{ij}, \\ 1, & d_{ij} < W_{ij}, \end{cases} \end{aligned} \tag{6}$$

where C represents the number of conflicts; c_i is the number of conflicts flight i experiences; d_{ij} is the separation between two continuous flights i and j at any time; and W_{ij} is the separation of wake turbulence specified by the International Civil Aviation Organization (ICAO).

(3) Constraint on range:

$$\begin{cases} 30^\circ \leq \alpha \leq 120^\circ, \\ -90^\circ \leq \beta \leq 90^\circ, \\ 2000 ft \leq H_M \leq 4000 ft, \\ 8000 ft \leq H_L \leq 12000 ft, \\ 0 \leq \alpha_i \leq \alpha, \end{cases} \tag{7}$$

where α is the convergence angle; β is the offset angle; H_M is the altitude of merge point; H_L is the altitude of sequencing leg; and α_i is the angle at which the flight i turns on the sequencing leg.

The optimization of point merge procedure should not only consider the safety and rationality of its structure but also comprehensively consider the operation situation and benefits of the flight. Combining with the characteristic indexes and constraints, the multi-objective optimization model is established as follows:

$$G = \text{Min}\{w_1 T^* + w_2 F^* + w_3 E^* + w_4 Q(L)^*\}. \tag{8}$$

Formula (8) represents the evaluation function of operation efficiency, and the weighting factor $w_t\,(\sum_{t=1}^{4} w_t = 1)$ is the weight of each objective. Here, it is set as 0.25, and T^*, F^*, E^*, and $Q(L)^*$ are the indexes after standardized treatment of the following:

$$x^* = \frac{x - \min}{\max - \min}. \tag{9}$$

4. Optimization Model Solution

4.1. Optimization Strategy. As shown in Figure 1, the specific structure of point merge procedure depends on various parameters including merge point, sequencing leg, border, and the corresponding altitude and angle of each parameter in the procedure. For meeting the actual situation of TMA and improving the procedure performance, the optimization strategy is formulated as follows,

4.1.1. Construction of TMA Environment. At the halfway point of the airport runway entrance from the origin, the Cartesian coordinate system is established and TMA is divided by the grid method.

4.1.2. Altitude Adjustment. When H_M (the altitude of merge point) or H_L (the altitude of sequencing leg) is not properly set, which will result in the altitude of the route not meeting the obstacle clearance requirements or affecting operation performance of the procedure, the altitude can be adjusted by GA to ensure the regular operation of the procedure.

4.1.3. Angle Adjustment. When convergence angle or offset angle is too large or too small, it is easy to cause conflict between flow and capacity, affecting the safe operation separation of aircraft. The angle can be improved by GA to ensure the regular operation of aircraft.

4.2. Optimization Steps. The optimization of point merge procedure requires a comprehensive consideration of various factors. The optimization should not only consider the rationality of the external structure of the procedure but also the stability of the internal operation of the procedure. Therefore, it is necessary to plan the optimization strategy and design optimization method comprehensively. According to the structural characteristics and operation rules of the point merge procedure, the optimization steps are as follows:

Step 1: determine the initial scheme of point merge procedure

Step 2: check whether the constraint is satisfied

Step 3: if it is not satisfied, then adjust the altitude, change the angle, etc., and use the optimization model of point merge procedure to solve the optimal layout, and finally, execute Step 2

Step 4: if yes, take the optimal solution set and the optimization is completed

The schematic diagram of optimization steps is shown in Figure 3.

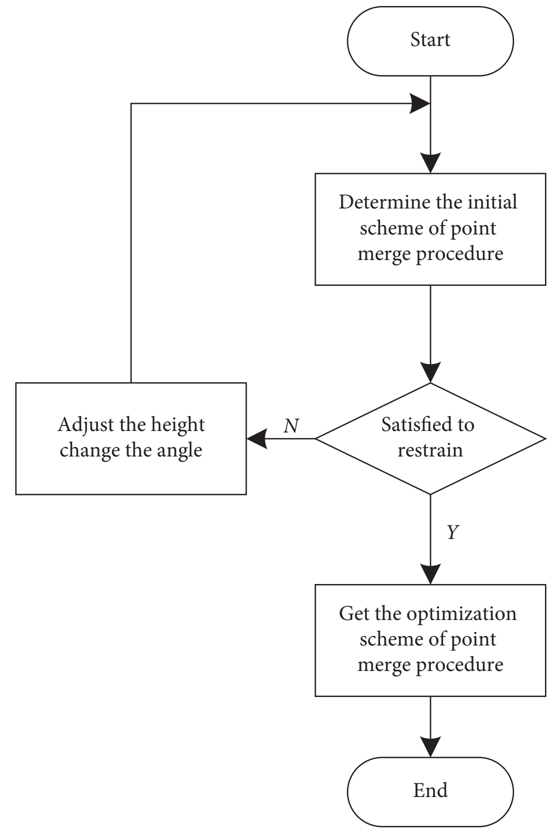

Figure 3: Schematic diagram of optimization steps.

