Merging Flows and Optimizing Aircraft Scheduling in Terminal Maneuvering Area Based on GA

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Abstract—**Runway capacity problem have been emerging in current overloaded congestion airports. This paper focuses on improving the runway capacity and resolution of conflicts of aircraft in terminal maneuvering area and proposes its method which can find the feasible solution using detour structure. In detail, our proposed method use alternative routes or sub-route as detour to avoid conflict and to change the position of arrival sequence. Through the intensive simulation on Paris Charles De-Gaulle airport, we revealed that our proposed method can find the efficient arrival sequence without conflict and detours contribute to optimize the landing sequence.**

Keywords-Air Traffic Control; Aircraft Merging Problem; Genetic Algorithm

I. Introduction

The air traffic demand is increasing yearly. In particular, an airport is a one of the high-density air traffic, which the air traffic controller considers their speed and angle of heading to avoid their conflicts. In the heavy traffic, congestion of aircraft makes the air traffic controller high cognitive load. In an airport, they decide to landing sequence of aircraft arriving to the destination airport and manage to their aircraft. To navigate aircraft, they consider a lot of aircrafts to avoid conflicts between any aircraft and determine the landing sequence based on first come first serve (FCFS). In aircraft landing, to determine both the landing routes of aircrafts and their landing order to minimize an occupation time of the airport as the air transport service are important issue because of directly affecting the occupancy time. This problem is called as the aircraft landing problem [1]. Some projects of future concept have launched such as SESAR in Europe, NextGEN in US and CARATS in Japan. To increase the runway capacity and resolve the conflict and navigate efficiently for aircraft, it is the key factors for air traffic management system in TMA to minimize the potential conflicts and increase the runway capacity. To support air traffic controller, our approach focuses on the route structure without holding pattern. This paper addressed new merging method without holding pattern the optimization of the landing sequence near a little far from terminal maneuvering area and proposed without holding pattern which improve the runway capacity and deal with the congestion in the terminal maneuver area. The proposed method based on Genetic algorithm to optimize landing sequence and to resolve the conflict between aircraft.

II. Related work

In this field, some heuristic methods can successfully obtain good result and save the calculation time for optimization such as GA [2], simulated annealing(SA), and ant colony algorithm and so on. Hu et al. proposed efficient search algorithm for arrival sequence based on GA. This method focused on computational time and employed the concept of receding horizontal control(RHC) [3]. RHC is the decomposition-based technique and divide the problem into several small problems. This method including RHC can obtain better performance than that of pure GA. As another method, Man et al. proposed an autonomous system with point merge (PM) method which contents the effective for applying the real situation [4]. PM is one of the new future technology of the air traffic management system proposed by [5] and [6]. This technique which is composed of predefined the route called sequential leg enables controllers to easily understand and provide with absorbing the required delay and changing the order of arrival sequence. In this paper, they conducted on the real environment in the Beijing airport which is the one of congestion airport in the world. Their method could optimize one all day traffic data even in the crowded condition thorough the SA. This concept is suitable for controller due to considering cognitive load of controllers in the objective function. However, PM is limited by the optimization performance. Since this optimization are is terminal maneuvering with holding pattern, it is required to extend the TMA. To absorb the time consumption, it is required for their model to extend the environment., Tuniga et al proposed the optimization method of arrival sequence based on GA [7]. In detail, they add the detours to landing in order to adjust the separation of the space between the aircraft. This paper contributed to find the feasible solution for arrival sequence without holding pattern. These are useful to apply into future tactical air traffic control Our purpose in this paper is that we show the potential of the optimization of the arrival sequence in the extend terminal maneuvering area (TMA). In detail, our proposed method applied the detours which is useful to change the arrival order.

