

DEVELOPMENT OF TECHNICAL AND PROCEDURAL REQUIREMENTS TO SUPPORT A SYSTEM OF FLEXIBLE ENDORSEMENT FOR UPPER AIRSPACE AIR TRAFFIC CONTROLLERS

Marco-Michael Temme, Jana Meier, Robert Hunger, Michael Finke, Rabeb Abdellaoui, Shruthi Shetty, Aleksander Cicvara

Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Braunschweig, Deutschland

Abstract

A severe shortage of air traffic controllers (ATCO) poses new challenges for air navigation services. They are only allowed to work in sectors where they have received certification including successful on-the-job training. This paper presents a method that makes it possible to aggregate the work experience of controllers in recent months and assess how efficiently and safely they could organize air traffic in another sector of upper airspace without a full traditional OJT. Rising air traffic volumes coupled with a simultaneous decline in qualified applicants for the air traffic controller profession means that some sectors cannot be adequately staffed for capacity reasons, particularly in peak seasons with many flight movements. New ATCOs receive a widespread theoretical training, after which they undergo extensive on-the-job training to get a new sector endorsement. After successfully completing this training, they are allowed to work in this sector as a partner in a team consisting of an Executive and a Planner controller. They must complete several months of training in each additional sector or sector group in which they are to be deployed in order to obtain a corresponding endorsement. To maintain these unit endorsements, they must complete regular endorsement maintenance tests and accumulate proven working hours. These requirements would practically mean that every controller is limited to a specific number of sectors, as they would otherwise have to dedicate a majority of their annual working hours exclusively for endorsement maintenance.

However, after completing their training and working at own responsibility in a sector, controllers should, in principle, be able to work safely and responsibly in any comparable sector with a much shorter training of a few days, maximum weeks, as most of the needed competencies have already been trained and developed. In order to obtain a metric for the comparability of sectors in connection with the most recent professional experience of a controller, a calculation rule was developed in the SESAR project IFAV3 that allows both the creation of an assessment vector for current experience and the mapping of these experience values to a sector for which a certain volume of traffic is predicted at a defined time. The developed assessment procedure Upper Airspace Skill Level Index (UASLI) now makes it possible to generate an estimate for each ATCO of how well they will cope with the expected traffic in a sector for which they have not received a full traditional on-the-job training. Particular challenges in the assessment are, for example, traffic loads that fluctuate significantly over time or experience gained a long time ago, which must be weighted accordingly in the index. The result is an individual experience-vector consisting of seventeen indices, which can now be compared with an expectation-vector based on the predicted traffic data for a sector and calculated using the same functions.

An automated comparison of these vectors provides supervisors with a tool for finding ATCOs with sufficient experience and competence who could be deployed in the event of a temporary shortage of ATCOs to any sector. Additionally, IFAV3 also deals with the legal adjustments that would have to be made for the deployment of controllers in non-endorsed sectors. The results of this experience validation presented here, provide valuable insights into the feasibility and potential benefits of a more flexible endorsement system, its impact on the work of air traffic controllers, and contribute to the further development of the upper airspace air traffic control systems.

1. INTRODUCTION

The training and qualification of air traffic controllers (ATCO) is a lengthy and cost-intensive process. Worldwide, almost all air navigation service providers (ANSP) select and train their own junior staff. The selection process is a major challenge for both school graduates and people with professional experience, which more and more potential applicants seem unable or are unwilling to face [1]. Even for those who complete their training, career advancement

remains limited. Changing a controller's place of work within a country is time-consuming, but is usually possible. Even within Europe, due to the different requirements for licenses, professional experience and health, it is difficult for air traffic controllers to move from one country to another [2]. Therefore, ensuring sufficient and nationwide availability of air traffic controllers remains a major challenge for every national ANSP.

This means that ANSPs in Europe [3] and North America

[4] are increasingly reporting a shortage of controllers, which leads to restrictions on supplied capacity and demands, as sectors cannot be divided or even have to be collapsed. Especially at times of high traffic demand, this results in flight delays and even complete cancellations, to the detriment of both airlines and passengers.

Even if ATCOs are qualified to manage one or more sectors, the expansion and regular renewal of endorsements (sector-specific authorization within an ATCO license to operate at a designated control unit or sector) is time-consuming and cost-intensive. As each unit endorsement must be maintained through annual working hours and examinations, controllers must work on the corresponding sectors regardless of actual traffic demand. The more endorsements controllers have, the more flexibly they can be deployed. However, the time required to maintain the endorsements also increases, meaning that the controller can be deployed less frequently, which will reduce overall schedule flexibility at some point.

Most air traffic services are required to cover uninterrupted work shifts 24 hours a day, seven days a week. The proper planning of a shift schedule requires the consideration of at least three elements. These are the specific characteristics of the ATCO task, physiological needs of the operator, and the definition of rest periods within the duty roster [5]. Therefore, planning the deployment of available controllers is a challenge, as it is not possible to perfectly match ATCO hours to demand [6]. This challenging situation has even prompted EUROCONTROL 2023 to issue a guideline for the deployment planning of ATCOs to avoid a permanent overload of ATC personnel [7].

In this context, determining which controllers are qualified and suitable for assignment to specific sectors at specific times becomes essential. Different approaches have already been chosen to quantify the workload of ATCOs. In addition to heart rate measurements [8], complexity analyses of the airspace under consideration have also been carried out [9] [10]. However, when considering the possible qualification of controllers for a sector with predicted traffic, the focus is on the work experience that a controller has gained in the past, rather than the performance or quality of the controller's work in the past in various situations while handling traffic. On this basis, an assessment of how well and safely the ATCO can organize a previously unknown sector with a certain predicted traffic load is made.

A sustainable solution to the persistent shortage of ATCOs in air navigation services could be a much more flexible licensing of unit endorsements, which is not only based on the classic endorsement but also enables deployment in previously unendorsed sectors if controllers can record appropriate work experience under different operating conditions. For this approach, IFAV3 drew on the proven practice of airspace and workplace complexity analyses and adapted them to the new field of application.