4.3. Algorithm Solution. In this paper, a nonlinear optimization method based on GA is proposed. Since there is a big difference in the magnitude of the subobjective, the corresponding objective function is converted into a dimensionless and equal-magnitude objective function G_j by using Min-Max normalization. The optimized objective function is as follows:

$$\min g(\theta) = \sum_j w_j G_j, \tag{10}$$

where the weighting factor w_j ($\sum_j w_j = 1$) is the weight of each target.

The population individuals adopt the binary encoding form of multiparameter cascade, and the encoding string with length (l_1, l_2, l_3, l_4) is used to represent the parameters to be estimated. The individuals are expressed as

$$\begin{gathered} \underbrace{\mu_1, \mu_2 \ldots, \mu_{l1},}_{\mu} \\ \underbrace{\nu_1, \nu_2 \ldots, \nu_{l2},}_{\nu} \\ \underbrace{o_1, o_2 \ldots, o_{l3},}_{o} \\ \underbrace{o_1, o_2 \ldots, o_{l3}}_{o}. \end{gathered} \tag{11}$$

The binary coding process is shown in Table 1.

Table 1: Binary coding process.

Gene	μ	ν	o	κ
Range	(30, 120)	(−90, 90)	(2000, 4000)	(8000, 12000)
Precision	1	1	1000	1000
Code string length	$2^7 = 128$	$2^8 = 256$	$2^2 = 4$	$2^3 = 8$

The GA has 4 parameters that need to be set in advance and is generally set in the range as follows: (1) Population size: 20~100. If the population size is too small, it is obvious that inbreeding will occur, resulting in pathological genes. However, if the population size is overlarge, the result is difficult to converge, resulting in waste of resources and a decline in robustness. On this basis, the paper sets it to 40 in order to improve the operating efficiency. (2) Iteration number of genetic algorithm: 300~1500. When the evolutionary algebra is too small, the algorithm is not easy to converge; if the evolutionary algebra is overlarge, it is meaningless to continue to evolve after the algorithm converges, which increases time expenditure and resource waste. So the paper sets it to 1000. (3) Crossover probability P_c: 0.4~0.99. When the crossover probability is too small, the population cannot be effectively updated. If the crossover probability is overlarge, it is easy to destroy the existing favorable phenotype, increase the randomness, and miss the optimal individual. So the paper sets it to 0.6. (4) Mutation probability P_m: 0.001~0.1. When the mutation probability is too small, the diversity of the population will fall too fast, which will easily lead to the rapid loss of effective genes. If the mutation probability is overlarge, the diversity of the population can be guaranteed, but the probability of the good phenotype being destroyed increases. So the paper sets it to 0.06.

In the case there are many parameters to be estimated in the target function and the individual binary coding string is long, multipoint variation is adopted here to consider the parameters to be estimated separately, and parallel mutation operation is carried out on the coding string corresponding to each parameter to be estimated. The process is as follows:

Step 1: operate on the individual k. According to experience, randomly generate four random numbers ($rand$ (1,4) = [κ_1, κ_2, κ_3, κ_4]) which are between 0 and 1 and then compare the values of κ_1, κ_2, κ_3, and κ_4, with the preset mutation probability P_m. If it is less than P_m, the mutation operation of Step 2 is performed for the coding string corresponding to the parameter which needs to be estimated. If the value is greater than P_m, the parameter does not change. After the four parameters are compared with P_m, $k = k + 1$, then Step 1 is performed again.

Step 2: mutation operation (l_1, l_2, l_3, l_4) represents the binary encoding length corresponding to the parameter. Generate a random integer Z ($1 \leq Z \leq l_x$). If the Z-bit binary bit in the encoding string is 1, it will be 0 after mutation, and vice versa. Then, return to Step 1 to execute the next parameter to be evaluated.

So as to avoid premature convergence and lead to the phenomenon that the algorithm is trapped in the local optimum, a penalty factor is introduced into the population. The specific operation is as follows: a certain number of new individuals are randomly added to each generation of the population in the iterative process, and the new individuals are distributed evenly in the population as far as possible. The same number of individuals in the population is deleted to keep the size of the population unchanged. The added new individuals can be generated randomly by the system or selected artificially and the original deleted individual cannot be the optimal individual of the population.

5. Application at the Shanghai Hongqiao International Airport

5.1. Experiment Design. In 2018, the Shanghai Hongqiao International Airport handled 266,985 flights, with an annual passenger throughput of 43,645,500. The passenger volume increased by 5.20% year by year, ranking 8th in the passenger throughput of Chinese airports [1].

