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VFR Flights and Airspace Capacity Model Analyses

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SUMMARY

This working paper examines various methodologies to determine controller workload, aerodrome and airspace capacity and analyses their usefulness

1. INTRODUCTION

1.1. A flight begins at the aerodrome. It is a defined area in land or water (including any buildings, installations, and equipment) intended to be used either wholly or in part for the arrival, departure, and surface movement of the aircraft[1]. Aerodrome controllers are responsible for the landing and take-off of flights, while ground controllers are responsible for ground movements of aircraft within the aerodrome. Together, they work hand-in-hand to ensure the safe, orderly, and expeditious flow of air traffic within their area of responsibility.

1.2. ICAO Annex 2 Chapters 4 and 5 contain general rules applicable to both visual flight rules (VFR) and instrument flight rules (IFR) flights respectively. IFR (Instrument Flight Rule) is a flight conducted following the instrument flight rules, while VFR (Visual Flight Rule) flight is a flight conducted by the visual flight rules. These include those related to the avoidance of collisions, and the specific VFR dealing with the conditions concerning visibility and distance from clouds. It also discusses provisions regarding air traffic services (ATS) to VFR flights at controlled aerodromes, operated as special VFR flights, or in controlled airspace (instrument or visual).[2]

1.3. Air traffic controllers separate traffic according to their area of responsibility and classification of airspace. Aerodromes have defined airspace, as the aerodrome traffic zone (ATZ). An aerodrome traffic zone is defined as an airspace of defined dimensions established around an aerodrome for the protection of aerodrome traffic[3]. Depending on the airspace requirements, ANSP policies, and the anticipated volume of traffic, most ATZs of busy airports are classified as Class B or C airspaces[4]. Class

[1] ICAO PANS-ATM Document 4444, 16th edition, 2016, Chapter 1
[2] ICAO Annex 2 – Rules of the Air. Chapters 4 and 5. 10th edition, July 2005.
[3] Policy Statement: Establishment and Dimensions of Aerodrome Traffic Zones (ATZ), by the UK CAA, February 2016
[4] Ibid.

B and C airspace permit both IFR and VFR traffic. All flights are provided with air traffic control service and are separated from each other[5].

1.4. In a busy aerodrome, air traffic flow management (ATFM) is necessary. ATFM is established to contribute to a safe, orderly, and expeditious flow of air traffic by ensuring that aerodrome capacity is utilized to the maximum extent possible and that the traffic volume is compatible with the capacities declared by the appropriate ATS authority[6]. ATFM aims to ensure optimal traffic flow when demand is expected to exceed the available capacity of the ATC system. ATC capacity reflects the ability of the system to provide service and is expressed in the number of aircraft entering a specified portion of the airspace in a given time[7]. The ATZ, being classified as Class B airspace, permits both VFR and IFR traffic. While IFR arrivals are subjected to slotting and flow control from ATFM, VFR flights aren't. Inbound and outbound VFR flights are subject to the Tower controller's judgment. Therefore, it adds workload to the tower controller. An uncontrolled flow of VFR aircraft to a controlled aerodrome may counteract fatigue management, which can be detrimental and a safety hazard in the long run. The cognitive and operational processes of an ATC vary not only according to the number of aircraft under control but also with the number and complexity of problems to be solved[8]. The main sources of stress reported by air traffic controllers are connected both to operative aspects and to organizational structures. For the former, the most important are peaks of traffic load, time pressure, limitations, and the reliability of equipment. The latter is mainly concerned with shift schedules, role conflicts, unfavorable working conditions, and the lack of control over work[9].

1.5. This paper presents existing studies and methodologies done by some States. These will be studied and further evaluated to help in amending existing procedures regarding flow control of VFR flights flying in and out of an aerodrome under airspaces that accept VFR flights and are given air traffic control clearances and separation.

2. DISCUSSION

2.1. ATS AIRSPACE CLASSES

2.1.1. Depending on the airspace class, this provides for positive control and positive separation of both VFR and IFR traffic through mandatory two-way communication.

