SECTORIZATION PROJECT

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Jose Carlos Aguirre Rojas, Manel Colominas Ruiz, EETAC (Escola d'Enginyeria de Telecomunicacio i Aeroespacial de Castelldefels), Degree Students, jose.carlos.aguirre@estudiantat.upc.edu, manel.colominas@estudiantat.upc.edu

Abstract — Air traffic grows every year, increasing its complexity and volume. Airspace sectorization is a crucial process for managing growth, as effective sectorization can lead to an even distribution of the air traffic controllers (ATCs) workload enhancing efficiency and safety.

The main aim of this project is to optimize airspace sectoring using Genetic Algorithm (GA) and Voronoi diagrams focusing on balancing the workload of ATC across all sectors of the Barcelona FIR. The ATC workload is composed of four types of tasks: background, transition, recurring, and conflict tasks, each one related to an objective function.

This project assesses and optimizes these objective functions individually, starting with one and then two objective functions simultaneously. By adjusting some GA parameters and utilizing Voronoi diagrams for initial sector creation, the GA adjusts the sector shapes to achieve a balanced workload distribution. The results demonstrate the potential of this approach to enhance the efficiency and effectiveness of air traffic management by providing a systematic method for airspace sectorization.

Keywords — ATC, GA (Genetic Algorithm), Voronoi, Workload, FIR

I. Introduction

Air traffic management faces increasing complexity due to growing traffic volumes. Effective airspace sectorization is crucial for distributing air traffic controller (ATC) workload evenly, enhancing safety and efficiency. This project focuses on optimizing sectoring within the Barcelona FIR using Genetic Algorithms (GA) and Voronoi diagrams. By adjusting sector configurations based on factors such as flight volume and traffic complexity, the objective is to minimize and balance the workload of ATCs, ensuring a more effective management of air traffic.

The project considers various workload tasks, including background, transition, recurring, and conflict, each one contributing to the overall workload of ATCs. Also, the complexity of every sector is computed using some complexity parameters. It aims to efficiently perform sectorization in the Barcelona FIR, and in the scenario under study, utilizing GA and Voronoi diagrams.

In summary, this project represents an effort to enhance airspace sectorization within the Barcelona FIR. By employing advanced techniques and considering key workload factors, it looks to establish a more flexible and efficient airspace management system. Through the optimization of sector configurations, it aims to enhance safety, efficiency, and overall air traffic management effectiveness.

II. ATC Workload

To understand why it is very important to optimize properly airspace sectorization, it is pivotal also to understand how the ATC tasks that lead to workload are classified [1], and which complexity parameter is associated with each task. These tasks are classified in four main groups, based on the impact on workload:

Background Tasks: These tasks are performed independently of the number of aircraft in a sector. They include activities such as display configuration, coordination with other ATCs, and weather forecasting. Sector size and length of airways are also considered as factors influencing these tasks, as they play a role in determining the overall complexity and management requirements of the airspace within the sector.

Transition Tasks: Each time an aircraft passes through an air sector, these tasks come into play. They include actions such as transferring an aircraft from one sector to another, familiarizing with the flight plan, and planning the route. The number of transfer points of the sector and transfer points of the FIR are additional factors considered in these tasks, as they influence the complexity of coordinating and navigating aircraft between sectors.

Recurring Tasks: These tasks happen continuously and repetitively while an aircraft remains in a sector. They include air traffic scanning, prevention of meteorological hazards, flight plan changes, conflict prevention, and maintaining separation distances between aircraft. The number of aircraft within a sector significantly impacts these tasks, as it directly influences the workload and complexity of managing air traffic.

Conflict Tasks: These tasks arise when conflicts occur between different aircraft. They involve detecting conflicts, providing guidance for conflict resolution, addressing secondary conflicts, and restoring routes after conflicts. The number of intersection points between airways (conflict points) is included in these tasks, as they are crucial for identifying potential conflicts and managing airspace safety.