The used Smart Competency Monitoring and Minimum Required Competency Level Prediction is one of the four complementary Solutions for a flexible rostering of ATCOs of the SESAR Working Area 1 (en-route) of the IFAV3 project [11]. This strategy aims to enable a unit-endorsed ATCO to manage sectors of a different unit (intra-ATSU), based on former experiences and transferable competencies (Fig. 1) [18].

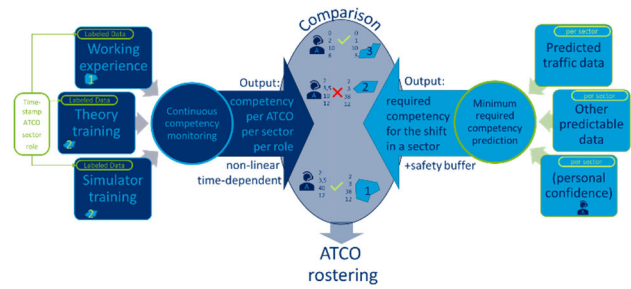


Fig. 1: Strategy of Smart Competency Monitoring and Minimum Required Competency Level Prediction.

Using application-based calculation methods, it is possible to assess the current work experience of ATCOs, using which it can be decided whether they can work safely as an executive or planner for short-term deployment in a sector for which they do not hold an endorsement. However, it must be considered that both the selection of criteria and the parameters must be adapted to each center, as different boundary conditions and working methods significantly influence the workload of ATCOs [12].

The assessment of the recent work experiences is conducted by calculating the Upper Airspace Skill-Level Index (UASLI) for each individual air traffic controller to estimate the expected capabilities in a previously unknown upper airspace sector (Fig. 2). 'Unknown' in this case means that it is a sector in which the respective controller does not have a regular unit endorsement and therefore has neither special training nor accompanied an on-the-job training (OJT). The result is a temporal unit endorsement.

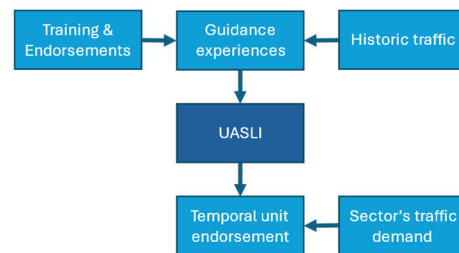


Fig. 2: The principle of individual UASLI calculation for a temporal unit endorsement.

A determined skill level can be based on a single measurable parameter, but it can also be an index composed of several criteria. In air traffic management, there have already been approaches to establish a connection between the capacity of an airspace and the workload of air traffic controllers using complexity analysis with equations and weighted parameters (e.g., [9] [13]). The approach of adapting trajectories or routes according to an ATC difficulty index was also proposed [14]. However, there are no existing approaches that aim to comprehensively measure capabilities in terms of experienced scenarios in order to leverage them when assigning controllers to sectors based on the specific requirements of those airspaces.

The temporal unit endorsement presented here is a two-stage process consisting of a monitoring and a prediction part. Monitoring refers to recording and evaluating a controller's experience using historic data, which is used to estimate the current skill level of an ATCO.

The prediction part is the evaluation of the required skills, which are based on the selected sector or sector group, the

expected air traffic demand, and military and weather-related boundary conditions. While prediction is based on flight plans, weather forecasts, NOTAMS and statistical evaluations, monitoring is much more complex and time-consuming. Today, the required empirical values of air traffic controllers are to a large extent not directly recorded by ANSPs and must be derived and standardized from other measured values. For this reason, this paper concentrates mainly on the calculation of the monitoring index and will only touch on the prediction part.

This paper presents eight out of seventeen skill parameters that could be used to summarize the actual experiences of air traffic controllers conducting area control services. The skill-parameters can be used to assess whether and how they will be able to work safely and efficiently as part of a team in a given sector at a particular time. Additionally, five countermeasures are proposed to counteract negative shift effects caused by regular services of controllers in non-endorsed sectors (Chapter 4.5). To compensate for this negative shift effect, it would also be possible to assign a greater weight to the experience gained in UASLI sectors. However, this weighting depends on the type of airspace and the typical tasks of the ATCOs and must therefore be determined individually for each ANSP. The endorsements for flexible rostering can be issued after a theory training without a full OJT and is in turn initially restricted to air traffic controllers' skill sets.

1.1. Definition of Terms

UASLI: The Upper Airspace Skill-Level Index (UASLI) introduced here is an index built from an air traffic controller-individual experience evaluation vector with up to seventeen dimensions. For each monitoring parameter, there must be a corresponding prediction parameter which are compared with each other in terms of their extent. If individual parameters are missing on the monitoring or prediction side due to technical constraints, these parameters must be removed from the assessment vector.

UASLI-Sector: An UASLI-Sector is one for which an ATCO does not currently have a valid traditional endorsement (but is nevertheless endorsed with additional conditions according to this concept). These are operational sectors for which controllers did not complete an on-the-job training (OJT) involving a final examination. The UASLI provides an indication of how well an air traffic controller with at least one valid unit endorsement could guide and safely organize the UASLI-Sector based on their current work experience.

Temporal Unit Endorsement: The aim of the UASLI is to assess whether an air traffic controller could be issued with a temporary endorsement for an unfamiliar sector with a given predicted traffic which he/she is nevertheless able to operate a sector based on past work experiences. A Temporary Unit Endorsement may never be issued without the consent of the concerned air traffic controller and the responsible supervisor.

1.2. Constraints

It should be borne in mind that the skill indices calculated here provide an indication of the current professional experience of the air traffic controllers in question. It neither assesses their performance and their ability to organize an airspace, nor how well they guided aircraft safely and efficiently [15]. Of course, some of the parameters from the

controllers' work considered in the concept could be used to make a rough estimate of performance, quality, or controller performance in relation to other controllers in the same center. However, the calculation rules proposed and applied here are designed solely to translate the amount and type of work from the near past into a simple traceable index-value vector. In the operational use, each individual index should also be safeguarded by a limit value below which no approval may be given for an unendorsed sector. This ensures that a massive experience deficit in a certain field of work is masked by other experience values and thus remains unrecognized.