2.1.2. For instance, to operate in Class B, you must receive a clearance; i.e., "Cleared into Class Bravo airspace." Unlike other airspaces, receipt of a heading, altitude, or transponder code does not constitute a clearance to enter Class B airspace.

2.1.3. In most airports with surveillance, a Mode C transponder is required when operating in Class B airspace. Special aeronautical charts, known as terminal area charts (TACs), are published specifically for Class B airspace.

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[5] ICAO Annex 11: Air Traffic Services, Chapter 2, Appendix 4. 13th edition. July 2001

[6] ICAO PANS-ATM Document 4444, 16th edition, 2016, Chapter 1

[7] ICAO Doc 9426 Air Traffic Services Planning Manual

[8] S. Ratcliffe and H. Gent: "The quantitative description of a traffic control process", in *Journal of Navigation*, Vol. 27, 1974, pp. 317-322.

[9] R.C. Smith: *Stress, anxiety and the air traffic control specialist*. Federal Aviation Administration Report No. FAA-AM-80-14 (Washington, 1980); E.W. Farmer, A.J. Belyavin, A. Berry, A.J. Tattersall and G.R.J. Hockey: *Stress in air traffic control. I. Survey of NATS controllers,* RAF Institute of Aviation Medicine Report No. 689 (Farnborough, 1990).

2.1.4. For airspace classes C, D, E, F, and G, a 250-knot speed limit is imposed under 10,000 ft above MSL[10] unless you are operating in the airspace within a VFR corridor, in which case the speed limit is 200 knots (VFR corridors will be discussed later). Certain Class B primary airports are prohibited for student pilot operations.[11]

2.2. AIR TRAFFIC FLOW MANAGEMENT

2.2.1. Paragraph 3.7.5.1 of ANNEX 11 states that the establishment of ATFM will be implemented in airspaces where air traffic demand at times exceeds, or is expected to exceed, the declared capacity of the air traffic control services concerned, and paragraph 3.7.5.2 states that *ATFM should be implemented based on regional air navigation agreements or, if appropriate, through multilateral agreements. Such agreements should make provision for common procedures and common methods of capacity determination.*[12]

2.2.2. The declared capacity is expressed as the number of aircraft entering a specific portion of airspace in a given time, taking due account of weather, ATC unit configuration, staff and equipment availability, and other factors that may affect the workload of the controller responsible for the airspace.[13]

2.2.3. The Air Traffic Service Authority shall periodically review the ATS capacity concerning traffic demand and should facilitate flexible use of airspace to improve operational efficiency and increase system capacity[14].

2.2.4. Suppose traffic demand regularly exceeds ATC capacity, resulting in continuous and frequent traffic delays, or it becomes apparent that traffic demand forecasts will exceed capacity values. In that case, the appropriate ATS authority should, if possible, take steps to maximize the use of existing system capacity and develop plans to increase capacity to meet current or foreseen demands[15].

2.2.5. ATFM aims to achieve a balance between air traffic demand and system capacity to ensure optimum and efficient use of system airspace. This is achieved by balancing demand and the capacity declared by the appropriate air traffic service providers to accommodate a maximum number of flights under a gate-to-gate concept. Gate-to-Gate means the period between push-back at the departure airport and on-blocks at the destination airport[16].

2.2.6. To understand the demand-capacity balance, it is necessary to know the statistics of the expected demand and volume of air traffic using an analytical calculation. This will help identify the limitations and possible improvements to the current system. It will also aid in developing a capacity improvement program.

2.3. MIXED IFR/VFR OPERATIONS

[10] ICAO Annex 11: Air Traffic Services, Chapter 2, Appendix 4. 13th edition. July 2001
[11] Landsberg, Murphy, Bell, and Partie. Air Safety Foundation Safety Regulations No. 1, Ed. 5, 2009
[12] ICAO Annex 11: Air Traffic Services, Chapter 3, 3.7.5 Air traffic flow management. 13th edition. July 2001
[13] ICAO Annex 11: Air Traffic Services, Chapter 2, Appendix 4. 13th edition. July 2001
[14] ICAO PANS-ATM Document 4444, 16th edition, 2016, Chapter 3
[15] Ibid.
[16] J. Lee, et al., INTEGRA: Specification of Environmental Metrics and Methodologies in ATM Trials and Simulations (Final Report), Executive Summary, pg. 9