The studies take the arrival routes of runway 36 of Shanghai Hongqiao International Airport as an example to optimize the point merge procedure. July 28, 2015, with a large flight volume, is selected as the typical busy day of the Shanghai Hongqiao International Airport for research. The total number of flights is 349, with a total of 10 types, as shown in Figure 4. The types of incoming flights are mainly medium and heavy, and the minimum safety interval between aircraft follows the minimum wake interval standard stipulated by the ICAO [20]. The distribution of flight between 00:00 and 23:59 during the typical day is shown in Table 2. The STARs of the Shanghai Hongqiao International Airport are shown in Figure 5.

Shanghai Hongqiao International Airport is located in the geographical center of Shanghai. The surrounding terrain of the airport is flat with good air clearance conditions and few tall obstacles. Arrival traffic flow is mainly through SASAN on the west side, DUMET on the east side, and AND on the south side. Considering the operation characteristics of TMA, we will take the convergence point JTN located on the runway extension, 20.37 km to the threshold of runway as the merge point. As a preliminary scheme of point merge procedure, the convergence angle is 100°, the offset angle is 0°, merge point level is 900 m, and the altitude of sequencing leg is 2 700 m. Preliminary design scheme of point merge procedure is shown in Figure 6. Since there is less flight flow in ZSSS-SASAN-1A-36 and ZSSS-AND-2A-36, the two routes are allocated to the same sequencing leg to avoid the waste of airspace resources.

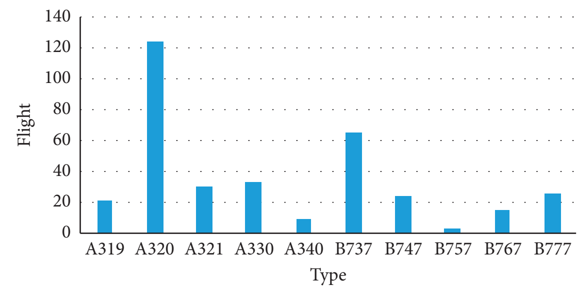

Figure 4: Type distribution of arrival flights.

5.2. Design Scheme. Through optimization calculation, as shown in Figure 7, the fitness decreases rapidly from 0.95 to 0.75 within 200 generations, decreases slightly to 0.73 within 600 generations, and tends to be stable after 700 generations. The maximum fitness individual is obtained after iterative calculation by GA. The optimized procedure structure has the following parameters: the convergence angle is 80°, the offset angle is 15°, the altitude of merge point is 1,200 m, and the altitude of sequencing leg is 3,000 m. The optimization scheme is shown in Figure 8.

As shown in Table 3, during the simulation period, the characteristic indicators (the average flight time, fuel consumption, average pollutant emission, and noise influence range in TMA of the airport) were all reduced after optimization. In addition, the route structure of STAR is shown in Figure 5 (When the operating interval between adjacent flights does not meet the standard, the latter executes the standard holding procedure in Figure 5 until the interval between the two aircraft meets the requirements). The noise isogram is shown in Figures 9–11. Figures 9–11 show the noise isogram of STAR, preliminary scheme of point merge procedure, and optimized scheme of point merge procedure.

Compared with the gradient descent of the instrument approach procedure, the point merge procedure sets up the sequencing leg to integrate traffic flow, which ensures that flights can continuously descend from the higher sequencing leg to the merge point. On the vertical profile, the point merge procedure allows the flights to maintain a high level before the merge point, enabling a large angle continuous approach. Besides, it advances the application of continuous descent operation. The flight trajectory after optimization is shown in Figure 12.

The sequencing legs of the point merge procedure increase the adjustment space for converged flights. In addition, if the actual traffic exceeds the capacity of the sequencing leg(s), individual flights can be sequenced before actually entering the point merge procedure. Before the controller issues the instructions of "direct to" the merge point, the flight is at a relatively high altitude, which avoids low-altitude holding of aircraft in the traditional procedure. Compared with the traditional procedure, the point merge procedure has a longer structural path, but its structure transfers the aircraft's low-altitude adjustment to the sequencing legs in high-altitude, avoiding aircraft speed

Table 2: Arrival flow distribution in each period.