In our approach, the exact period considered for the assessment is set to 90 days in the past. However, there are arguments for significantly extending this to six or twelve months in order to be able to consider seasonal influences on traffic. Ultimately, the length of the period considered retrospectively depends on ANSP's data availability and the mathematical modeling of skill decrease (Chapter 3).

When generating the index, no distinction is made between civil and military aircraft, and both are treated for calculation equally. In many countries, it is common practice for military aircraft in upper airspace outside temporary reserved airspaces (TRA) to be integrated into regular flight operations by the local civilian controllers [16]. For the calculation of the controller's experience, these aircraft therefore count in the same way as regular IFR traffic.

Both static and dynamic parameters are required to calculate the different skill level indices. Static parameters usually refer to the properties of the airspace (sector areas, sector border edge lengths, etc.), while dynamic parameters refer to the properties of the controllers and their recent activities. The influence of individual skill levels on the overall endorsement can be adjusted by weighting them accordingly. Some of the input data are used differently in several skill-parameters. Sometimes they are used as a direct indicator, in other places only to put correlations into perspective. All skill parameters presented here have the same thing in common that higher values indicate higher skills.

The UASLI could be calculated at any time but should be done at least on a daily basis. In addition, it should be possible for the supervisor or the controller's staffing manager to recalculate the skill level indices at the touch of a button, so that current values are available at all times. There is no theoretical limit for the prediction period. However, it should be borne in mind that controllers' experience levels change every day, meaning that forecasts for future days and sectors will be subject to significant inaccuracy the further ahead in time the task is scheduled. In addition, the accuracy of traffic forecasts is also reduced over longer periods of time and reliable weather forecasts are clearly reaching their limits over a period of more than five days. However, all parameters and evaluation criteria are designed in such a way that they also allow short-term planning. The most reliable period in which the UASLI and its forecasts can be used is between a few hours and around five days due to the availability of data and technical possibilities.

The objective of the upper airspace skill level index is to provide an estimate of how much traffic an IFATV controller can handle in a defined period of time in a sector for which he or she is not currently certified and does not own a classical unit endorsement. Since the traffic forecast can always be subject to a time-dependent estimation error, the predicted traffic load of a sector should always be slightly

below the maximum traffic that can actually be handled by the IFAV controller as predicted by the skill value. However, this means that the skill value of a controller slowly decreases over time, as controllers in IFAV-sectors on average always handle sectors with less traffic than they have handled in the past and are therefore allowed to handle. For this reason, a Competency Requirement Flexibility procedure is proposed, which calculates a buffer that is added to the expected traffic up to which a controller is allowed to work based on their current skill level.

There are flight sectors and operational sectors. Flight sectors are the smallest entity of airspace that can be worked separately as area of responsibility. An operational sector may consist of either an individual flight sector or a combination of multiple flight sectors (collapsed sectors). For the evaluation of skill levels, sectors are always considered in their smallest possible units. A sector counts as one unit if it is controlled by a controller team. If the same airspace is horizontally split into additional layers, each of these layers is counted separately. For example, the undivided sector counts as one unit, if it is divided horizontally, tree units, the two sub-units and the combined subunits (undivided sector), are obtained. With further subdivisions, for example an East/West split, finally a total of seven independent air space sectors is obtained. These subdivisions are illustrated in Fig. 3, where a single operational sector is shown split into Low/High layers and further divided into West High, West Low, East High, and East Low. It is important to note that each resulting unit has its own geometry and boundary conditions (for example capacity or volume limitations due to area-specific altitude limitations, military restrictions or severe weather).

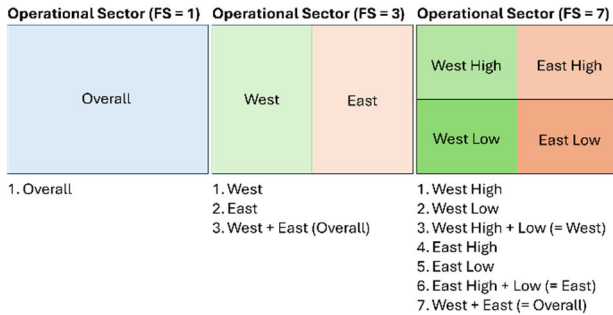


Fig. 3; Exemplary Definition of Operational Sector and Flight Sector.

A similar procedure is used when counting flights. In this case, callsigns that occur twice are included in the calculations as separate flights. This may result if short-haul flights occur twice or more during a shift or are separated in the data recordings by the date transition at the midnight change of day. The smallest time unit in which the work data of controllers are used are shifts per sector configuration. Typically, this period is understood to span from the controller's start time on a day until the end of their shift on the same day. However, in practice, it is common for controllers to switch sectors during a shift, meaning that the time frame for the calculation is not fixed and should be adaptable. The duration of a shift or sector assignment can vary depending on factors such as the best allocation of available controllers to sectors, optimizing for efficiency, or resource management. As a result, the calculation period must be flexible and adjust according to operational needs and constraints, including controller assignments and sector transitions throughout the day. This means, for example, that handling

a complete sector in the morning followed by handling only a part of that sector in the afternoon, which is separated due to traffic are counted as two different shifts in two sectors.

The procedure presented here offers predictions based on current professional experiences of upper airspace controllers as to whether they can organize the demanded traffic in a sector safely and efficiently in a certain period of time. If a controller meets the predicted requirements, he or she may receive a temporary unit endorsement for the UASLI-Sector. The assessment is based on the finding that the practice and training of air traffic controllers is necessary not only to improve individual skills, but also to increase overall operational efficiency [17]. However, it should never be inferred from this that a controller can be forced to take over a sector for which she or he have not received a regular unit endorsement inclusive a full on-the-job training. The controller must therefore always be free to decide whether she or he is confident enough to take over a sector or would first like to gain more professional experience.