2.3.1. ICAO Annex 11 contains provisions concerning airspace organization and ATS, and creates provisions for controlled airspace, without any restriction clause, as well as for controlled airspace with restrictions as follows:[17]

> *"Controlled airspace (instrument restricted);*
> *Controlled airspace (instrument/visual); and*
> *Controlled airspace (visual exempted)."*

2.3.2. The application of the existing provisions concerning VFR flights in a mixed IFR/VFR environment differs considerably amongst and within the States, depending mainly on the traffic volume, composition, and complexity. As traffic increases at and around an aerodrome, there may be a need to introduce specific provisions for VFR operations. Where traffic density and prevailing meteorological conditions warrant a further tightening of ATS provisions, it may be necessary to segregate VFR flights from IFR arrivals and departures. The introduction of VFR corridors and VFR routes, entry and exit points, and holding fixes should then be considered. As an alternative or as a complement, it may also be advisable to upgrade the airspace around an aerodrome from Class C to Class B. At aerodromes with a significant number of IFR operations, traffic schedules for VFR flights during peak traffic hours may have to be considered. Specific types of VFR operations, e.g. pilot training exercises, etc., may have to be rescheduled, restricted, or even curtailed during specific periods.[18]

2.4. PROVISIONS CONCERNING VFR FLIGHTS AND RELATED PROBLEMS

2.4.1. In addition to the existing requirements of the various types of aircraft engaged in VFR operations, new types of activities such as skydiving, power-driven hang gliding, and parachuting, have been introduced and must be considered concerning the provisions regarding VFR operations.[19] Most aerodromes that handle a considerable number of aircraft operations with a large mixture of IFR and VFR flights and which experience a wide variety of weather conditions have found it necessary to introduce provisions supplementary to those of ICAO to maintain an appropriate level of safety in their areas. As existing ICAO provisions give little guidance in this respect, the specific national provisions, developed individually to cater to specific circumstances, tend to vary from State to State, thus creating difficulties for pilots engaged in international VFR operations.[20]

2.4.2. Some States have found it necessary when dealing with the procedural aspects associated with the mix of VFR and IFR traffic to develop new procedures, in addition to those contained in the ICAO provisions wherein aircraft operating following VFR flights are subject to additional rules. These rules are applied to those areas where the density of traffic warrants such additional procedures, but where the imposition of control of VFR traffic is not justified.[21]

2.5. AIRSPACE CAPACITY

2.5.1. Airspace capacity is defined as the maximum number of aircraft that can be accommodated in a given period by the system or one of its components[22]. The capacity of an ATS system depends on many factors: route structure, aircraft utilizing

[17] ICAO Annex 11 – Air Traffic Services. Chapter 2.5 13th edition. July 2001
[18] ICAO Doc 9426 – Air Traffic Services Planning Manual, Section 4, Chapter 2, Mixed IFR/VFR Operations
[19] ICAO Doc 9426 – Air Traffic Services Planning Manual, Section 4, Chapter 2.3
[20] Ibid.
[21] Ibid.
[22] ICAO Doc 9882 - Manual on Air Traffic Management System Requirements

the airspace, prevailing weather, available equipment, and existing procedures. Increasing the airspace capacity is necessary to address the demands of the consumers. However, an increase in capacity should not result in reduced safety levels. Therefore, the number of aircraft being provided with ATC service should not exceed a point where safety is compromised. The maximum number of flights that can be safely accommodated is assessed using an appropriate method and then declared to the parties concerned[23]. This is done for control areas (as well as the sectors within) and for aerodromes.

2.5.2. When the ATC system is approaching saturation during high traffic, delays and disruption of services are inevitable. Some solutions include: taking all reasonable steps in maximizing the capacity of the air navigation system, developing more efficient SIDs, STARs, VFR, and IFR routes, negotiating letters of agreement between adjacent controls and states, developing procedures between units to improve flow management, ensuring the new measures will be adopted with minimum delay and preferably simultaneously by adjacent units, designing ATC procedures that maximize the efficiency of handling both arriving VFR and IFR flights and achieving efficient arrival and departure operations through improved runway and taxiway designs, such as the provision of parallel taxiways and high-speed rapid exits[24], RECAT (Wake turbulence recategorization), and Time-Base Separation (TBS).