Each one of these tasks is associated with an objective function to be optimized with GA, with the objective of minimizing the relative standard deviation of the tasks, so an optimal balance of workload is achieved.

III. Scenario Study

A. WP0

Firstly, various proposed scenarios were explored, varying the population size and number of generations, adjusting the fraction of mutants, the crossover fraction, the number of elite individuals and newcomers. The goal was to determine the approximate values of these parameters for the study of a specific scenario with defined requirements, except for population size and maximum number of generations, as a deeper study will be done later.

Among the different scenarios provided, the scenario from 07:55 to 08:10, with 72 aircraft within the Barcelona FIR, was selected. In this scenario, different numbers of sectors were tested changing the values of the parameters.

After analyzing the various tests done, it was concluded that the necessary number of sectors for the scenario of the 07:55-08:10 is 5. This ensures a uniform distribution of workload among the different air traffic controllers across the various air sectors, with each sector handling a maximum of 15 to 17 aircraft [1].

Sectors	*Elites*	*Cross.*	*Mut.*	*New.*
5	7	40%	40%	20%

Table 1. Parameters values

Table 1 shows all the values of the parameters chosen in this section, the number of sectors, number of Elites, crossover, mutation and newcomers, with these values being chosen after numerous tests.

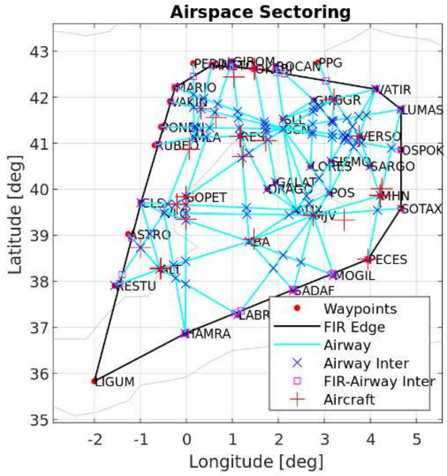

Figure 1. Studied scenario.

In Figure 1, the studied scenario is shown with greater precision.

B. WP1

In the scenario of Figure 1, an attempt will be made to find a sectorization that optimizes the distribution of background tasks among the different air traffic controllers associated with the various air sectors, using AGA function, for computing background tasks only sector areas have been taken into account.

AGA has been selected over GA because it is more accessible and easier to understand, resulting in it being a little more efficient than GA.

From the results obtained by optimizing the distribution of the background tasks, we see how the area of the sectors is equally well distributed between the different sectors of Barcelona FIR as opposed to the other complexity parameters, as shown in Table 2. The complexity parameters are explained in section II.

	RSTD
Aircraft in Sector	0.679
FIR Transfers	0.3662
Sector Transfers	0.5590
Airways Intersections	0.5316
Airways Length	0.3309
Sector Area	0.0246

Table 2. Results Complexity Parameters

IV. Single Objective Optimization

A. Method of Montecarlo Implementation (WP2)

To determine the optimal population size and number of generations without incurring excessive computational costs for the optimal sectorization (the main objective of this project), a single objective optimization approach was performed. This aimed to evenly distribute the workload among the different air traffic controllers in Barcelona FIR, especially aiming at having the same number of aircraft in approximately every sector. A study was conducted implementing the Monte Carlo Method.

To carry out this study, only background tasks have been considered, as they are the only tasks that remain constant regardless of the number of aircraft. This is because the other types of tasks grow exponentially with the number of aircraft per sector, ensuring that each sector is on an equal footing in front of the single optimizer, independently of the aircraft flow that there is in that sector.

For computing the cost of Background Tasks only the size of the sector area is considered.