2. THE UASLI VECTOR

UASLI consists of seventeen individual parameters. Each of these parameters can be used to assess the potential skill level of a controller to provide an air traffic control service in a new and unfamiliar upper airspace sector (UASLI-Sector) without accompanying additional OJT. However, there is also the option of accrediting all the proposed parameters to a single value. This is usually done by adding them together. However, as the individual skill parameters have different ranges and the final result therefore reacts with different sensitivities to parameter differences, each skill parameter should be preceded by a weighting factor when summing up. So, it is possible to use a weighted summation formula to add up all individual indices to an overall index L_C : the skill-level of controller C , n as number of skill parameters, a_x as weighting factor of skill x , and B_x is the skill x :

$$L_C = \sum_{x=1}^n a_x \cdot B_x$$

In total, seventeen parameters have been used when calculating the skill level [18]. As they are based on measured values with different dimensions, they must be leveled for indexing and weighted according to their importance. Another option would be to assign greater weights to the experience gained by ATCOs in non-conventionally endorsed sectors, regardless of the parameter. The seventeen considered individual skill parameters are Sector Structure and Area, Working Time, (experienced) Traffic Diversity, Actual Regular Unit Endorsements, Entry-Exit Altitude Differences, Radar-Support-System Handling Time, Intersection Complexity, Military Airspace Restrictions, Experiences in Neighboring Sectors, Sector Occupation, Professional Experience, Radio Contact Times, Communication Events, Simulator Practice Time, Transition Time, Number of Vertical to Horizontal Movements, and Weather Handling,

3. CONSIDERING THE DECREASE OF SKILLS

The calculation of a skill-level is based on various criteria depending on the skill in question. This includes the frequency, but also the time period in which it was used. The longer ago it was used, the less influence it should have on the index values. In cognitive research, there are two fundamental differences in the way knowledge and memory

are viewed. On the one hand, there is short-term memory, which stores information such as telephone numbers or addresses. However, the information stored and “learned” here is quickly lost, so that within a very short time only a fraction of the original information can be retrieved [19]. The situation is different with trained knowledge. This includes intensively learned skills such as riding a bike, swimming, playing an instrument, or mastering a craft. Based on a consideration of applications of 90 days, this means that only the use cases of the last three months are included in the calculation.

The weighting factor for individual skills and their application in the index calculation should decrease over time, as it can be assumed that the influence of experiences is slowly decline if they are not applied. In addition, it can be assumed that a skill acquired through application is initially retained before it is lost again through the process of forgetting or its application requires more time. To take this context into account, the time-dependent weighting factor is presented as an exponentially decreasing curve. This considers the fact that applied and acquired skills are almost as present on the following days as they were on the first day, but decrease significantly after a longer period of non-application. To model the forgetting as part of the experience weighting, we used an adaption of the Memory Chain Model (MCM) [20].

$$w_d = \frac{1}{1 + e^{-k_0(90-d_0-d)}}$$

The constants rate of forgetting $k_0=0.1$ and number of days without skill-level loss $d_0=20$ ensure that the exponential progress w_d after 90 days is around 13% (Fig. 4).

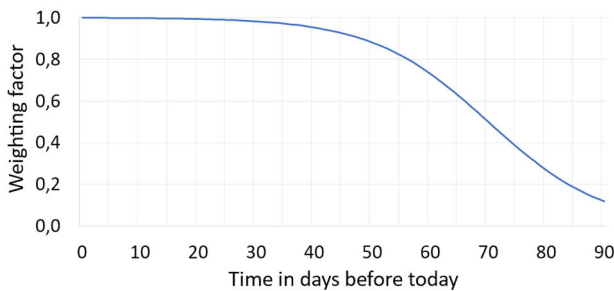


Fig. 4: The progress of the weighting factor w_d for the number of days d since last use of a skill.

Skill levels are calculated on a weighted daily basis d . As controllers work in shifts and these shifts may well take place in other sectors with different boundary conditions on the same day, the shifts must be calculated individually. However, the weighting w_d is calculated per day. In order to not complicate the required calculation rules unnecessarily, in some equations the parameters are specified on a shift basis s , but the surrounding summations are specified on a daily basis d . For the calculation, this means that the totals must be calculated per day, which in turn can be made up of one or more work shifts. For the implementation, this means that values for all shifts of a day are first calculated and then the daily index must be added together with the day-dependent weighting w_d .

The same calculation rules are used for the requirement prediction for a sector as for the experience monitoring. However, there is no parameter for forgetting, so that w_d is set to one. In addition, for the comparability of monitoring and prediction in the integrative calculation methods

presented, the days must be standardized, as otherwise different time periods would be compared with each other. If only the methods with maximum values are used, there is no need for time standardization.

4. THE UASLI PARAMETER CALCULATION FOR MONITORING AND PREDICTION

UASLI is made up of different factors, which in turn are calculated using different input parameters. The parameters are categorized into different groups such as Traffic and Movement Indicators, Time Dependent Indicators, Sector and Area Indicators, and Qualification and Experience Indicators for classification.

Two different approaches can be used to calculate indices on the basis of work experience. On the one hand, it is possible to offset all experience values against each other by weighting and integrating them in terms of time and space. On the other hand, it is also possible to evaluate only the maximum value of each experience parameter and combine them into an overall index. The advantage of the maximum value approach is that it is quicker to determine and the results are easier to understand. The drawback, however, is that many experience values and their time dependency cannot be considered. The maximum value method therefore only allows a statement to be made that a controller has had a certain experience at least once, while the integration method also provides indirect information on how often the experience was gained.

For this reason, both methods have been developed and implemented in some calculation procedures. In this way, both indices can be determined and the ANSPs later have the opportunity to weigh up their advantages and disadvantages and decide which method for issuing temporal unit endorsements is better suited to their policy.

