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THE EFFECT OF AIR ROUTE INTERSECTION ANGLE ON THE EFFICIENCY OF AIR TRAFFIC CONTROL OPERATIONS

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ABSTRACT

In order for air traffic operations to be carried out effectively, airspace design, route configurations and the interaction / intersection of these routes become important. In the case of intersection of the routes at the same level, it is necessary to prevent conflict of the aircraft approaching to the intersection point. How far this prevention initiative should start from the intersection point depends on the route intersection angle. In this study, the effect of the change in the angle of route intersection on the average delay, which is an important parameter in terms of the efficiency of air traffic operations, is examined. The change of the intersection angle from 5 degrees to 45 degrees with 5 degrees interval is investigated by SIMMOD fast time simulation model. As a result of the study, it is observed that the delay time of the aircraft increases in the small intersection angles while it decreases as the intersection angle approaches 45 degrees. In addition, the minimum intersection angle between the routes is investigated by associating with the acceptable delay time.

INTRODUCTION

The configuration of the air routes, which refers to the intersection of the routes, distances from each other and their location, is one of the factors affecting airspace complexity. It is important to establish safe routes that can meet the demand in the airspace and minimize the number of intersecting routes as much as possible. However, it is not possible to remove intersecting routes completely from the airspace in today's intense air traffic conditions. Therefore, in order to provide an efficient traffic flow, intersecting routes need to be designed in a proper configuration especially in terms of intersection angles.

Decreasing the angle between intersecting routes is a factor that increases the level of airspace complexity. The value of the intersection angle is also important for the separation procedures to be applied to prevent aircraft from conflict at this point. Chatteri and Sridhar point out that the number of intersecting routes is a significant influence on sector complexity. It is stated that the level of complexity of the routes merging in a small angle is greater while it is minimum at 90 degrees [Chatterji and Sridhar, 2001]. Several conflict detection and resolution studies have been conducted on intersecting routes [Iamratanakul et al, 2004; Treleaven and Mao 2008; Devasia et al, 2011; Huang et al, 2014].

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The use of simulation as a tool for evaluating airspace problem is a common approach in air traffic management (ATM). SIMMOD (The Airport and Airspace Delay and Consumption Simulation Model) is a gate to gate simulation tool written in Simscript for the United States Federal Aviation Administration (FAA), and it allows to design an airport including the runway, taxiways, aprons, and the associated terminal airspace, or a regional airspace. It has various options to simulate probability events and can provide very detailed statistics for each flight. SIMMOD is based on detailed representation of airport and airspace structures using nodes and links. Traffic flows through the network of node-links where each node or link can accommodate a single flight at one time. When two aircraft meet on the same node or link, it is decided by programming strategies of the model which aircraft pass first and which will be delayed. The separation is provided by reducing or increasing the speed, or holding the aircraft at a node. Some of the inputs required to model an airspace in SIMMOD are the determination of the lengths and altitudes of the routes, the definition of aircraft that will fly in the route network, aircraft speeds and separation minimums. The major outputs are travel time, traffic flow, capacity, delays and fuel consumption [Simmod PLUS Reference Manual, 2012; Odoni et al, 1997; Smith, 2014].

SIMMOD has been used worldwide to estimate airport, runway and terminal airspace capacities and to improve the air traffic system's efficiency. Kleinman et al. and Gao et al. used a simultaneous perturbation stochastic approximation (SPSA) optimization method to reduce air traffic delays and tested the results with SIMMOD [Kleinman et al, 1999; Gao et al, 2008]. Peng et al. used Agent Unified Modeling Language (AUML) to illustrate aircraft arrival and departure procedures for a runway capacity analysis and evaluation in parallel runway operations, and then they tested the model with ARENA and SIMMOD simulation tools [Peng, 2013]. Simaiakis and Balakrishnan assessed the effects of congestion at major airports on taxi times, fuel consumption, and emissions through SIMMOD [Simaiakis and Balakrishnan, 2010]. In the study carried out by Bubalo and Daduna, the maximum practical capacity of Berlin-Brandenburg International Airport during independent parallel runway operations was investigated through simulation, depending on the increasing number of traffic and different traffic mix [Bubalo and Daduna, 2011]. In another study by Lee and Balakrishnan, the impact of uncertainties such as taxi speed, runway exit times, and pushback time at Detroit International Airport was investigated by means of fast time simulation. As a result of the simulation, it was emphasized that ground delay increases with an increase in uncertainty level in most scenarios [Lee and Balakrishnan, 2012].