Type / Time	A319	A320	A321	A330	A340	B737	B747	B757	B767	B777	Total
00:00~00:59	0	5	0	2	0	0	0	0	0	0	7
01:00~01:59	0	0	0	0	0	0	0	0	0	0	0
02:00~02:59	0	0	0	0	0	0	0	0	0	0	0
03:00~03:59	0	5	0	0	0	0	0	0	0	1	6
04:00~04:59	0	0	2	0	1	2	2	1	0	0	8
05:00~05:59	1	0	0	4	0	0	0	0	0	0	5
06:00~06:59	0	20	0	0	2	0	0	0	0	4	26
07:00~07:59	0	18	0	0	0	5	3	1	0	0	27
08:00~08:59	0	7	0	0	1	4	0	0	0	0	12
09:00~09:59	3	2	5	6	1	1	10	0	3	0	31
10:00~10:59	5	0	5	5	0	0	0	0	0	0	15
11:00~11:59	3	10	0	0	0	7	2	0	0	0	22
12:00~12:59	0	5	2	0	0	8	0	0	2	0	17
13:00~13:59	1	8	8	0	0	7	4	0	0	3	31
14:00~14:59	0	7	5	5	4	0	0	0	0	4	25
15:00~15:59	1	3	0	0	0	8	0	1	2	7	22
16:00~16:59	0	5	0	6	0	0	1	0	0	0	12
17:00~17:59	0	0	1	5	0	0	0	0	0	0	6
18:00~18:59	0	3	0	0	0	2	0	0	3	0	8
19:00~19:59	3	5	2	0	0	0	2	0	0	6	18
20:00~20:59	1	8	0	0	0	9	0	0	0	0	18
21:00~21:59	3	0	0	0	0	12	0	0	0	0	15
22:00~22:59	0	8	0	0	0	0	0	0	5	0	13
23:00~23:59	0	5	0	0	0	0	0	0	0	0	5
Total	21	124	30	33	9	65	24	3	15	25	349

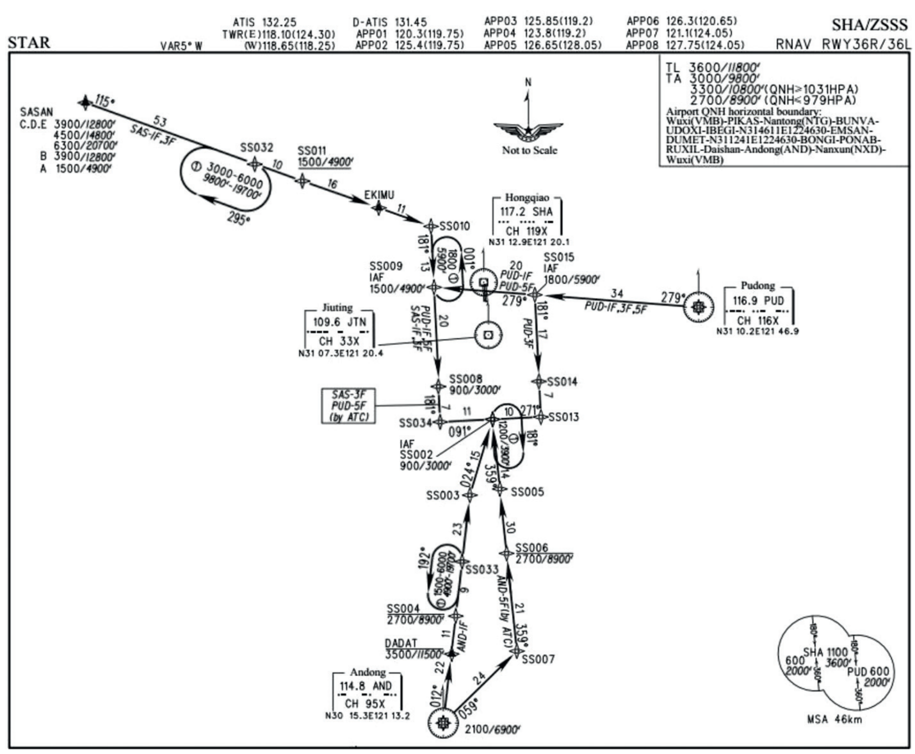

Figure 5: STARs of the Shanghai Hongqiao International Airport.

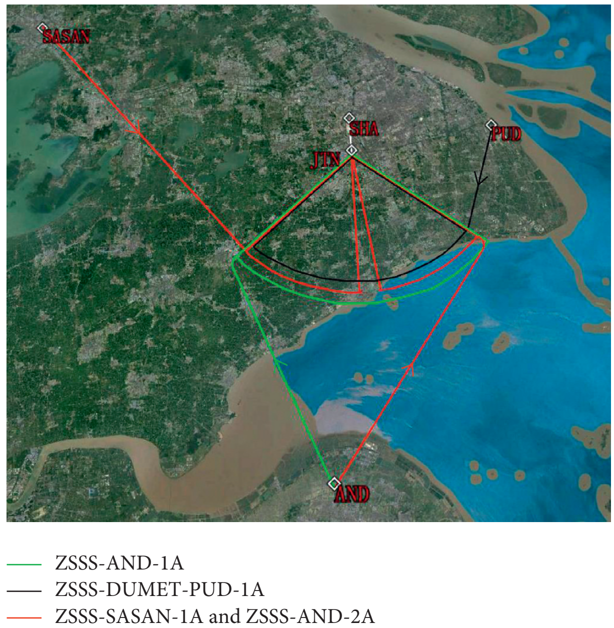

Figure 6: Preliminary scheme of point merge procedure.