4.1. Traffic Handling and Complexity Indicators

The group of Traffic Handling and Complexity parameters includes six indicators, four of which are introduced here. These are the experienced Sector Occupation and its diversity, the Ratio of Vertical to Horizontal Movements, the Intersection Complexity, and the Communication Events.

4.1.1. Sector Occupation

One suggested parameter is the maximum load factor (occupancy O) of the sector(s) in which controllers have worked so far. For this purpose, the maximum value $O_{max,s}$ of each shift s from the last 90 days is used, divided by 100 and then multiplied by the daily weighting factor w_d . This results in individual values between zero and approximately 1.2, as the maximum permissible short-term utilization of a sector in the upper airspace is around 115% or 120%. The occupancy of a sector can be considered either via the average values of the period under consideration or via the maximum occupancy of each sector that a controller has processed in the period.

4.1.1.1. Occupancy – The Average Values Method

In addition, the maximum utilization of a sector in a shift is extended by the time component of the 10%-down-time t_{10} . Here, t_{10} describes the duration of working time in minutes during which the sector utilization is at most 10 percentage points below the highest sector utilization in a working shift period (Fig. 5).

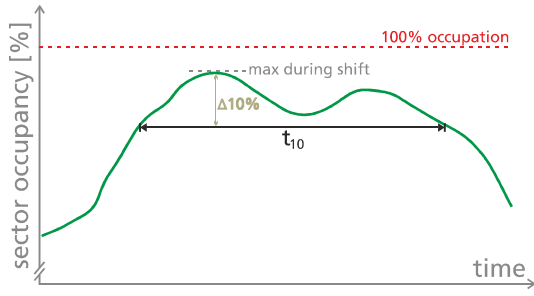


Fig. 5: Definition of t_{10} 10%-down-time. The period should refer to a working shift that a controller has completed. The green line describes the relative occupation of a sector over time.

In this way, it is possible to differentiate between working shifts in which the occupation of the sector only increased once for a short time, and shifts in which a controller had to work continuously at the maximum limit of the sector capacity. This makes it possible to filter out short experienced peaks and instead show what an ATCO has experienced over a longer period of time as a maximum in relation to the declared capacity.

The load in the latter case is of course significantly greater than in the former and should be reflected accordingly in the index:

$$O_c = \sum_{d=1}^{90} w_d \cdot \frac{O_{max,s} \cdot t_{10,s}}{100}$$

This index O_c should be determined individually for all N sectors a controller handled during the last 90 days, then added up and mathematical standardized:

$$O_c = \frac{1}{N} \sum_{i=1}^N \sum_{d=1}^{90} w_d \cdot \frac{O_{max,i,s} \cdot t_{10,i,s}}{100}$$

The determination of O_{max} can be simplified to the effect that it is not necessary to measure occupancy continuously or every second within a day or shift. Instead, it is sufficient to divide the period under consideration into coarser units of five or ten minutes. To measure O_{max} , the day is divided into ten-minute intervals and the highest value for occupancy is determined for each of these intervals. This means that it is theoretically possible for a higher occupancy to be present for a short time within these ten-minute intervals, which is not recorded. However, this clustering significantly speeds up the detection of the maximum values.

4.1.1.2. Occupancy – The Maximum Values Method

Instead of considering all occupancy rates of each individual work shift during the last 90 days for O_c , which reduces the influence of days with both particularly high and low loads, the maximum value of sector occupancy in the same period can also be used as a measure. The time in days that has elapsed since this maximum value occurred is also considered and weighted accordingly with the time dependent weight factor w_d :

$$O_c = \max \left| w_d \cdot \frac{O_{max,s} \cdot t_{10,s}}{100} \right|_{d=1}^{90}$$

If the double sum is to be avoided in the calculation rule, the maximum value of the last 90 days d over all N handled sectors can also be used for the valuation index O_c instead:

$$O_c = \max \left| \max \left| w_d \cdot \frac{O_{max,i,d} \cdot t_{10,i,s}}{100} \right|_{d=1}^{90} \right|_{i=1}^N$$

This reduces the magnitude of the value compared to the other valuation measures, but this can also be leveled out using the scaling factor introduced above.

When applying the Sector Occupation parameter for the prediction, the flight plan data must be used with the information on the number of aircraft expected in the sector during the period under consideration. The t_{10} can also be derived from the planned arrival and departure times of the aircraft.

4.1.2. Ratio of Vertical to Horizontal Movements

The entry and exit situation of aircraft have a significant influence on the way controllers work in a sector. Sectors in which only lateral entries and exits occur are easier to organize than sectors in which upward and downward passages occur. The changes in altitude of aircraft require a significantly higher level of concentration to ensure the absence of conflicts as compared to almost exclusively horizontal flight movements. Similarly, aircraft entering or leaving a sector from above or below (vertically) also requires higher concentration on the part of the controllers, as the exact point at which an aircraft enters or leaves can only be roughly estimated on a two-dimensional monitor image, even with a lot of practice. It can therefore be assumed that the skill level for deconflicting aircraft in sectors with a significant proportion of vertical passages is higher than in airspaces with mainly horizontal flights.

The parameter V_c calculation therefore considers how many aircraft in the processed sectors left A_{vd} or entered A_{va} it vertically upwards or downwards in relation to the total number A_s of aircraft in the sector i in the same shift s . As with the other skill level calculations, the number of days d since the last time a certain activity was performed play a role in the weighting w_d of the influence on the result.

$$V_c = \sum_{n=1}^N \sum_{d=1}^{90} w_d \cdot \frac{A_{va,d,n} + A_{vd,d,n}}{2 \cdot A_{s,n}}$$

A special feature of this equation to calculate V_c is that the term from the sum of the aircraft above the fractional line, which leave or enter the sector vertically, can be greater than the total number A_s of all aircraft during the shift. This is due to the fact that an aircraft can enter and leave a sector vertically and is therefore counted twice.