This study focuses on the effect of the intersection angles on delay time and capacity, which are important factors for the airspace efficiency. In this context, 9 different scenarios for intersecting routes are created through SIMMOD changing the intersection angle from 5 degrees to 45 degrees by 5 degrees interval.

METHOD

The average delay time of the aircraft flying in the designed routes is one of the parameters used to determine the relationship between different intersection angles. The delay time of a flight is the time difference between the actual arrival time and the planned arrival time. Another important parameter is sector capacity. One of the most appropriate methods for determining the capacity is to measure the hourly, daily or weekly traffic flow, and it can be expressed as the number of traffic served in a specified time period under specified conditions [Majumdara et al, 2005].

The arrival frequency of aircraft and the conflict of two or more aircraft at the intersection point can affect aircraft delay and sector capacity. In the simulation model designed for two intersecting routes, aircraft enter the sector at the same time, and this means that the aircraft of the same performance arrive at the intersection point at the same moment if they are not delayed. In such cases, one of the aircraft must be delayed before it reaches the intersection point, and thus, it may be possible to demonstrate clearly the effects of the change of the intersection angle on crossing routes.

The study is carried out at FL360 and using medium and heavy aircraft since they are mostly used flight levels and categories in en-route operations, and the distribution of the categories (13% of them are heavy and 87% of them are medium) is based on the statistical data between July 2014-June 2015 for European airspace [EUROCONTROL, 2016].

The flight speeds used in the simulation for different categories are calculated considering the aircraft's performance characteristics in User Manual for the Base of Aircraft Data (BADA) and given in Table 1 [EUROCONTROL, 2014].

Table 1: Flight speeds according to aircraft categories (knots)

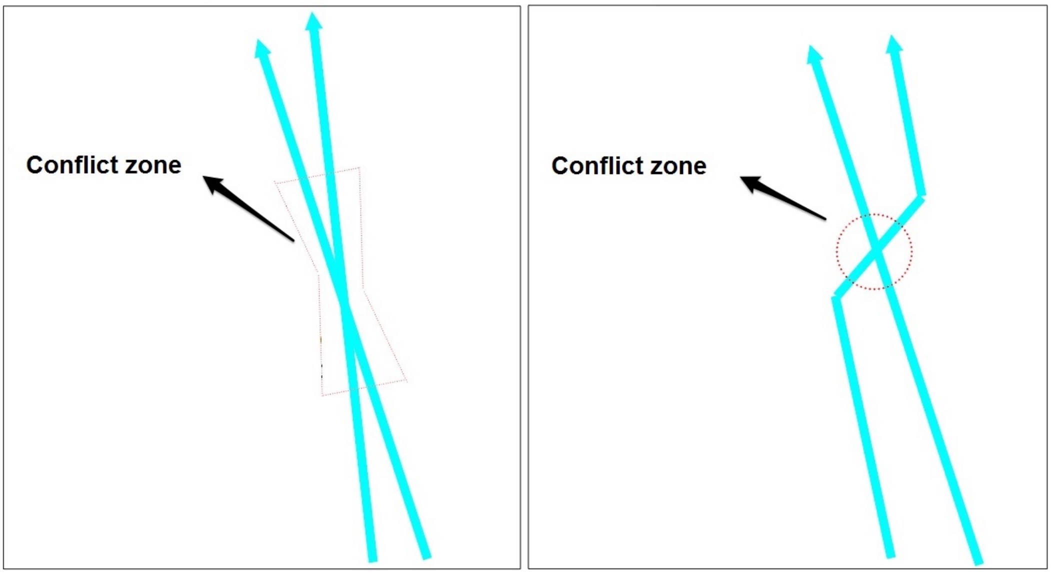
	Minimum	**Reference**	**Maximum**
Heavy	377	441	504
Medium	350	415	481

The study is carried out in the en-route phase of flight and created with the assumption of a radar controlled airspace. In accordance with the horizontal separation distance applied in Turkish airspace, 5 NM separation is used. Since the simulation model is designed on a horizontal plane, there are no climbing and descending aircraft. In addition, the total number of aircraft is 90, and they are considered to be flying in calm wind conditions.