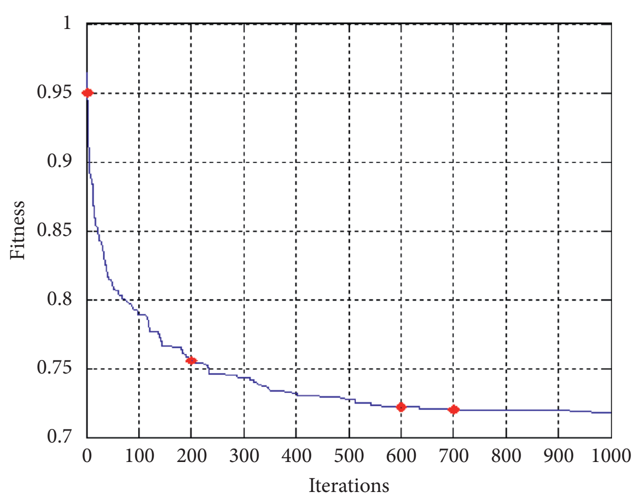

Figure 7: Algorithm training process diagram.

adjustments/holding at low altitude. During operation, the higher the altitude, the higher the aircraft speed. Although the length of the route has increased, the aircraft has reduced operating time at low altitude (low speed). In a word, flight operational efficiency has improved.

For exploring the operation of point merge procedure in high-density traffic flow, the flow pressure operation was conducted during peak hours from 13:00 to 13:59. Simulation results are shown in Table 4.

Under normal traffic flow, the average flight time, average fuel consumption, and average pollutant emissions of aircraft of STAR are 12.25 min, 7048.87 kg, and 12.19 kg, respectively. And the average flight time, average fuel consumption, and average pollutant emissions of aircraft of the point merge procedure are 11.90 min, 5278.19 kg, and 10.23 kg, respectively. When the flow increases to 150%, the average flight time, average fuel consumption, and average pollutant emissions of aircraft of STAR are 13.79 min, 9658.54 kg, and 14.89 kg, respectively. And the average flight time, average fuel consumption, and average pollutant emissions of aircraft of the point merge procedure are 12.42 min, 6530.72 kg, and 12.31 kg, respectively. When the flow increases to 200%, the average flight time, average fuel consumption, and average pollutant emissions of aircraft of STAR are 16.98 min, 13625.36 kg, and 18.13 kg, respectively. And the average flight time, average fuel consumption, and average pollutant emissions of aircraft of the point merge procedure are 14.13 min, 9489.71 kg, and 14.71 kg,

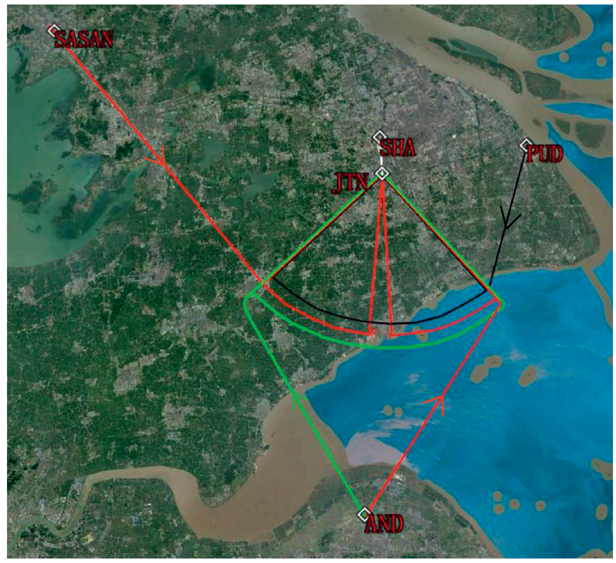

FIGURE 8: Optimized scheme of point merge procedure.

TABLE 3: Experimental results.

Mode	Average flight time (min)	Average fuel consumption (kg)	Pollutant emission (kg)	Noise effect scope (km^2)
STAR	11.82	5863.89	9.74	187
Preliminary scheme	11.65	4908.13	9.04	149
Optimized scheme	11.56	4623.25	8.65	132