III. MODELING

A. Given data

As the data set, we use a set of flights F. This flight data is represented as following:
t_i : time of flight f_i at initial point
v: speed at enter point
w: wake turbulence category

Aircraft speed do not change drastically in near the TMA. Such a speed change indicates as the following equation.

$$v_k^{'} = v_k * (1 + \Delta v), \Delta v \in \psi \quad (1)$$

Where, v_k, Δv and $v_k^{'}$ are initial aircraft speed, speed change rate and new speed of aircraft i respecticely. we define the percenage of change as $\psi \in [-20\%, 5\%]$ As following this equation, the aircraft is restricted of the speed and route and altitude. this is because that near the airport, there is very crowded condition and risk of the conflicts aircraft. Our simulation model set the speed only one time.

B. Detour design

During congestion situation, there are a lot of conflicts between aircrafts in near the airport. The controllers take two types of actions to manage aircrafts. One is speed change of aircraft and the other is heading change of aircraft. We employed route structure which enable aircraft to change route. Our model develops STandard Arrival Route (STAR) with the detour. To control the detours, our model uses the parameter of deter (dr) which can change the total distance of the detour. Such parameter is described as following equation $0 \leq dr \leq 1$ This parameter has a range from 0 to 1 (e.g.,when the dr takes 1, the total distance to the destination is maximum.)

C. Conflicts detection

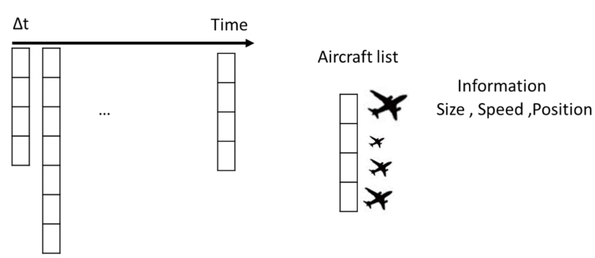

Fig. 1. Hash map

It is the key factor how to detect the conflict between any two aircraft. Our route design is that each route does not cross another route, however, there has a possibility to occur the conflict. The regulation of the air traffic control say that any two aircraft keep the appropriate space to avoid the conflict. Controllers pay attention to the speed and altitude and separation of all aircraft in every sector. Normally, we have to only consider node and link conflict using graph model. Node conflict is that aircraft need to the separation between this aircraft and any aircraft through the same node. Link conflict is that aircraft need to separation according to wake turbulence of leading aircraft when aircraft navigate through the same link. However, our detour design is not enough to detect conflict using these two methods. To detect the conflict, we use hash map which record the position of the aircraft every Δ t minutes. In detail, hash-map has discrete value of time and aircraft information. Fig. 1 indicates the example of the hash map. The vertical axis indicates the time schedule in near the destination. Each time has the list of aircraft. The aircraft flying at that time is added to the aircraft list. Into the list, aircraft size, speed, and position are on the aircraft list. According to this information, this algorithm calculates the distance of each space of distance at the same time. Such a distance is checked whether the constraint condition is met or not. If the value of the distance smaller than the threshold, this model considers the conflict. Our prosed method repeats this process until the end of the time schedule and count the total number of conflicts. Generally, the aircraft are categorized into three types on the basis of the size of aircraft. The size of aircraft significant impact on the landing space interval. The different size of aircraft makes the difference of ditstance. In this figure, left side and top of table indicate the trailing and leading aircraft respectively. The number show the minimum space distance between the leading trailing aircraft. 6NM for the requirement of the minimum distance is needed between the light trailing aircraft and the heavy leading aircraft while 3NM is needed between the light trailing aircraft and the light leading aircraft (see Table I).

