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A Novel Capacity Evaluation Model for Functional Control Sector

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Abstract. With rapid developing of the civil aviation recently, an increasing traffic flow exerts much pressure on airspace resource, which leads to crowded sectors and heavy workload for controllers. In order to make better use of airspace resources, keep balance between the controllers' workload among different sectors, a novel capacity evaluation model for functional control sector was proposed in this paper. This paper firstly analyzes the factors involved for functional sectors. Then a functional sector division method based on the controller workload model was given to balance of controller workload. The proposed model is verified with an example of Kunming Control Sector at Southwest of China. The results show that the proposed functional sectors are more effective for the safe and stable operation of the control sector.

Keywords: air traffic control, sector capacity, controller workload, functional sector

1. Introduction

China's air traffic is growing rapidly and it is necessary to improve the construction and management of civil aviation. However, there is a phenomenon of unbalanced flow distribution in China's air transportation at present since most of the flow concentrates in some major airports. Meanwhile, China's route congestion in air traffic is becoming more and more serious. The traditional sector design is often based on geographical characteristics, which means dividing the geographical factors of the geometric space under the jurisdiction of the airspace into several sectors. However, they are not designated according to the needs of environmental conditions and air traffic flow. Hence, the airspace structure lacks scientific and rationality and people cannot make full use of airspace resources.

In order to optimize the existing airspace and utilize airspace resources more rationally, the concept of functional sector gradually emerges. Aiming at the above problems, this topic evaluates the capacity of the area control sector which was divided according to its function. And then this topic makes suggestions and proposes an optimal division plan on the functional division of the airspace according to the capacity evaluation results. Under the condition of existing airspace resources, it is of great importance to better meet the airspace flow demand and improve the air traffic service capability of the airspace, which is very necessary to ensure flight safety and has great economic value and practical significance.

There are many theoretical and methodological studies on airspace sector planning in the world, most of which focus on determining the planning of sector in a two-dimensional area through the selection of mathematical models and geometric algorithms. In 2010, Joseph S.B.Mitchell [1] proposed a geometric algorithm to optimize airspace design and air traffic controller workload balance on the basis of previous research, modeling the problem of optimizing the sector as a constrained geometric partitioning problem. In 2018, German scholar Ingrid Gerdes [2] proposed a flight-oriented dynamic sector division, which provided a solution for dealing with non-convex airspace boundaries, and provided the use of the current operating airspace structure and made the proof of concept for flight-oriented air traffic management.

The research on domestic airspace sector planning has been carried out relatively late, and domestic scholars have also achieved certain results in this regard in recent years. In 2009, Zhou Rui, Han Songchen, Zhang Ming [3] proposed a terminal airspace sector optimization model based on the principle of airspace

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functional identity under the condition of separation of arrival and departure routes. In 2015, Wang Chao and Zheng Xufang [4] proposed the concept of functional sector in the terminal area, and studied the two-stage division method based on computational geometry and genetic algorithm.

At present, the division of airspace according to functional sector has gradually become a qualitative planning method widely used at home and abroad. Some of the functional sector division research on airspace is basically based on mathematical models and geometric algorithms. However, the process is relatively complicated, and it is a subversive change to the original sector structure, and the implementation of the plan is difficult.

2. Functional Sector Capacity Evaluation Model

2.1. Considered Factor of Functional Sector

Air traffic operations within a regional sector have the following characteristics compared to traffic in other types of airspace:

(1) Aircraft fly at high speed and altitude, usually above 6000 meters long distance controllers consider and calculate delays in time and distance while deciding to change the aircraft's state.

(2) Usually, aircraft must follow a fixed route, and when flying activities in the route or route, the aircraft should fly according to the flight altitude layer equipped.

(3) The scope of regional control airspace is very wide, and aircraft may pass through multiple sectors when flying in the same area control airspace. There are also differences in the types of communication, navigation, and surveillance equipment between the various parts within the region, with fewer waiting procedures and the possibility of collisions in flights due to the convergence, dispersion or crossing of routes.

(4) There are many factors restricting regional airspace resources, and it is necessary to pay attention to the impact of military aviation activities and the latest developments in restricted areas, danger zones and restricted areas.

(5) The severe weather in the region is complex and varies greatly. The severe weather will lead to more tension of airspace resources and increase the difficulty of control work.

Traditional geographical sectors usually contain various types of traffic flows; Moreover, the traditional sectors divided according to geographical characteristics lack the analysis of the characteristics and flow of traffic flow in the airspace, resulting in large traffic and large control load in some sectors. The other sectors have smaller traffic, smaller control load, unbalanced flight flow and control load, and insufficient rational and balanced utilization of airspace resources. With the rapid growth of aircraft traffic, for many areas with dense flight flow and complex airspace structure, the traditional geographical sector division has been unable to meet the demand, so the airspace has been divided into functional sectors, and the regional functional sectors mainly have the following advantages:

(1) Functional sectors can envelop traffic flows with large similar characteristics, which can effectively reduce the complexity of sectors.