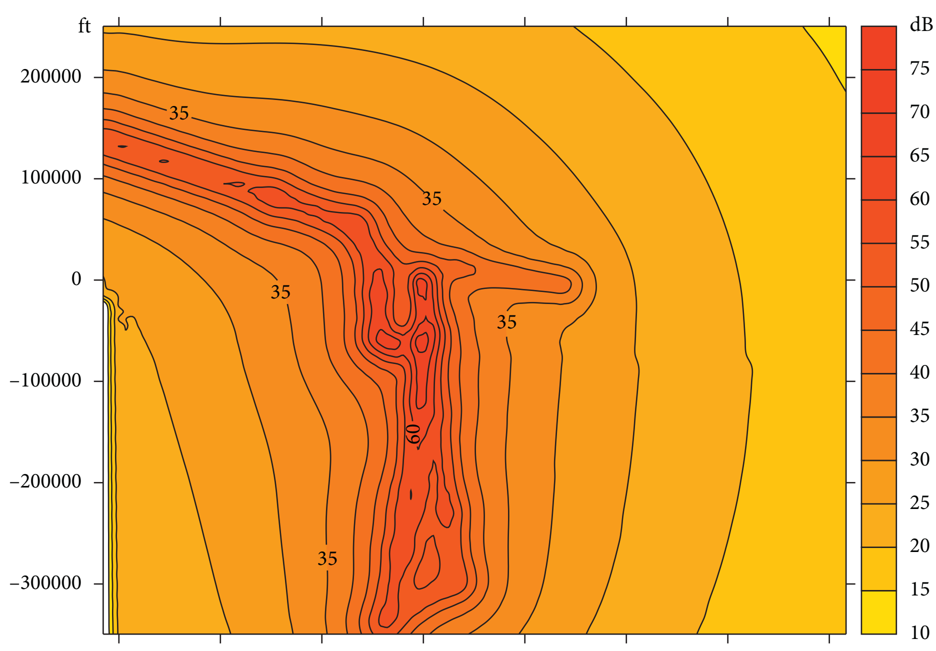

FIGURE 9: Noise isogram of STAR.

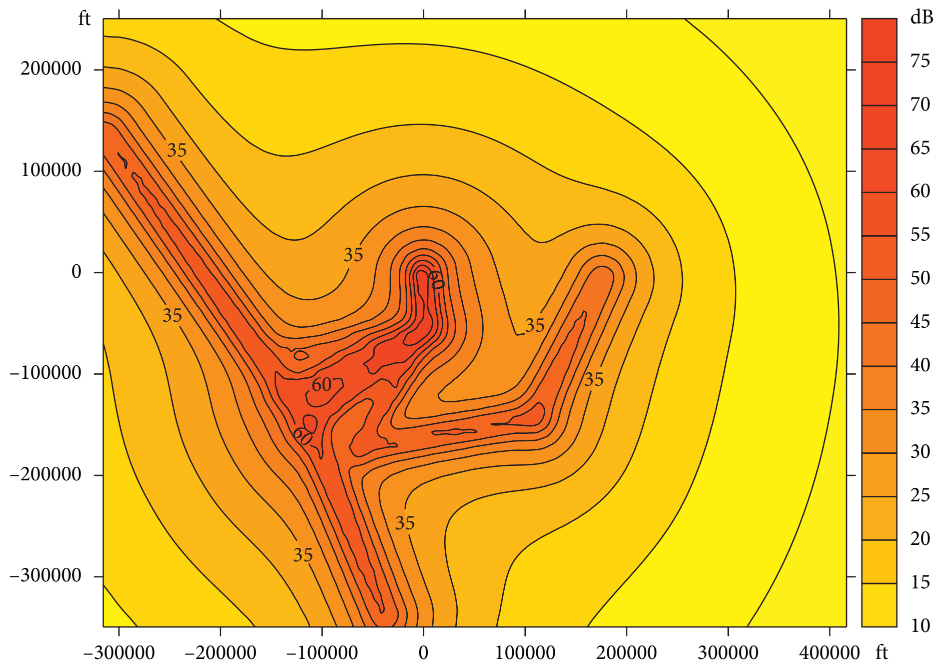

Figure 10: Noise isogram of preliminary scheme of point merge procedure.