2.5.3. When all of the requirements agreed upon are duly met, service capacity is deemed to be 100%. This capacity is reduced when such requirements have operational limitations; the greater the constraint in resources, the lower the service capacity. However, the declaration of a percentage lower than the actual capacity may also be taken into account to manage contingencies or any other type of unforeseen operation.

2.5.4. Airspace capacity is not unlimited but it can be more or less optimized depending on many factors, such as:

a. Airspace design and flexibility;
b. ATC system capacity;
c. Number of sectors and their complexity;
d. Segregated airspace;
e. Availability, training, and response capability of personnel;
f. Available Communications, Navigation, and Surveillance System (CNS) infrastructure;
g. Degree of automation; and
h. The equipment and type of aircraft in the fleet.

2.5.5. When analyzing airspace capacity, we are interested in focusing on ATC system capacity and, in this sense, we have highlighted some concepts that must be taken into account as indicators to calculate the ATC sector capacity, such as workload, the importance of observable and non-observable tasks performed by air traffic controllers.

2.6. THE WORKLOAD CONCEPT

[23] ICAO Doc 9971 Manual on Collaborative Air Traffic Flow Management (ATFM) 3rd Ed., 2018, Chapter 5.2 Capacity-Planning Meetings
[24] ICAO Doc 9426 Air Traffic Services Planning Manual, Part II, Section 1.2.5 Measures to Increase ATC Capacity

2.6.1. It is necessary to analyze the impact that controller 'workload' has on the measurement of ATC capacity in a given airspace sector and to identify the techniques necessary to calculate traffic management in an automated system by using models. Attempts have been made to measure workload by assigning a value to the various tasks (task load) performed by the controller.

2.6.2. Consideration should also be given to the extensive studies on and approaches to, a workload that take into account human factors, where situational awareness, error detection and system monitoring, teamwork, trust and proper training, human error, etc., are fundamental aspects to be taken into account[25].

2.6.3. When analyzing capacity, it is important to consider the nature of the tasks that make up the workload, since there are tasks that can be observed and quantified, while others cannot be observed and, hence, are hard to quantify[26].

2.6.4. Nevertheless, it is possible to establish some constant values for these non-quantifiable tasks based on statistical analyses and, thus, factor them into the methodology used in some models.

2.7. THE DORATASK MODEL

2.7.1. A DORATASK model is widely used for task assessment and workload analysis. This analytical model based on a Fast Time Simulation (FTS) provides clear examples and logical calculations. Fast Time Simulation or FTS is a system used to simulate an airport and/or airspace by the specific requirements to develop and implement new procedures. This will yield highly realistic simulations of aircraft operations, contributing to the support from the different stakeholders involved.[27]

2.7.2. This model was first used by the United Kingdom Operational Research and Analysis Bureau to estimate ATC sector capacity (DORA Interim Report 8818), for terminal sectors (DORA Interim Report 8916) and to calibrate a simulated model for two route sectors of the London ACC (DORA Report 8927). The model was used for sector capacity assessment as early as 1989.[28]

2.7.3. In this model, the workload is calculated by adding up the time the controller takes to perform all the necessary, observable, and non-observable tasks associated with air traffic flow in his/her sector and working position. Sector capacity is determined by adding the total task load to a parameter that indicates the amount of time needed for controller recovery.[29]

2.7.4. Observable tasks are routine tasks performed by the controller, such as those applicable to all aircraft, irrespective of how many aircraft are under his/her control

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[25] ICAO South American Regional Office, Fourth Workshop/Meeting of the SAM Implementation Group, 2009

[26] Ibid.