TABLE I
AIRCRAFT MINIMUM SEPARATION

Trailing aircraft \ Leading aircraft (NM)	Heavy	Medium	Light
Heavy	4	3	3
Medium	5	3	3
Light	6	4	3

D. Objective function

Our goal is to increase the runway through put which means that aircraft land on the destination airport as much as possible. What important thing is that aircraft land on a destination airport on time for passengers. For this purpose, our proposed method considers the delay of the arrival. The objective function is defined as below:

$$Fitness = \sum_{k=1}^{N} (t_k - ETA_k) \quad (2)$$

In Eq. 2, t_k and ETA_k indicate the i-th actual landing time and estimated time of arrival respectively. ETA subtracted from t means the delay of the schedule. Note that the delay become small when fitness is small. For safe aircraft landing, no conflicts in the TMA is indispensable. Since our fitness function does not consider the conflict, the individual with conflict is identified as an infeasible solution. In detail, firstly

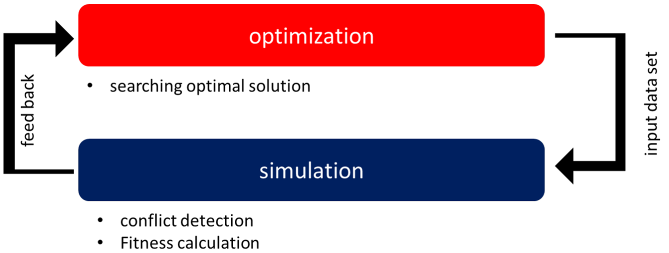

Fig. 2. Modeling method

our algorithm ranks individuals according to the total number of conflict, then these individuals are ranked according to the fitness. These order aims at not only resolving the conflict preferentially but also keep the landing schedule.

IV. Proposed Algorithm

A. overview

Fig. 2 shows the structure of our approach. The optimized solution. The optimization unit plays a role of finding a feasible and optimal solution. In this paper, we proposed method based on GA proceeding parallelly. The simulation unit using above the model is that aircraft flying with the parameter which the optimization unit generates the candidate of the solution. Note that the simulation takes much time to detect the conflict and evaluate the fitness of the solution. After calculating fitness and counting the total conflicts, the simulation unit gives the feedback to the individuals. These processes continue repeatedly until the termination condition. Optimization solution is generated.

B. Genetic algorithm

To optimize the landing sequence of the destination airport. This paper applied genetic algorithm to this problem. In this section, we describe the mechanism of our proposed GA. Our GA is composed selection, crossover, mutation and evaluation besides local search. The procedure of the GA is as followings; Firstly, population is initialized, our algorithm selects two individuals as the parents the based on the tournament selection and applies these to crossover operation. Such the individual is regard as the child and child's gene changes the value with certain probability. To calculate the fitness value and count the total number of conflicts of all aircraft, our algorithm simulates the management of the air traffic using the value of this evaluated individual. After all individuals estimate the value of the fitness and conflicts, our algorithm sorts by the fitness and conflict and progress next generation. To search more efficiently, we explain mutation operator and crossover operation.

1) gene structure: As shown Fig. 3, this figure indicates the structure gene. Each gene corresponds to one aircraft. Aircraft need to decide the velocity and route. The velocity indicates the integer value and parameter value is real value. For example, in case total aircraft is N, each individual has to decide 2^N decision values.

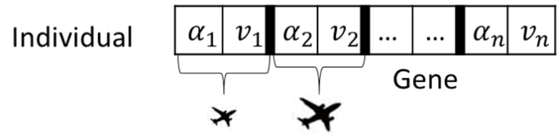

Fig. 3. Gene structure

Fig. 4. Experiment environmet

2) crossover operation: The crossover operation is the important factor to find the feasible solution efficiently. We use the bias crossover operation which promotes to generates better child individual than the other child.Two parents selected according to the selection method are operated crossover, then two individuals take over the characters of gene. One of the new individual takes over the better chromosome from the parents, while the other individual takes over the worse chromosome. Here, better chromosome means that less total number of conflicts of gene. Our proposed method applies the simulated binary crossover (SBX) to detour parameter

3) mutation operation: Our algorithm operates mutation to the new individuals with some extent probability. Generally speaking, some values in chromosome are changed randomly. In this problem, speed of aircraft and parameter of detour are changed by mutation operator. Note that the value of the probability changes each gene according to the number of conflicts. This is because the aircraft which has a large amount of conflict disturbs another aircraft. The mutation operator promotes to change the values in such the bad effective aircraft. Our algorithm makes less total conflict to give a higher probability value.