(2) The regional functional sector reduces the variety of sector control tasks, which can effectively reduce the difficulty of sector control work and the workload of controllers, which is conducive to ensuring flight safety.

(3) To enable the use of airspace more efficiently and more intensively, increase airspace capacity, alleviate aircraft congestion, and improve the quality of control services.

2.2. Capacity Evaluation Model Based on Controller Workloads

In this paper, a simplified model is used, and the characteristics of high similarity of traffic flow in the envelope in the functional sector are combined to establish a controller load assessment model with traffic flow as the classification. The model established in this section will measure the controller workload separately based on traffic flow as a classification, which is mainly subdivided into three load types:

communication, non-communication, and thinking. The controller workload calculation formula established according to the above classification is shown in Formula 1:

$$\overline{W_j} = \overline{W_j}^{com} + \overline{W_j}^{incom} + \overline{W_j}^{thk} \tag{1}$$

Where $\overline{W_j}$: The load weight of each aircraft controller on the traffic flow j, that is, the average workload of a single aircraft on the traffic flow j to complete the entire flight process (unit: seconds/aircraft);

$\overline{W_j}^{com}$: The communication workload weight of each aircraft on traffic flow j , that is, the average communication workload (unit: seconds/aircraft) on traffic flow j to complete the entire flight process;

$\overline{W_j}^{incom}$: The non-communication workload weight of each aircraft on the traffic flow j, that is, the average non-communication workload (unit: seconds/aircraft) on the traffic flow j to complete the entire flight process;

$\overline{W_j}^{thk}$: The weight of the thinking load of each aircraft on the traffic flow j , that is, the average thinking load (unit: seconds/frame) of a single aircraft on the traffic flow j to complete the entire flight process.

Functional sector is characterized by the strong similarity of traffic flow wrapped up, traffic flow is the most important factor in the functional sector, so the traffic flow as the research object, first by collecting the flow data on each path in the airspace, and then the traffic flow in the airspace is analysed, the characteristics and flow are analysed, and then the traffic flow is classified, and finally according to the analysis of the traffic flow, on the basis of the original sector division, the height layer is used as the sector boundary. Wrap the traffic flow with strong similarity to the same sector, and try to control the flight flow balance in each sector.

This method is simpler in practical application, and the functional sector optimization is based on the original sector, and the amount of change required in the actual operation process is small and easy to implement.

3. Case Study

3.1. Parameter Setting

Vertical range of Sector 01 in Kunming area: from above the surface to unlimited height, except for Kunming approach-controlled airspace and tower-controlled airspace of Kunming and Zhaotong.Vertical range of Sector 02 in Kunming area: from above the surface to unlimited height, except for Kunming approach controlled airspace and Kunming tower controlled airspace.

According to the collected traffic flow data on various paths in Kunming area, the traffic flow data in Kunming Sector 01 and Sector 02 were screened out, and the traffic flows on the paths were classified. The traffic flows and traffic flow types on each path are shown in Table 1 below.

Table 1: The air route traffic flows of Kunming sector 01 and sector 02

Direction of air route	Average flights	Traffic flow types
A581 air route	4	Guiyang-Xishan flyover
Chengdu, Chongqing direction-SAGAG	69	Chengdu-Xishan flyover
Chengdu, Chongqing direction-KATBO	13	Chengdu-Xishan flyover
Chengdu, Chongqing direction-LINSO	9	Chengdu-Xishan flyover
Guiyang direction-LINSO	40	Guiyang-Xishan flyover
Baoshan-Guiyang direction	1	Guiyang-Lijiang flyover
Lijiang-Dali-Guiyang direction	20	Guiyang-Lijiang flyover
Lijiang-Panzhihua-Guiyang direction	27	Guiyang-Lijiang flyover
Diqing-Panzhihua-Chongqing direction	2	Chengdu-Lijiang flyover

Banna-Chengdu, Chongqing direction	7	Chengdu-Xishan flyover
Banna-Guiyang direction	6	Guiyang-Xishan flyover
Chengdu DONLA direction-MEBAN	30	Chengdu-Kunming landing
Chongqing IDSID direction-MEBAN	114	Chengdu-Kunming landing
ENTOV direction-DADOL	115	Kunming-Chengdu taking off
Chongqing IDSID direction-DADOL	29	Kunming-Chengdu taking off
LPS, P249 direction-XISILI	119	Guiyang-Kunming landing
LPS direction-KIBES	49	Kunming-Guiyang taking off
P249 direction-P146	62	Kunming-Guiyang taking off