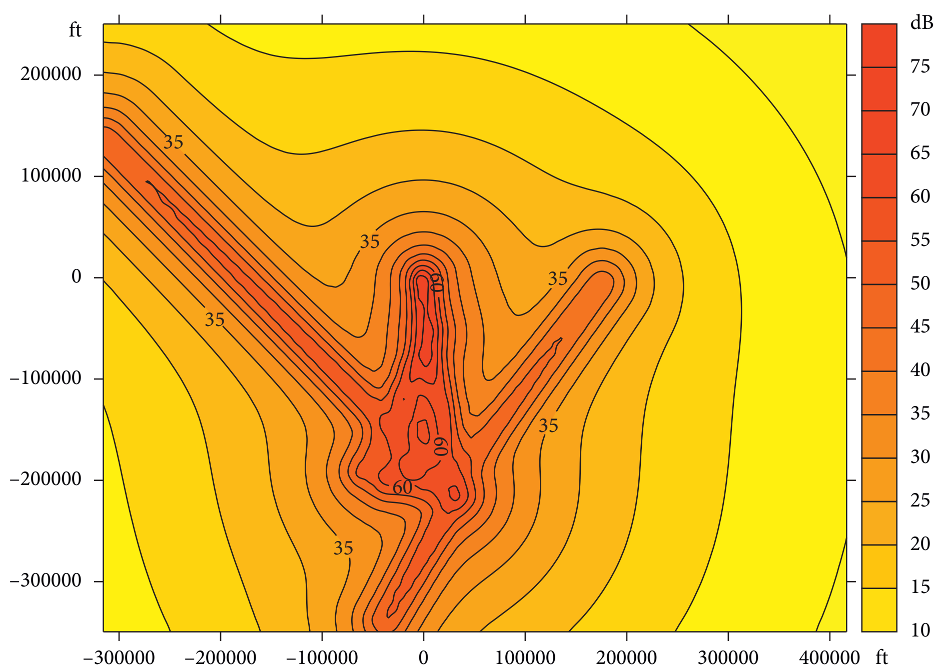

Figure 11: Noise isogram of optimized scheme of point merge procedure.

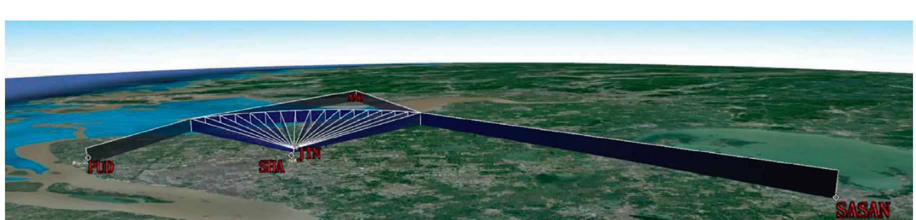

Figure 12: Flight trajectory diagram.

Table 4: Flow pressure results.

FF ratio (%)	STAR				Optimized scheme of PM procedure			
	Average flight time (min)	Average fuel consumption (kg)	Pollutant emission (kg)	Noise effect scope (km^2)	Average flight time (min)	Average fuel consumption (kg)	Pollutant emission (kg)	Noise effect scope (km^2)
100	12.25	7048.87	12.19	0	11.90	5278.19	10.23	0
150	13.79	9658.54	14.89	0	12.42	6530.72	12.31	0
200	16.98	13625.36	18.13	1	14.13	9489.71	14.71	1

respectively. With the increase of traffic flow, the average flight time, average fuel consumption, and average pollutant emissions of aircraft all increase. Due to the small number of flights, the impact of noise is not obvious. As the flow is boosted from 100% to 200%, the flight time, fuel consumption, and pollutant emissions of conventional procedures are significantly increased. With the increase of traffic, the indicators of point merge procedure present a relatively stable rise on the whole. The leg structure of the procedure enhances the capacity of flights, so as to improve the stability of the operation.

6. Conclusion

This paper focuses on the approach route in TMA. Considering the efficiency of the aircraft's operation, it takes the flight time, fuel consumption, pollutant emissions, and noise effects as the optimization goal. A multiobjective program optimization model is established in this paper. And the model is solved by GA to verify the feasibility of the optimization method of the point merge procedure in reducing the average flight time, fuel consumption, pollutant emissions, and noise effect scope. Then, the flow pressure operation was conducted during peak hours to explore the operation of point merge procedure in high-density traffic flow. With the increase of traffic, the indicators of point merge procedure present a relatively stable rise on the whole.

The optimization method of point merge procedure in TMA is studied, but this study does not consider the objective factors such as the division of the control sector and the weather problems faced in actual operation. And the procedure layout does not combine the departure route structure. Due to the complexity of the actual operating conditions and the limitations of the simulation models in the study, the planning of the terminal area's approach and departure routes can be further explored in the future.

Nomenclature

ATC:	Air traffic control
A-CDA:	Advanced continuous descent approach
CDA:	Continuous descent approach
FAA:	Federal Aviation Administration
GA:	Genetic algorithm
ICAO:	International Civil Aviation Organization
PMS:	Point merge system
P-RNAV:	Precision area navigation
RNAV:	Area navigation
STAR:	Standard instrument arrival route
TMA:	Terminal area
WECPNL:	Weight equivalent continuous perceived noise level.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Yong Tian conceived and designed the experiments. Dawei Xing performed the experiments. Lili Wan analyzed the data. Bojia Ye contributed analysis tools. Yong Tian and Dawei Xing wrote the paper.

Acknowledgments

This research was supported by the National Natural Science Foundation of China (Grant no. 61671237) and the Natural Science Foundation of Jiangsu Province of China (Grant no. BK20160798).

References

[1] Prospective Industry Research Institute, *China's Civil Aviation Transportation Industry Market Prospects and Investment Strategic Planning Analysis Report for 2019-2024*, Prospective Industry Research Institute, Beijing, China, 2019.