V. Experiment and Result

To investigate effectiveness of our proposed method, we conduct the simulated experiment in the Charles de Gaulle Airport as shown in Fig. 4 where there 8 routes, five merging point and five detours. At first each route is merged into one route. These four merged routes are connected to the final approach point. There are four runways in this airport and these two long runways and two short runways parallelly setting. Although Actually this airport operates aircraft departing and arriving with both long runways, our experiment use the only one runway as fundamental experiment.

We define 5 detours added on the routes which meet the requirements of the rule for detour route reguration. In this experiment, the total detours are 5. The aircraft in the data fly along with the waypoints. We use the real traffic data in the Charles de Gaulle Airport . The total number of aircraft is 29 per one hour. Table II indicates the traffic ratio of each route. The air traffic from south is much congested during this time. We used the following parameter setting (Table. II). All process is run on a 2.71GHz and 12 GB RAM Windows10 operating system operating PC. As the evaluation criterior, we used the total confilicts of any aircraft and fitness value which indicates the runway through put.

TABLE II
PARAMETER

parameter	value
population size	100
generation	500
crossover rate	1
mutation rate	0.8
trial	10

Our approach can find the feasible solution in all trials and use the detour to minimize the delay of the schedule (See Fig. 5). These values in Table III are the average of all 10 runs. In Fig. 5 , the left and right vertical and horizontal axis indicate fitness value, total conflicts between aircraft and generation. From 200 generation, our prposed method can obtain feasible solution without conflict. Fitness is fluctuated until 200 generation because it is possibily to select the best fitness including conflicts in every generation. If all individuals in population are infeasible solution (including conflict), The lower value of fitness is selected. After this generation, this value gradually decrease to find better solution in terms of runway through put. In table III, the number of aircraft which did not select detour is 14.7. This mean that sub-route sutructure contributed to resolve the confilicts and improve the optimization performance.

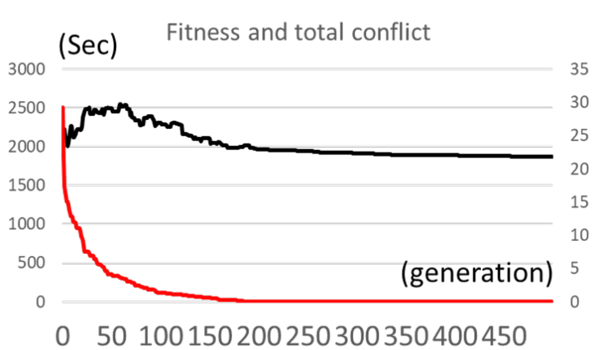

Fig. 5. Fitness and total conflict

TABLE III
RESULT

Number of aircraft without detour	14.7
Average delay of schedule	79.3 s
Maximum delay	240 s
Maximum speed change	23.7 Nt
Minimum speed change	-93.9 Nt

VI. Conclusions and future development

This paper addressed new merging method without holding pattern and proposed new merging and optimizing techniqe which improve the runway capacity and deal with the congestion in terminal maneuver area. In detail, the proposed method based on GA optimizes landing sequence and resolves the conflict between aircraft using hash map. The following implications to be found; our proposed method can find the feasible solution in the real environment where we conducted the experiment on the Charles de Gaulle Airport. Our proposed method developed the detour which adapt estimate arrival time and contributes to decrease the runway occupation time. Note that our result shows the only one hour traffic data and our optimized schedule did not consider the departure aircraft. And our proposed method takes much calculation time to simulate the experiment. Now we are tackling on improvement finding solution quickly. What should be noticed that our proposed method only used the detours to extend the estimated arrival times flexibly without holding pattern. Our environment is more a little far from the TMA, which enable arrival scheduling easy to find the arrival sequence.

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