Intersecting routes

The conflict zone between the routes must be kept to a minimum so that the aircraft can safely and easily be separated horizontally. This can be achieved by keeping the intersection angle as large as possible [EUROCONTROL, 2015].

Figure 1 shows the conflict zones for small and larger angles. When the two figures are compared, the conflict zone is smaller in Figure 1a which has small angle while it is smaller in Figure 1b which has larger angle. Hence, in the latter case, the safe separation between aircraft is provided earlier and the airspace can be used more efficiently.



(a) (b)

Figure 1: (a) The conflict zone for the small angle (b) The conflict zone for the large angle [EUROCONTROL, 2015]

Horizontal separation (longitudinal and lateral) in crossing routes is based on conflict zone around the intersection point. It is provided by a controller preventing the same level of aircraft from being at the same time in the conflict zone [ICAO, 1998].

For intersecting routes or the routes located closer than the minimum lateral separation distance (Sy), a lateral separation must also be provided together with the longitudinal separation. A flight traveling on a route that intersects the course of another aircraft is laterally separated until it reaches the lateral separation point. After crossing the intersection point, the aircraft has been separated laterally by the other aircraft after passing the lateral separation point, which is located at a certain distance measured perpendicular to the course of the other aircraft [ICAO, 2007]. In the study, the horizontal separation between intersecting routes is established in accordance with these rules, and the conflict area for the two intersecting routes is shown in Figure 2.

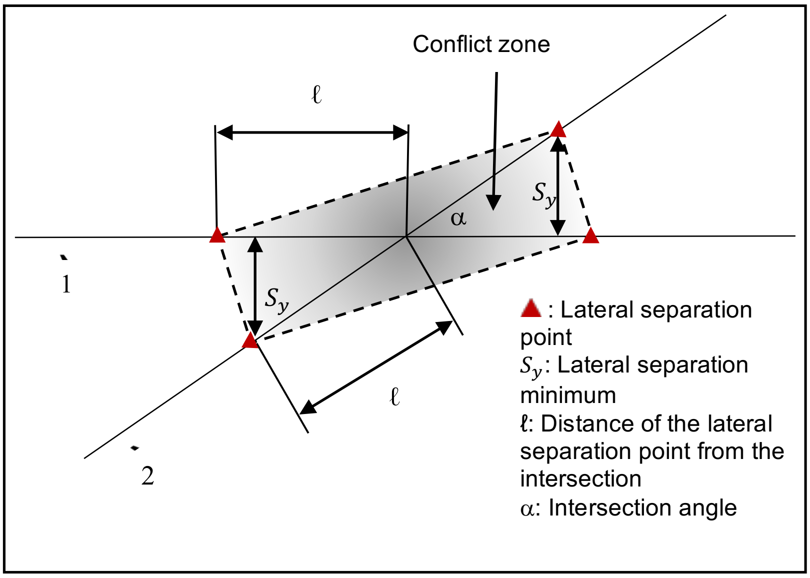


Figure 2: Lateral separation points and conflict zone in intersecting routes [ICAO, 1998]

In practice, the aircraft that are at the risk of the collision at a certain point are separated vertically before a sufficient distance from the conflict point, if possible. However, it is assumed that only horizontal separation procedures are executed in the study to analyze the angle of intersection. Besides, vertical separation is not always possible especially in intense traffic conditions. The conflict area and the traffic flow at the intersecting routes are shown in Figure 3.

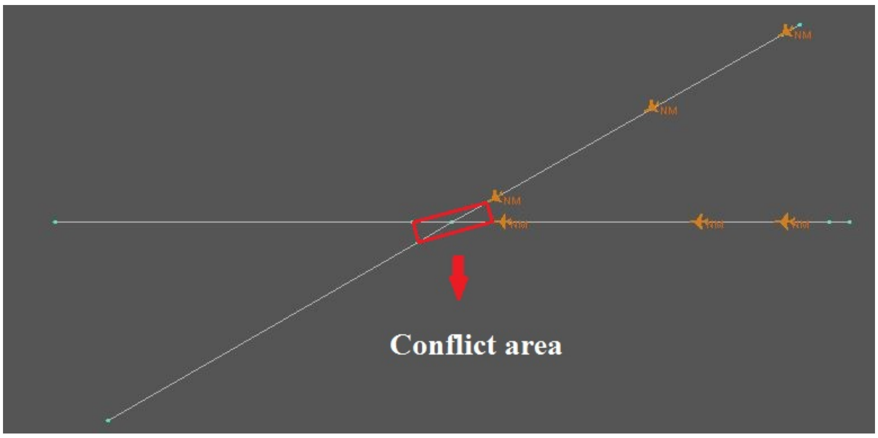


Figure 3: Conflict area at intersecting routes - a screenshot from SIMMOD

RESULTS

The size of the conflict zone varies depending on intersection angle between the routes. In Table 2, the area of the conflict zone is given for different intersection angles.