[27] Fast Time Simulation - NLR. (n.d.). Netherlands Aerospace Centre. Retrieved August 8, 2023, from https://www.nlr.org/capabilities/fast-time-simulation/#tab-id-1

[28] Richmond, G.C. (1989). The DORATASK Methodology of Sector Capacity Assessment: an Interim Description of its Adaptation to Terminal Control (TMA) Sectors. DORA Report 8916. London: Civil Aviation Authority.

[29] ICAO South American Regional Office, Fourth Workshop/Meeting of the SAM Implementation Group, 2009

(e.g., standard communications), and those tasks are aimed at solving conflicts when an aircraft is facing an actual or potential conflict.[30]

2.7.5. Non-observable tasks are the planning tasks carried out by the controller and the mental tasks required to detect or forecast conflicts. It is important to note, however, that some tasks cannot be observed in procedural systems, but can be observed and quantified in automated systems (e.g., planning, conflict forecasting). Although planning is a non-observable task–with the aforementioned caveats–, the DORATASK Model contains algorithms that estimate workload, which is the time the controller spends on planning tasks. These estimates and examples are based on statistical data that provide constant values used to adjust analytical formulae.[31]

2.7.6. The DORATASK Model has served as the basis for many other capacity calculation applications and models, taking into account the air traffic controller's workload. However, it is not the only model to be taken into account since, as noted, it has some limitations. Nevertheless, this model is quite suitable for ATC sector capacity studies and, with the appropriate modifications, can be adjusted to automated systems.

2.8. METHODOLOGICAL MODELS FOR ESTIMATING CAPACITY

2.8.1. Currently, the estimated sector capacity value can be considered to be the maximum number of aircraft that each air traffic controller can control simultaneously in a given sector, thus providing capacity applied by the ATC unit.[32]

2.8.2. A study of the literature shows that there are no documents about the dynamic management of airspace. Some of the software provides functions related to the dynamic sectors division and should be applied. When calculating the ATM sector capacity different models and methods are used.

2.8.3. To review, the DORATASK is an analytic method used for estimating working tasks and analysis of workload[33]. It is based on simulation (Fast-Time Simulation - FTS). An air traffic controller's workload is defined by the time needed for executing 'observed' and 'non-observed' tasks. In contrast, the capacity is defined as the workload level by which the air traffic controller has enough time for 'recovery'.

2.8.4. Another method presented in the ATM sector capacity evaluation is the maximum number of aircraft that a single ATC can handle simultaneously in one sector[34]. With this method, different working tasks done by the ATC are considered altogether.

2.8.5. The ATC Capacity Analyzer (CAPAN) method is a FTS. This was developed by EUROCONTROL. This method uses an airspace model in which workload is generated for the simulated working position with given air traffic. After the exercise, CAPAN evaluates the workload. The result is compared to a preset upper limit to traffic-handling capacity. To make the simulated airspace model as similar to real

[30] The DORATASK Methodology of Sector Capacity Assessment: an Interim Description of its Adaptation to Terminal Control (TMA) Sectors. DORA Report 8916. London: Civil Aviation Authority.
[31] Ibid.
[32] ICAO South American Regional Office, Fourth Workshop/Meeting of the SAM Implementation Group, 2009
[33] R. Jaurena, Guide for the application of a common methodology to estimate airport and ATC sector capacity for the SAM region, Lima, Peru, July (2009)
[34] F. Dowling, EEC Note No. 4/98 – Sector capacity assessment for Dublin ACC, EUROCONTROL, February (1998)

airspace as possible, the correlation between qualitative (high and low workload) and quantitative evaluation is determined experimentally.[35]

2.9. ATC sector capacity calculation used in Brazil.[36]

2.9.1. The Airspace Control Department (DECEA) uses a methodology to determine the Approach Control (APP) and Area Control Center (ACC) sector capacity, which provides a sector capacity reference value. This methodology consists of obtaining a value based on a mathematical formula. The basic data for such a formula are derived from an investigation carried out by a special working group at the ATC unit, taking into account a busy period in which controller actions and availability to manage control sector traffic are observed and timed; this provides a data sample to be used in the ATC sector capacity calculation methodology.