The extended flight plan data of the airlines can be used here for the request forecast (prediction), as it also indicates in which sector which flight altitude is planned. Using appropriate database queries, it is possible to extract vertical and horizontal entries and exits from the flight plans.

4.1.3. Intersection Complexity

The number of intersecting flight routes in a sector is a measure of the complexity of the airspace, since resolving conflicts is one of the main tasks of ATCOs in the upper airspace. Systematic analyses have shown that between 5% and 6.5% of aircraft in the Upper European Airspace have to be deconflicted [21]. For an accurate calculation of potential conflicts between two aircraft, their trajectories must be compared with each other in high temporal and spatial resolution. However, since the trajectories are often

not available in sufficient resolution and, in cases where they are, the calculation becomes extremely time-consuming, it makes sense to use simpler and faster approximation methods. The potential conflict risk is sufficient as an approximation for estimating the parameter Intersection Complexity I_c .

The first approach assumes that two aircraft transiting simultaneously through the same sector are potential conflict partners that require increased attention from ATCOs. For this reason, all aircraft pairs whose duration in the sector overlap, are counted when calculating the index, regardless of their position or altitude in the sector and the location of their planned routes. This means that all known positions of all aircraft are compared with each other. In order to consider the increased congestion in airspace when there are a large number of aircraft and thus emphasize the difficulty of finding space for a safe evasive maneuver (deconflicting) in the event of impending conflicts, the number of aircraft A_g is raised to the power of 1.2 for the index calculation. As a result, I_c grows disproportionately as traffic increases.

$$I_c = \frac{1}{N} \sum_{i=1}^N \sum_{d=1}^{90} w_d \cdot (A_{g,d,i})^{1.2}$$

“Simultaneity” takes into account all aircraft that are in the sector at the same time for longer than one second. Even though the probability of a conflict actually occurring in this short period of time is very low, this also considers aircraft that are moving just outside of the sector and thus also represent potential conflict partners for the aircraft within the sector.

For the reasons mentioned above, it also makes perfect sense for this indicator to consider only the maximum value of the aircraft pairs that were in a sector at any time and were processed by the controller instead of the integrated individual events. Since only a single point in time with the maximum number of aircraft counts for the calculation of I_c in this case, the exponentiation of the aircraft measured simultaneously in a sector can be dispensed with without any loss in the significance of the index.

$$I_c = \max \left| \max w_d \cdot A_{g,d,i} \right|_{d=1}^{90} \Big|_{i=1}^N$$

The maximum number of aircraft pairs simultaneously in the airspace over all N sectors processed by a controller in the last 90 days is searched for, weighted by the time w_d that has elapsed since then and used as the index.

For the prediction, the extended flight plan data of the airlines can also be used here, as these contain the planned entry and exit times of all sectors the aircraft will transit during a flight.

4.1.4. Communication Events

Communication events here include both direct radio contacts and Controller-Pilot Data Link Communications (CPDLC) messages. The parameter Communication Events is a comprehensive measure of an ATCO's communication workload and proficiency. It combines both radio contacts and CPDLC messages into a single value, representing the total number of communication events between ATCO and flight crews. However, it is also possible to consider these two elements separately, for example to include them in different indices or with different weightings. These events reflect the instructions or information transmitted by

the ATCO, whether through voice communication or digital messaging, including instructions on heading, speed, altitude, or other flight parameters. This combined parameter provides a more accurate and holistic view of an ATCO's skill level by considering both traditional voice communications and modern, data-based communication systems. The parameter is particularly relevant in assessing an ATCO's workload in complex and high-traffic environments, where both types of communication are frequently used.

Based on the assumption that more communication events r_s and b_s indicate a higher experience with rapid and/or more complex communication, a summation formula R_c for controller C can also be used here, which contains the day-dependent weakening parameter w_d :

$$R_c = \sum_{d=1}^{90} w_d \cdot (r_s + b_s)$$

An alternative approach is to focus on the day with the highest number of communication events. In this case, the ATCO's skill level is assessed based on their peak communication load over the last 90 days, considering the time-dependent weighting w_d :

$$R_c = \max |w_d \cdot (r_s + b_s)|_{d=1}^{90}$$

This approach highlights the ATCO's workload during their most demanding day, providing insight into their ability to handle maximum communication loads under high-pressure conditions. However, it is important to note that more communication events do not necessarily imply higher performance, as experienced ATCOs may handle complex situations with fewer but more efficient communications by combining different clearances in one communication event. In the opposite case, however, it can also happen that a controller has to repeat almost every command due to a language barrier or a poor radio connection. In order to be able to take these cases into account, the individual instructions for another parameter called Traffic Diversity (D_c) are included separately in the evaluation, but not described in this paper.

For the demand assessment (prediction), statistical mean values must be used for this parameter by evaluating how often communication events occur on average per aircraft in the sector under consideration and multiplying these with the current traffic.

4.2. Time-Dependent Indicators

The group of the time dependent parameters contains five different parameters. In this paper, because of the paper volume, only the skill-parameter radio contact times is introduced here.

4.2.1. Radio Contact Times

Another important parameter for describing the controller's experience of working with pilots is the total duration Q_c of all radio calls made by controllers to flight crews in a given period. In addition to the greeting and farewell phrases, this includes in particular all standard guidance instructions as well as special features in the case of warnings, diversions, or traffic context-related queries from both sides. The two obligatory radio contacts with greeting and farewell can be regarded as constants, which therefore have an equal influence on the contact rating calculations. However, in the event that one or more clearances are also given at the

greeting, these are counted correctly when these two contacts are considered. These are included as a total weighted over the days for all sectors handled in the last 90 days.

Index Q_C , which is relatively easy to calculate, adds up all the time durations $q_{j,d,n}$ in seconds of all r_d radio contacts that a controller has had in all N sectors worked in the last 90 days, all weighted over the time w_d in days since the last practice:

$$Q_C = \sum_{n=1}^N \sum_{d=1}^{90} \sum_{j=1}^{r_d} w_d \cdot q_{j,d,n}$$

As with the communication events, the statistical mean value of the average radio contact times can be used to perform a prediction depending on the scheduled traffic volume.