Table 2: Area of conflict zone

Intersection angle (˚)	**Area of conflict zone (NM²)**
α=5˚	573.7
α=10˚	287.9
α=15˚	193.2
α=20˚	146.2
α=25˚	118.3
α=30˚	100
α=35˚	87.2
α=40˚	77.8
α=45˚	70.7

There is an inverse ratio between the intersection angle and the area of the conflict zone as it seen in Figure 4. The area of the conflict zone is extremely large especially below 20 degrees. As the intersection angle increases, the area of the conflict zone decreases. However, the rate of decrease in the conflict zone reduces as the angle value increases.

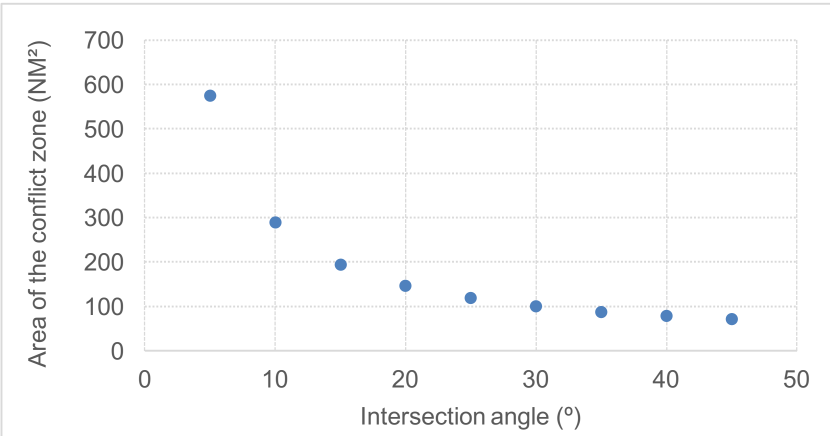
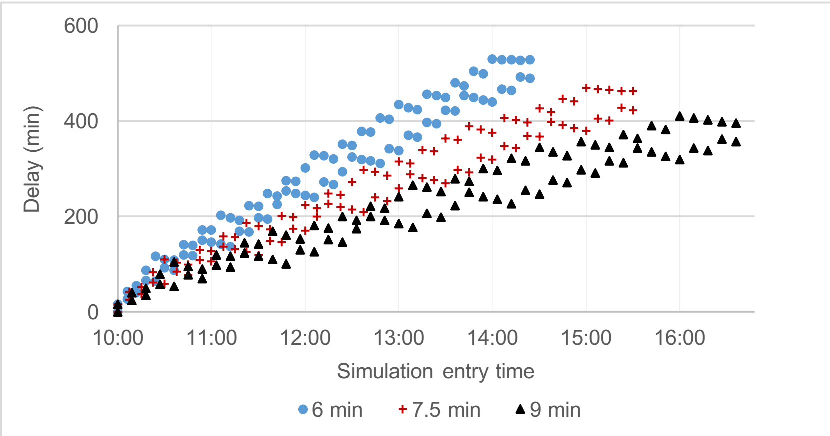