2.9.2. The ATC Sector Capacity Calculation Model used in Brazil appears in Attachment 1 to this paper.

2.9.3. DATA SAMPLING FOR ESTIMATING ATC SECTOR CAPACITY

2.9.4. Data collection is significant for this study to dilute temporary random statistical deviations and represent reliable ATC unit values. The method used in this example to determine sector capacity takes into account the load carried by an air traffic controller in performing their tasks and is based on the assessment of the tasks performed by the controller at times of high traffic volume, as seen in the DORATASK model.

2.9.5. The controller workload is the summation of times spent on:

- Communication (transmissions/reception);
- Manual activities (filling out flight progress strips or aerodrome log) and coordination; and;
- Traffic planning and distribution

2.9.6. This Brazilian methodology applies the controller 'availability factor' (φ) concept, which is defined as the percentage of time available for the air traffic controller to plan aircraft separation procedures.[37]

2.9.7. This availability factor normally falls between a minimum value of 40% of the air traffic controller's time for non-radar control and 60% for radar control. It is thus clear that efforts need to focus on increasing the 'availability factor (φ).[38]

2.9.8. Studies conducted by Brazilian experts, who analyzed the sampling techniques, show that it is advisable to make at least 30 observations of each parameter for each controller, during peak traffic, respecting the minimum number of controllers specified by the sampling technique used.

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[35] T. Todorov and P. Petrov, A study of sector configurations capacity for air traffic service, Technical University, Sofia, Bulgaria, 2017

[36] ICAO South American Regional Office, Fourth Workshop/Meeting of the SAM Implementation Group, 2009

[37] ICAO South American Regional Office, Fourth Workshop/Meeting of the SAM Implementation Group, 2009

[38] ICA 100-30- ATC personnel planning and work timetable, Airspace Control Department (DECEA). Rio de Janeiro, 2007

2.9.9. The model applied in Brazil is quite complete since it applies a modern airport capacity approach, and is also very accurate in quantifying ATC sector capacity. However, as with other models, it assumes ideal conditions. It would be convenient to quantify a standard adjustment for each State when such conditions are not met in a given system, to reduce the acceptance number or the capacity in the formula.

2.9.10. **AIRPORT CAPACITY CALCULATION MODELS**

2.9.11. The runway capacity calculation method assumes a take-off operation between two consecutive landings, maintaining the regulatory separation minima. Runway capacity is estimated for a 60-minute interval of average runway occupancy times.[39]

2.9.12. The following factors are taken into account to determine the capacity of the set of runways:

2.9.12.1. Planning factors; and

2.9.12.2. Factors related to landing and take-off operations.

2.9.13. Planning factors are elements and assumptions used to simplify the mathematical models or the operations aspects that bear on the determination of runway capacity. The most commonly used are:

Ideal air traffic sequencing and coordination conditions;
All personnel are considered to have the same training and same operational performance;
All navaids and visual aids are considered to be technically and operationally unrestricted; and
All (VHF/telephony) communication equipment considered is operating normally.

2.9.14. These are the dependent variables for this study:

Variation of aircraft types flying within the airport;
Length of the final approach segment;
Aerodrome layout; and
Average runway occupancy time

2.9.15. Aircraft mix is defined as the percentage distribution of the aircraft fleet operating at the aerodrome according to aircraft categories. The aircraft mix for aerodromes must be estimated based on the total daily movement, which is determined using the arithmetical average of a sample containing data for at least one week.

2.9.16. According to Doc 8168, aircraft are subdivided into five categories, depending on threshold speed, which must be 130% of the value of the stall speed in the landing configuration (full flaps, gear down). The aircraft are classified as follows:

CAT A – speed less than 90 kt
CAT B – speed between 91-120 kt
CAT C – speed between 121-140 kt
CAT D – speed between 141-165 kt
CAT E – speed between 166-210 kt

[39] Ibid.

2.9.17. The average runway occupancy time is the weighted arithmetic mean of runway occupation times, by aircraft category, where the aircraft mix operating in the aerodrome is the weighing factor.

2.9.18. For greater precision, data gathering is done during peak hours since air traffic flow is more fluid during such a period, thus reducing runway occupancy time. If the data collected does not cover all categories, additional data may be gathered at other times and even on different days. Runway occupancy time during take-off shall be counted from the time the aircraft leaves the holding position up until it crosses the opposite threshold.