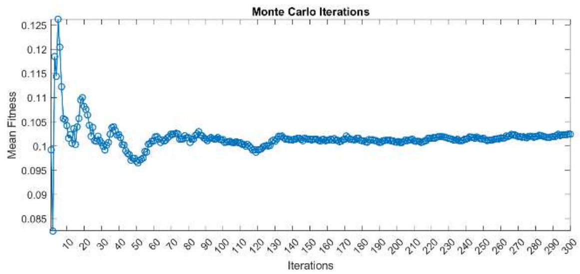

Figure 2. Monte Carlo Iterations

From Figure 2, it can be observed that after 140 Monte Carlo iterations, the average value begins to stabilize. Due to the computation time required (4.2 hours) to conduct a study with only a population of 30 individuals and 30 generations with 300 Monte Carlo iterations, it has been decided to use 40 Monte Carlo iterations for the complete study of all population sizes and all maximum values of the number of generations.

If more time and more powerful computational resources were available, the number of iterations would have been increased to at least 140 to increase the probability of obtaining better results in accordance with the law of large numbers. Additionally, the computational cost for 40 iterations is already very high with the resources available in this project, as it took 7 hours to complete.

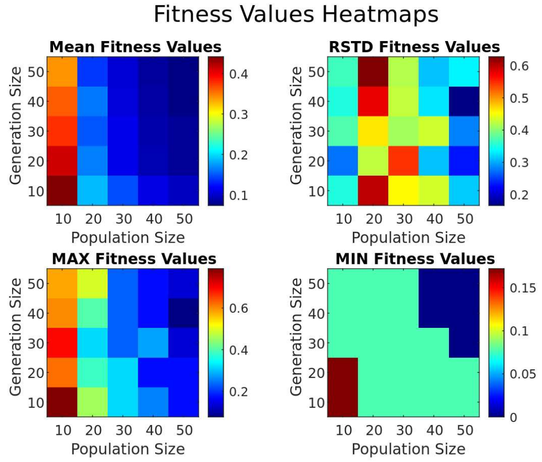

Figure 3. Fitness Values Heatmap

In Figure 3, the mean, maximum, minimum, and RSTD values of the optimized cost for the optimizer across all Monte Carlo iterations can be seen. It can be observed that as the population size increases, the optimal solution found by the optimizer decreases. On the other hand, with a higher number of generations, the optimal solution also decreases, but more slowly, showing an asymmetric decline.

As the population size increases, more reliable results are obtained cause there is a greater distribution of optimal values among the different individuals.

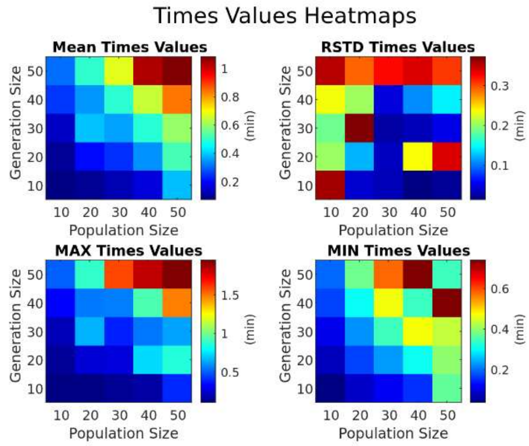

Figure 4. Computational Cost Heatmap

In Figure 4, the average, maximum, minimum, and RSTD computation times are shown. It can be observed that as the number of generations and population size increase, the computation time also grows. The heatmap of the mean values, maximum times, and minimum times shows a symmetric increase along the diagonal direction.

From Figures 3 and 4, it can be concluded that a population of 50 individuals and 40 generations will be used. This setup is chosen to maximize the probability of obtaining an optimal solution, even though it results in a slight increase in computation time.

In Genetic Algorithms, it is preferable to have a larger population rather than a higher number of generations. This is because a larger population provides greater diversity among different individuals, which increases the probability of reaching an optimal and reliable solution.

V. Multi Objective Optimization

A. Method of Montecarlo Implementation for MOO (WP3)

Now, with the parameters obtained previously it will be performed another little study with a MOO (Multiple Objective Optimization) implementing the Method of Montecarlo.