Figure 4: The change of the intersection area with intersection angle

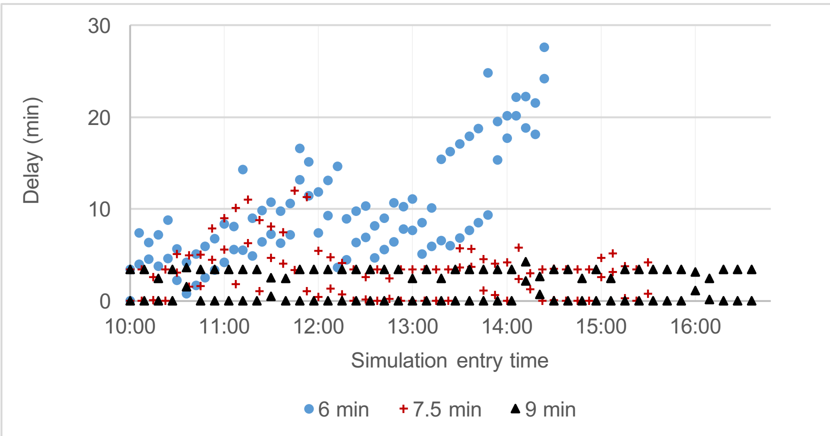
Figure 5 shows the delay distributions for aircraft with different arrival intervals for 5, 25 and 45 degrees. 5 and 45 degrees are chosen since they are the smallest and largest of the examined angles, and 25 degrees are medium value. The end times of the delay distributions are different since the arrival time of the last flight for 6, 7.5, and 9 minutes is 14:24, 15:30 and 16:36, respectively.

Looking at Figure 5a, it is seen that the delay times continuously increase in all three cases for a 5-degree angle of intersection. This indicates that 5 degrees is not an appropriate angle value for current traffic conditions, especially considering the delay times approaching to the end of the simulation. For 25 degrees, the delay times for 9 minutes are fixed at a reasonable level while for 7.5 minutes they exceed 10 minutes at the beginning of the simulation and then balance over time at a reasonable level (Figure 5b). For 45 degrees, the delay times in all three cases reduce while the distribution of 6 minutes are still unstable (Figure 5c).

As can be seen, the increase in the intersection angle reduces the delay times while the high-density traffic flows cause high delay times. Therefore, the intersection angle plays an important role for the efficiency of the flight routes, on the other hand traffic density should not be overlooked.



(a)



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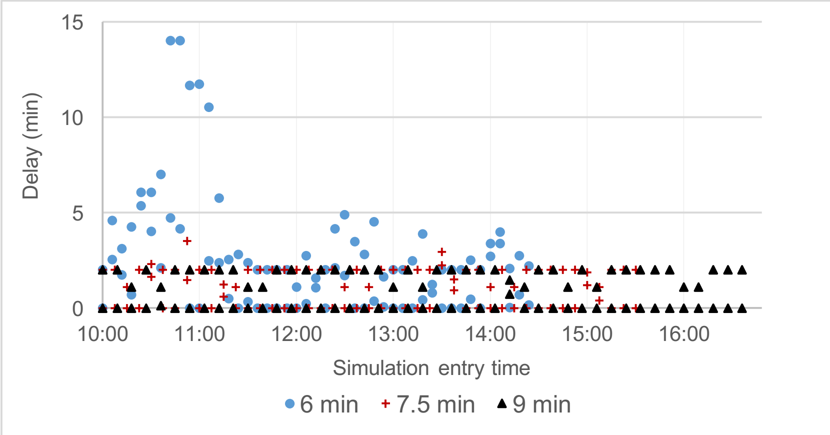

(c)

Figure 5: (a) Delay distributions for α=5°, (b) Delay distributions for α=25°, (c) Delay distributions for α=45°

In Table 3, average delay times depending on the intersection angle are given for different arrival frequencies including 6, 7.5 and 9 minutes.

Table 3: Average delay time of aircraft for different arrival frequencies (minutes)

Intersecting Angle (°)	6 minutes	7.5 minutes	9 minutes
5	289.2	256.2	223.2
10	82.4	57.2	36.6
15	57.7	35.9	18.8
20	27.3	8.2	2.3
25	9.9	3.2	1.7
30	8.1	1.6	1.4
35	3.1	1.4	1.2
40	2.9	1.2	1.0
45	2.5	1.1	0.9

For the aircraft arriving at intervals of 6, 7.5 and 9 minutes, the change of average delay time by the intersection angle is shown in Figure 6a.

The similarity between the Figure 4 showing the change in the area of the conflict zone depending on the intersection angle and Figure 6a showing the effect of intersection angle on the average delay of aircraft indicates that the area of the conflict zone affects the average delay time especially at small angles. As it seen in Figure 6a, while it depends on aircraft arrival frequency, the average delay time is very high between 0-20 degrees, but it drops to a reasonable level after approximately 20 degrees.