2.9.19. The separation criteria adopted by the air traffic controller varies, in light of the regulations required in this matter in each State.

2.10. ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN AIR TRAFFIC MANAGEMENT

2.10.1. Artificial Intelligence (AI) is the simulation of human intelligence processes by machines and computer systems. In recent years, Artificial Intelligence has become one of the promising technologies that could aid air traffic controllers in their duties. One of the primary applications of AI in air traffic control is to help controllers manage airspace by providing real-time data and automated decision-making support. In this case, AI algorithms can analyze traffic scenarios, patterns, and other factors to help controllers make informed decisions on routing and scheduling flights. AI can also be used to predict potential conflicts between aircraft and provide early warning to controllers. [40]

2.10.2. With the present traffic flow, air traffic controllers can identify and resolve possible conflicts. However, as traffic flows increase, so as the number of conflicts and the frequency with which they occur. This adds workload to air traffic controllers, compromising flight safety and delays are inevitable. Therefore, decision support technologies that can automatically perform conflict detection provide ATCs with appropriate conflict resolution schemes and reduce the workload of ATCs.[41]

2.10.3. The higher level of ATC automation requires automation to adapt to a broad range of scenarios and tasks while giving the human operator appropriate action advice[42]. Therefore, this work uses the deep reinforcement learning (DRL) method to implement a core function in decision support systems, i.e., conflict resolution, to improve the CR model's intelligence level.

2.10.4. This aims to assist ATCOs in resolving tactical conflicts. 'Tactical' here corresponds to the second level of ICAO's conflict management 'separation regulations'[43]. Based on ATCOs' decision-making habits and dynamic decision-making processes in conflict resolution, this work designs a conflict detection and resolution (CD&R)

[40] Durgut, M. (2023, March 1). Artificial Intelligence and air traffic control - aviationfile. aviation related posts, aviation pioneers and aviation accidents. https://www.aviationfile.com/artificial-intelligence-and-air-traffic-control/

[41] Sui, D., Ma, C., & Wei, C. (2023). Tactical conflict solver assisting air traffic controllers using deep reinforcement learning. *Aerospace*, *10*(2), 182. https://doi.org/10.3390/aerospace10020182

[42] Eurocontrol. European ATM Master Plan [Internet]; Eurocontrol: Brussels, Belgium, 2020. https://www.sesarju.eu/sites/default/files/documents/reports/European%20ATM%20Master%20Plan%202020%20Exec%20View.pdf

[43] International Civil Aviation Organization. Doc 9854, Global Air Traffic Management Operational Concept; International Civil Aviation Organization: Montreal, QC, Canada, 2005.

mechanism capable of handling continuous traffic flow under the CD&R framework. The tactical conflict solver (TCS) agent is trained in the actor–critic using a Kronecker-factored trust region (ACKTR), taking into account multiple constraints, such as ATC regulations, uncertainty in the real environment, and the real airspace environment. The DRL environment was developed based on the Air Traffic Operations Simulation System (ATOSS). Depending on the real-time situation, the TCS can resolve conflicts in real 3D airspace with high quality by using altitude, speed, or heading adjustments used by ATCOs and taking into account the operations of other aircraft. Tactical conflict resolution is an essential part of intelligent ATC. The critical problem in tactical conflict resolution is clarifying the framework and mechanism of conflict detection and resolution and improving the model's conflict resolution ability in various scenarios.

2.10.5. The conflict resolution model uses the same altitude, speed, and heading adjustments as the controllers. Using performance data from different aircraft types during the agent's interaction with the environment can ensure that the model solutions fit the aircraft's dynamic constraints. The conflict resolution rate did not reach 100%; however, a resolution rate of nearly 90% is acceptable for a tool that assists ATCOs in decision-making. The conflict resolution rate of the testing set decreased as the airspace density increased.[44] The underlying reason is that the airspace structure and traffic flow density determine the size of the available solution space. In practice, to ensure flight safety, airspace density is usually restricted by holding aircraft or controlling traffic flow.