4.3. Sector and Area Indicators

The sector and area parameters encompass three indicators, of which only the Weather Handling parameter is presented here. However, the influence of weather on the experience can be calculated using three different methods, depending on the availability of ANSP and meteorological data.

4.3.1. Weather Handling

Three methods based on different input parameters are proposed for taking experience in severe weather situations into account. The first idea counts controller's shifts influenced by severe weather events. The second method considers the sector volume that was not available due to the weather. In the third method, the index is based on the number of aircraft that had to be diverted from their flight plan route due to weather conditions in the upper airspace. The choice of which method is the most suitable for an Air Traffic Service Unit (ATSU) depends not only on the availability of data but also on the variability of the severe weather events that typically occur in the airspace.

4.3.1.1. Counting Severe Weather Influenced Shifts Method

Due to the nature and scope of the measurement method and data collection, it is possible that the affected volume or area of a severe weather is not or only rudimentarily recorded. If possible, the planned traffic in one sector is reduced in line with the forecasted severe weather restrictions, so that there is no congestion of the airspace, which could only be compensated by short-term measures at the expense of neighboring sectors (The only exceptions are "ad hoc" measures. However, these are only approved if civil air traffic permits). In best case, this reduces the additional work and organizational burdens for controllers.

Due to this, it may make sense to only count the work shifts s_w in which a controller was restricted in the guidance by severe weather areas. This calculation also uses the root function to attenuate the influence of individual events, as a high number of severe weather areas processed should not be equated with a linear increase in work experience.

$$W_C = \sqrt{s_w}$$

4.3.1.2. Reduced Sector Volume Method

This calculation of the Weather Handling Parameter W_C offers an approach by emphasizing the impact of reduced sector volume caused by adverse weather conditions. It assesses the experience of an ATCO in managing air traffic when available airspace is limited due to weather. This parameter captures the heightened challenge ATCOs face in such scenarios, where constrained airspace demands greater situational awareness and precision in control. They are considered regardless of where or for how long the restrictions applied in the sector. The day-dependent index W_{C_d} is calculated as:

$$W_{C_d} = w_d \cdot t_{w,d} \cdot w_{av,d}$$

This calculation provides a measure of the difficulty an ATCO faced during a specific shift, adjusted for the time w_d elapsed since the weather events were experienced the last time. Similar to the alternative calculation of the military restricted area parameter M_c , the maximum value of W_{C_d} over the last 90 days is used as a measure of the highest skill level demonstrated by the controller under challenging weather conditions:

$$W_C = \max |W_{C_d}|_{d=1}^{90}$$

4.3.1.3. Number of Diverted Aircraft Method

Weather encompasses a whole range of parameters that can have an influence on the traffic organization in upper airspace sectors. These include the type of weather phenomenon, its severity, the duration, the volume of the affected area and the altitude. The sum of these parameters results in a large number of weather variations with an influence on aviation that are difficult to summarize in a single evaluation index.

However, the frequency with which controllers have to take aircraft off their planned route in order to divert them within the same or a neighboring sector without conflict is decisive for the ability to deal with severe weather in the sector. For this reason, the weather index W_C considers the number of aircraft d_w that a controller has had to take off their flight plan route in the past 90 days due to severe weather in all N sectors a controller has worked.

$$W_C = \sum_{n=1}^N \sum_{d=1}^{90} w_d \cdot d_w$$

For the prediction, weather forecasts must be evaluated according to the selected evaluation method. MET services usually offer a comprehensive portfolio of specific weather parameters for this purpose [22].

4.4. Qualification and Experience Indicators

Additional parameters consider the qualification and experiences of the controllers. These include the earned unit endorsements and the actual overall professional experience. Unlike the parameters presented so far, the ratings of these indicators cannot be used directly in the prediction calculation. However, they can be used to determine an experience value, which can then be applied to grant approval for a Temporal Unit Endorsement with the help of limit values.

4.4.1. Number of Actual Unit Endorsements

The more endorsements for different sectors controllers already have, the more experience they are considered to have with different traffic situations. As sectors can be separated and combined, which results in slightly different operational procedures, the calculation is different when determining the number of unit endorsements. For the calculation of UASLI, every part of the sector or sector group that remains after a split to the maximum possible extent counts as a separate endorsement if the controller holds an endorsement for the entire sector or sector group (Chapter 1.2).

However, it can be assumed that controllers with two endorsements do not have twice as much experience as controllers with one. For this reason, the influence of the pure number of endorsements is attenuated by a root function:

$$E_C = \sqrt{e_s}$$

4.4.2. Professional Experience

In addition to work experience in specific sectors, professional experience as an ATCO is of course one of the most important criteria when assessing professional experience in order to be able to work in an UASLI-Sector. It can be assumed that the experience curve rises particularly sharply in the first few months in a job before flattening out significantly over time. Mathematically, this can be represented quite simple by taking the square root of the number of months of professional experience rather than the skill level itself. This approach reflects the steep increase in experiences at the beginning of professional life, which flattens out over time, but the accretion never falls to zero over any length of time:

$$P_C = \sqrt{m_C}$$

The use of the root in the parameter calculation P_C always guarantees an increase with more unit endorsements, but the increase is reduced with a large number of licenses.

4.5. The Competency Requirement Flexibility

The use of the UASLI makes it possible to generate an estimate of how much and what kind of air traffic an ATCO will be able to handle in a given period of time in a likely be unknown sector. As the traffic forecast is always subject to a time dependent estimation error, the allowed traffic load of a given sector should on the first thought always be slightly below the maximum traffic that can be handled by the controller as predicted by the skill value. This would mean that the proposed procedure values of a controller slowly decrease, as controllers always would process sectors during periods with less traffic than they experienced in the past, which would then in turn be the basis for future calculations.