[2] L. Boursier, B. Favennec, E. Hoffman et al., "Merging arrival flows without heading instructions," in *Proceedings of the 7th USA/Europe Air Traffic Management R&D Seminar*, Barcelona, Spain, 2009.

[3] B. Favennec, F. Vergne, and K. Zeghal, *Point Merge Integration of Arrival Flows Enabling Extensive RNAV Application and Continuous Descent-Operational Services and Environment Definition Brétigny-sur-Orge, France*, EUROCONTROL Experimental Centre, 2010.

[4] D. Ivanescu, C. Shaw, C. Tamvaclis, and T. Kettunen, "Models of air traffic merging techniques: evaluating performance of point merge," in *Proceedings of the 9th Aviation Technology, Integration and Operations Conference*, September 2009.

[5] Ö. Sahin Meric and O. Usanmaz, "A new standard instrument arrival: the point merge system," *Aircraft Engineering and Aerospace Technology*, vol. 85, no. 2, pp. 136–143, 2013.

[6] M. Liang, "An agent-based approach to automated merge 4D arrival trajectories in busy terminal maneuvering area," *Procedia Engineering*, vol. 99, pp. 233–243, 2015.
[7] M. Liang, D. Delahaye, and P. Maréchal, "A framework of point merge-based autonomous system for optimizing aircraft scheduling in busy TMA," in *Proceedings of the 5th SESAR Innovation Days*, SESAR, Bologna, Italy, 2015a.
[8] M. Liang, D. Delahaye, and X.-H. Xu, "A novel approach to automated merge 4D arrival trajectories for multi-parallel runways," in *Proceedings of the 4th ENRI International Workshop on ATM/CNS*, Springer, Tokyo, Japan, November 2015b.
[9] M. Liang, D. Delahaye, M. Sbihi, and Ji Ma, "Multi-layer point merge system for dynamically controlling arrivals on parallel runways," in *Proceedings of the 35th Digital Avionics Systems Conference*, IEEE, Sacramento, CA, USA, September 2016a.
[10] M. Liang, D. Delahaye, and P. Maréchal, "Potential operational benefits of multi-layer point merge system on dense TMA operation hybrid arrival trajectory optimization applied to Beijing capital international airport," in *Proceedings of the 7th International Conference on Research in Air Transportation*, Transportation Research Procedia, Philadelphia, PA, USA, June 2016b.
[11] Y. Hong, B. Choi, and K. Lee, "Dynamic robust sequencing and scheduling under uncertainty for the point merge system in terminal airspace," *IEEE Transactions on Intelligent Transportation Systems*, vol. 99, pp. 1–11, 2017.
[12] S. Lee, Y. Hong, and Y. Kim, "Optimal scheduling algorithm in point merge system including holding pattern based on MILP," in *Proceedings of the 7th European Conference for Aeronautics and Aerospace Sciences*, AIAA, Milan, Italy, 2017.
[13] C.-Z. Chu, B. Yang, and W.-F. Huang, "Merging point approach procedures and its technical analysis," *Air Traffic Management*, vol. 1, pp. 9–12, 2010.
[14] H. Shuai, *The Operation Research of CDA Based on PBN Flight Procedure*, Civil Aviation Flight University of China, Deyang, China, 2012.
[15] M.-B. Chao, X.-L. Zhao, P.-C. Li, and Bi-Y. Lei, "Research on point merge approach procedure design in terminal area," *Aeronautical Computing Technique*, vol. 46, no. 2, pp. 10–14, 2016.
[16] Y. Qi, X. Wang, and C. Chen, "Research on arrival integration method for point merge system in tactical operation," in *Proceedings of the International Conference on Combinatorial Optimization and Applications*, Springer, Shanghai, China, December 2017.
[17] X.-L. Zhao and B.-Y. Lei, "Research on method for assessing risk in ground approach under point merging procedure," *China Safety Science Journal*, vol. 27, no. 03, pp. 157–162, 2017.
[18] J.-Z. Wang, C. Wang, and B.-C. Zhang, "4D trajectory planning method for arrivals based on merging point Approach," *Science Technology and Engineering*, vol. 17, no. 14, pp. 333–337, 2017.
[19] B. Favennec, E. Hoffman, A. Trzmiel, F. Vergne, and K. Zeghal, "The point merge arrival flow integration technique: towards more complex environments and advanced continuous descent," in *Proceedings of the 9th AIAA Aviation Technology, Integration and Operations Conference (ATIO)*, AIAA, Hilton Head Island, SC, USA, pp. 21–23, September 2009.
[20] ICAO, *Doc 4444, Procedures for Air Navigation Services–Air Traffic Management*, ICAO, Montreal, Canada, 16th edition, 2016.