3. CONCLUSION

3.1.1. There are two reasons why knowing the capacity of air traffic sectors or ATC operating positions is important. Firstly, this aids in long-term planning. Based on the air traffic forecast, the demand for air travel is always upward. Secondly, if there is already a reduction in capacity that calls for flow control, it must be known to restrict traffic without overloading the system or excessively affecting airline operators or to implement best practices on operational performance.

3.1.2. Several methods were used for calculating capacity. The workload is a significant parameter in these models, however, there are numerous variables present such as communication deficiencies, adverse weather, aerodrome layout, military operations, emergencies, and preferential aircraft operations that can affect the results and misleading conclusions if not properly weighted.

3.1.3. Another possible solution for this predicament is Artificial Intelligence (AI) through machine learning and deep reinforcement learning. This method doesn't involve mathematical equations and computations to come up with a particular number to ensure the safety of VFR flights. While having a specific number of accepted VFR flights in a sector offers an overview of how an air traffic controller should handle VFR traffic in their sector, the number doesn't always apply to everyone and in every work situation, as VFR flights are more dynamic than IFR flights.

3.1.4. Sectorization can also help increase the airspace capacity, as well as staff sizing requirements to cover all operating positions in the event of maximum configuration.

3.1.5. As for the models applied in the region, no major differences in the results obtained for airport acceptance rates are found between the FAA model and the model used in

[44] Sui, D., Ma, C., & Wei, C. (2023). Tactical conflict solver assisting air traffic controllers using deep reinforcement learning. *Aerospace*, *10*(2), 182.

Brazil for purposes of determining runway capacity. If we analyze the various ATC sector capacity calculation models, we will note that, to a greater or lesser extent, the main parameters are derived from the DORATASK Model.

3.1.6. With few exceptions, as we have seen, most of the States in the Region have little practical experience in using a model for calculating capacity. This has an impact on the size of the available database that could be used to adjust constant values in each of the different operational scenarios in the systems of the Region, unlike the FAA, whose databases have been fed with data collected for many years and are constantly updated.

4. RECOMMENDATIONS

4.1. It is recommended that this working paper is accepted as information material.

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APPENDIX

ATC Sector Capacity Calculation Model Used in Brazil

The number of aircraft that can be controlled simultaneously by a single controller (N) in a given sector is estimated using the following formula (ICA 100-30):

$$N = \varphi \cdot \delta \cdot (\eta \cdot \tau m \cdot vm)^{-1}$$

Where ATC capacity is a direct or inverse function of some factors (ICA 100-30) to be considered.

Factors directly proportional to ATC capacity:

φ: the controller availability factor, defined as the percentage of time available for planning aircraft separation procedures;

δ: average distance flown by aircraft in the sector, which is a function of the paths and enroute or terminal procedures established for each sector.

Factors inversely proportional to ATC capacity:

η: number of communications for each aircraft in the sector, which must be limited to the least possible number required for an understanding between the pilot and the controller. This number can be minimized by issuing a complete clearance sufficiently in advance for flight planning;

τ_m: mean duration of each message. This factor can be minimized by issuing messages objectively, without long explanations that are detrimental to an understanding between the pilot and the controller; and

v_m: mean speed of aircraft in the sector.

If δ and v_m are replaced with the average flight time of the aircraft in the sector (T), this formula can be replaced with a simpler version:

$$N = \varphi \cdot T \cdot (\eta \cdot \tau_m)^{-1}$$

The values of factors φ, T, η, and τ_m are empirically obtained following the standard procedures (DECEA, 2007).

For example, we can consider T= 12 minutes, τ_m = 9 seconds, φ = 60%, η= 6, which gives several aircraft N = 8 simultaneously controlled by the controller in the given sector. In other words, in this sector and under these conditions, a controller would simultaneously control 8 aircraft.

Several factors are constantly influencing the number N and that is directly related, such as the size of the sector or route modification. Consequently, whenever a significant change is observed, the value obtained must be updated.

Under ideal conditions, data collection must be done in busy traffic. Therefore, the selection of the ideal period is a factor to be taken into account, since it has a direct impact on the final result.