Figure 6b shows the capacity changes for the different arrival frequencies of the aircraft depending on intersection angles. The graphs of the average delay (Figure 6a) and the capacity (Figure 6b) change inversely, and this indicates that the decrease in the average delay increases the capacity.

When the intersection angle increases, the capacities increase significantly while they are very low at the small intersections. To analyze capacity changes in detail, Figure 6b is examined in three separate regions. In the first region, the capacities increase with the increase of the intersection angle for all arrival frequencies. However, for 5 degrees, with the decrease in the arrival frequency (from 6 minutes to 9 minutes), the capacity increases from 2 to 4. In the second region, for 9 minutes, the number of aircraft was fixed at 12 after 20 degrees. For 6 and 7.5 minutes, the capacities increase until 35 degrees while the rate of increase decreases. 20 degrees for 6 minutes and 35 degrees for 7.5 and 9 minutes can be considered as the saturation point. In the third region, the capacities for 7.5 and 6 minutes are fixed at 14 and 15, respectively.

As can be seen, it is possible to obtain a higher capacity by reducing the traffic intensity at the small angles while achieving a higher capacity with high density of traffic at larger angles. This demonstrates that small intersection angles should be avoided, especially intense traffic conditions.

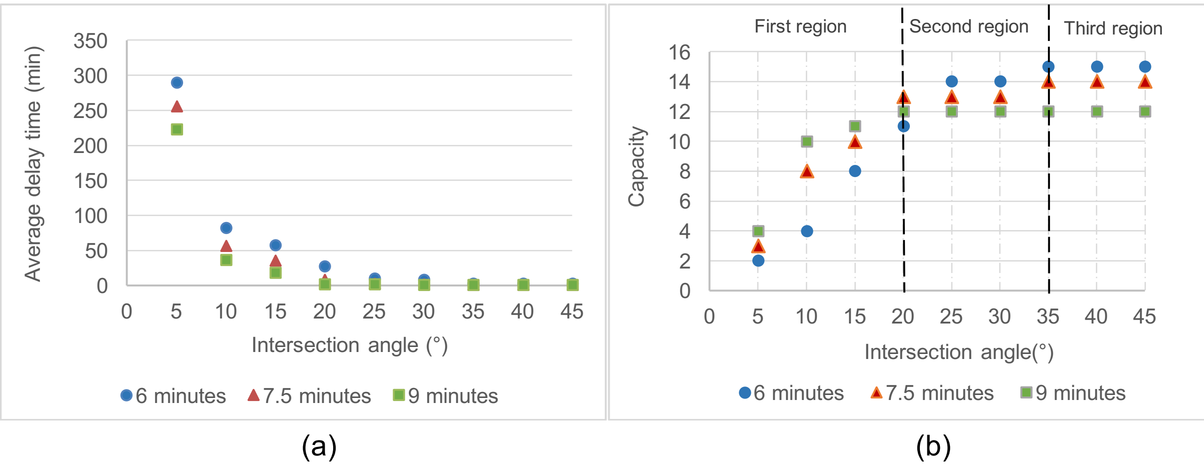

Figure 6: (a) The change in the average delay time by different angles, (b) The change of the capacity

Chao et al. noted that the acceptable flight delays may vary depending on the airport and the airspace, however experts agree that the average delay time per flight is a maximum of 3-5 minutes [Chao et al, 2008]. By assuming an acceptable average delay of 5 minutes per flight and looking at Table 3, the minimum intersection angle that can be used for 6, 7.5 and 9 minutes is between 30-35, 20-25 and 15-20 degrees, respectively. These angles can change for different amount of acceptable delay, for instance, they would be larger for 3 minutes.

As can be seen, the increase in traffic density also increases the average delay time, which also increases the minimum intersection angle that can be established for the corresponding acceptable delay time.

CONCLUSIONS

In the study, firstly, the relationship between the intersection angle and the area of the conflict zone is investigated. It is observed that the conflict area is very large below 20-25 degrees and that the average delay times below these angles are at unacceptable level. Secondly, the change in the average delay time is investigated depending on the intersection angle for different arrival frequencies. It is found that with the increase of the intersection angle, the average delay time decreases in all the cases, and the average delay time increases as the traffic density increases. In this context, although the minimum intersection angle that can be established in the route design can vary depending on the airspace, it is demonstrated that traffic density should also be taken into account in determining this angle.

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