Delimited on functional sectors need to analysis the characteristic of traffic flows. According to various traffic flows on the path towards, the main traffic flows through Kunming Sector 01 and Sector 02 are divided into eight categories, the first category is the overflights between Chengdu and Lijiang direction, the second is the overflights between Chengdu and Xishan direction, the third is the overflights between Guiyang and Lijiang direction, the fourth is the overflights between Guiyang and Xishan direction, the fifth is the flight from Chengdu to Kunming, the sixth is the flight from Kunming to Chengdu, the seventh is the flight from Guiyang to Kunming, the eighth is the flight from Kunming to Guiyang. .

3.2. Results and Analysis

Traffic flow in the same functional sectors, usually there will be a stronger resemblance between each other. Before classifying the above main traffic flows, the characteristics of each traffic flow are analyzed firstly. Chengdu-Lijiang flyover, Chengdu-Xishan flyover, Guiyang-Lijiang flyover and Guiyang-Xishan flyover these four traffic flows all belong to the flyover traffic flow. The characteristics of flyover aircraft are usually flying at a higher height, and the flight mode is mainly cruise, not frequently changing through the height. The two traffic flows of Chengdu-Kunming landing and Kunming-Chengdu taking off are mainly flights taking off and landing between Chengdu and Kunming, departure city and arrival city has a strong similarity, as well as the direction of traffic flows. Meanwhile, Aircrafts on take-off and landing routes rise or fall more frequently, requiring more height allocation by controllers. The two traffic flows of Guiyang-Kunming landing and Kunming-Guiyang taking off are mainly flights taking off and landing between Guiyang and Kunming, departure city and arrival city has a strong similarity, as well as the direction of traffic flows. Therefore, the main traffic flows in Kunming Sector 01 and Sector 02 can be divided into three types: overflight traffic flow, take-off and landing traffic flow in Kunming-Chengdu and take-off and landing traffic flow in Kunming-Guiyang. The flow proportion of these three types of traffic flow is calculated. Categories and proportions are shown in Table 2.

Table 2: Traffic flow classification and proportion

Types	Traffic flows contained	Flow proportion
Flyover	R1, R2, R3, R4	28.9%
Kunming-Chengdu taking off and landing	R5, R6	37.7%
Kunming-Guiyang taking off and landing	R7, R8	33.4%

It can be seen from the flow proportion in Table 2 that the flow proportion of each category is in a relatively balanced state after the classification of overflight traffic flow, take-off and landing traffic flow in Kunming-Chengdu and take-off and landing traffic flow in Kunming-Guiyang, which can make the flow relatively balanced after the division of functional sectors.

Based on the above analysis, the airspace of Kunming Sector 01 and Sector 02 were divided into functional sectors, and the traffic flows with strong similarity are enclosed in the same sector, and the flow of each sector is balanced as far as possible. The airspace above 8400m (excluding) contained by Kunming Sector 01 and Sector 02 is divided into Sector A, the airspace below 8400m (including) contained by Sector 01 into Sector B and the airspace below 8400m (including) contained by Sector 02 into Sector C.

In order to test the effectiveness of functional sectors, we compared and analyzed the capacity evaluation results of functional sectors after the functional zoning of Kunming airspace with the current sector capacities of Kunming Sector 01 and Sector 02. Table 3 shows the sector capacities of fan 01 and fan 02 in Kunming.

Table 3: Capacity of Kunming sector 01 and sector 02

Sector number	Sector capacity (flights per hour)
Sector 01 in Kunming area	43
Sector 02 in Kunming area	38

It can be found that after dividing the original airspace of Sector 01 and Sector 02 in Kunming area according to their functions, the capacity of the whole airspace has been significantly improved, which can effectively improve the utilization rate of the airspace in Kunming area. Meanwhile, because when delimited on functional sectors, traffic flows which have similarities will be divided into the same sector, which makes the new delimited on traffic flow of each functional sector to reduce the complexity, reduce the control difficulty of sector controller, which has a significant effect on easing the workload of controllers and is beneficial to promote the safe and orderly operation of air traffic in the whole airspace.

4. Conclusion

This paper analyzes the factors involved in the layout of functional sectors, and gives a functional sector division based on the controller load model to achieve the balance of controller load. The proposed model is verified with an example of Kunming control sector, and the results show that the layout of functional sectors is more effective for the safe and stable operation of the control sector. In the future, the controller load assessment model will be further optimized to provide more scientific and accurate sector assessment results.

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