In MOO the Pareto Fraction represents the proportion of individuals to retain from the first Pareto front, while the optimization algorithm selects individuals from higher fronts [2].

To determine the optimal Pareto front fraction for obtaining, on average, a point with the smallest distance to the origin, a study was conducted using the Monte Carlo method. This study iterated over the same population size and number of generations obtained from the previous Monte Carlo study for single-objective optimization.

Due to time constraints and the computational load involved in conducting a Monte Carlo study under normal conditions, it has been decided to perform a Monte Carlo simulation with 3 iterations specifically for each Pareto Front fraction, as shown in Figure 6.

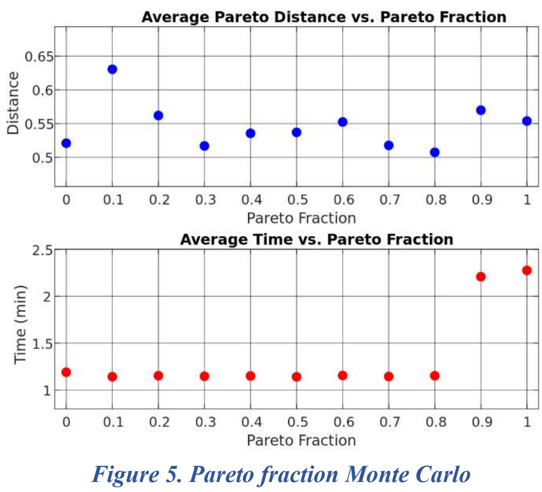

Figure 5. Pareto fraction Monte Carlo

Based on the graph in Figure 5, the optimal value to achieve a point with the smallest distance to the origin on average, among the different Pareto fronts for the various values of Pareto fractions, is a Pareto Fraction of PF = 0.3.

The points with the shortest distance to the origin of each pareto front have been chosen, as reference points, to choose the pareto fraction, but any other point on the pareto front could have been chosen, depending on the ideals of the client to optimize.
Due to discrete data and limited CPU resources, decisions are made based on the available graph, assuming that the last Monte Carlo studied was correct. On the Pareto Front, it is impossible to improve both objectives, but a solution based on the requirements must be chosen in the Pareto Front, in this study the optimal solution is the one closest to the origin, representing the most favorable result. Despite its central position, a point in the middle of the Pareto Front does not hold any particular significance compared to other solutions.

VI. Results

With the values obtained from the previous pre-studies, both for the population size (PS = 50) and for the number of generations (MaxGen = 40), along with a Pareto Fraction (PF = 0.3), an optimal sectorization has been found to evenly distribute the workload among the different airspace sectors.

The objectives to be optimized are the costs associated with recurring and background tasks. In recurring tasks, the number of aircraft in every sector is taken into account, while in background tasks the size (area) of the sector is.

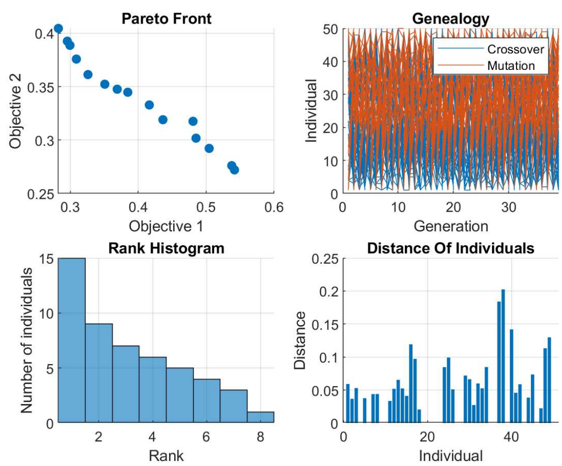

Figure 6. Results Pareto Front

Figure 6 shows the Pareto Front obtained with the parameters mentioned before, having multiple options that can be explored. This includes prioritizing the optimization of one objective over the other, or vice versa. Additionally, an optimal solution that effectively balances both objectives can be chosen.

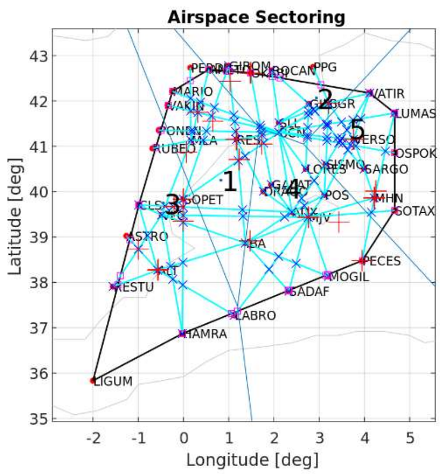

Figure 7. Final Optimal Sectorization

Figure 7 represents an example of the final optimal sectorization, from the different optimal solutions of the pareto front, having in total 5 sectors, and ensuring that all the sectors have a similar area and number of aircraft.

	Aircraft in Sector	*Sector Area (m^2)*
RSTD	0.1521	0.1569
Sector 1	11	61313
Sector 2	14	57263
Sector 3	15	53315
Sector 4	15	42316
Sector 5	17	44368

Table 3. Background and Recurring tasks results

Table 3 shows the results obtained for the sectorization that is shown in Figure 7.

From the tables, it can be observed that the distribution of aircraft and area among all the sectors is evenly balanced, as indicated by the low Relative Standard Deviation (RSTD) values. The RSTD for aircraft is 0.1521 and for the sector area is 0.1569, demonstrating a uniform distribution across the sectors.

VII. Conclusions

Airspace sectorization is essential for managing the continuous growth and complexity of air traffic, ensuring both efficiency and safety in aviation. This project focuses on optimizing airspace sectorization using Genetic Algorithms (GAs) and Voronoi diagrams, aiming to balance the workload of air traffic controllers (ATC) across the sectors of the Barcelona FIR.

As a result, the project successfully distributed the workload of ATCs by optimizing the number of aircraft and the area of each sector. The airspace has been effectively divided into five sectors, ensuring a well-balanced distribution of both traffic-related workload and sector area. The low Relative Standard Deviation (RSTD) values of 0.1521 for aircraft and 0.1569 for the sector area demonstrate the uniformity of this distribution.

In conclusion, despite the challenges and limitations associated with Genetic Algorithms, their ability to handle the restrictions of airspace sectorization makes them a valuable tool for enhancing air traffic management efficiency.

VIII. References

[1] «Curs: MODELS PER A LA GESTIÓ DEL TRÀNSIT AERI (Curs Total) | CAMPUS VIRTUAL UPC». Accessed on April 26th, 2024. [Online]. Available in: https://atenea.upc.edu/course/view.php?id=90665

[2] «Find Pareto front of multiple fitness functions using genetic algorithm - MATLAB gamultiobj - MathWorks España». Accessed on May 24th, 2024. [Online]. Available in: https://es.mathworks.com/help/gads/gamultiobj.html

[3] A. Welch y S. Martin, «Macroscopic Workload Model for Estimating En Route Sector Capacity». Accessed on May 24th, 2024. [Online]. Available in: https://archive.ll.mit.edu/mission/aviation/publications/publication-files/ms-papers/Welch_2007_ATM_MS-28122_WW-18698.pdf

[4] [Zhang, 2023] Zhang, W.; Hu, M.; Yin, J.; Li, H.; Du, J. Multi-Objective 3D Airspace Sectorization Problem Using NSGA-II with Prior Knowledge and External Archive. Aerospace 2023, 10, 216. Accessed on May 20th, 2024. Available in: https://doi.org/10.3390/aerospace10030216