Two methods are proposed to counteract this negative trend. Firstly, it is recommended that controllers work for at least half of the 90-day period under consideration in sectors and sector groups for which they have a classic unit endorsement, enabling them to be deployed without restrictions. Secondly, it should be possible for controllers to obtain a kind of buffer via defined threshold values in selected parameters, which allows them to work even if the predicted traffic volume is slightly above UASLI values monitored by the proposed procedure. This can be achieved by using a subset of measured parameters of the prediction as a prognose buffer. The parameters are

configured in such a way that they can only increase the current competence level.

Based on workshops with controllers and subject matter experts, the maximum amount of the Competency Requirement Flexibility (CRF) buffer that each controller can receive was defined as 10%. These are made up of 2% of each of five selected parameters. Each parameter includes two threshold values, each of which results in a buffer increase of 1% to the prognosed traffic volume. The parameters are:

1. Professional Experience ε_P
2. Working Time ε_C
3. Experiences in Neighboring Sectors ε_N
4. Simulator Practice Time ε_S
5. Number of Actual Unit Endorsements ε_E

Additionally, the requirements flexibility can be applied to both the overall index or the result of each individual operational parameter. As example for the first option, if an ATCO achieves an overall UASLI of 10, he or she can be deployed in a sector where an index of up to 11 is predicted. The limit values for the five selected ε must be defined individually by the respective ANSPs using the UASLI, as different boundary conditions apply in each airspace.

5. DISCUSSION AND OUTLOOK

The concept of assessing experience and predicting the minimum level of track records required offers a new approach to address the growing shortage of ATCOs. Based on their recent operational experience, the Upper Airspace Skill-Level Index (UASLI) provides a scalable value which allows conclusions if and how far an ATCO should, due to past experiences, already be able to work in sectors or sector groups without a traditional on-the-job training. On this basis, it may be possible to issue a Temporary Unit Endorsement to an air traffic controller. In this paper, eight of the seventeen assessment parameters – Sector Occupation, Vertical to Horizontal Movements, Intersection Complexity, Communication Events, Radio Contact Times, Weather Handling, Actual Unit Endorsements, and Professional Experience – were presented and their proposed calculation rules described. For each of these parameters, the methodology for monitoring historical experience and predicting future requirements was shown.

For example, the Sector Occupation parameter describes the maximum sector occupation within a working shift, considering the intensity and duration of traffic peaks. A detailed analysis has already shown that some parameters react particularly sensitively to changes in both maximum occupancy and traffic duration [18]. This shows that short-term but extreme traffic loads can have a significant influence on the competence value of ATCOs. Since sector occupancy is one of the most important criteria for both monitoring and prediction, this behavior corresponds exactly to the requirements for this experience level.

Another example are short-term meteorological airspace restrictions, which expand the experience of an ATCO to work effectively even under spatial restrictions. This experience value also reflects the desired behavior, as comprehensive airspace closures always mean a higher workload and monitoring effort.

For some parameters, both the integrated and the maximum value method were presented for determining the indices. It was found that integration should be preferred for

regular assessment planning, as it better reflects the typical level of experience [18]. For special deployment scenarios, however, the use of the maximum value method as an additional criterion can be very helpful.

Aggregating the parameters into an overall index as UASLI facilitates a quick and efficient decision to issue a Temporary Unit Endorsement. At the same time, this poses a challenge in terms of transparency and dependence on subjective parameter weightings. Depending on the application, a combination of an overall index and individual parameter analysis of the evaluation vector seems to be the most sensible strategy.

A key advantage of the proposed methodology is its flexibility and timeliness. By considering the time-dependent decline of skills based on experience and the possibility of daily updates, the UASLI dynamically adapts to changing traffic patterns and individual ATCO activities. Nevertheless, there are certain limitations. The UASLI only reflects quantifiable experience and does not directly assess a controller's work performance, skills or competence. In addition, its validity can be affected by incomplete or biased data sets. The UASLI should therefore only be seen as a supplement to traditional approval procedures and professional assessment by supervisors.

Several development steps are planned for the use of the assessment procedure in the near future. The global definition of the input parameter ranges must be specified and standardized for an air navigation service provider. These definitions must be made on the basis of validations and the evaluation of historical data. In addition, a structured evaluation of the suitability of the individual skill parameters is carried out in order to confirm their actual relevance and significance in the operational context or to adjust them if necessary.

A complete and automated assignment of Temporal Unit Endorsements on the basis of the UASLI would also require technical expansion at the ANSPs: Instead of the previous individual comparison of the dimensions of the assessment vector, complete controller pools and sector pools must be considered simultaneously in operational use. The simultaneous allocation is intended to facilitate optimal and flexible operational planning. The UASLI is currently intended primarily as a decision-making aid and basis for manual planning support, but could also be integrated into an automated optimization process for retraining in the future.

ACKNOWLEDGMENT

The IFAV3 project has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114683 under European Union's Horizon Europe research and innovation programme.

LITERATUR

- [1] Conzelmann, K., A. Heintz, and H. Eißfeldt (2011). A Large Scale Validation Study on Air Traffic Controller Selection and Training-Design, Challenges and Results. Proceedings 16th International Symposium on Aviation Psychology, pp. 375-380. 16th International Symposium on Aviation Psychology, Dayton, OH, USA.
- [2] EUROCONTROL. (2022). Think Paper #19 – Enhancing controller mobility to increase ATM capacity. <https://www.eurocontrol.int/publication/eurocontrol-think-paper-19-atc-mobility-and-capacity-shortfalls> [Accessed: 05.08.2025].
- [3] IFATCA (2024). Staff Shortage Survey – EUR Region. International Federation of Air Traffic Controllers' Associations (IFATCA), Montreal, Quebec, Canada. <https://ifatca.org/staff-shortage-survey-eur-region/> [Accessed: 05.08.2025].
- [4] Wallace, G. (2024). FAA still short about 3,000 air traffic controllers, new federal numbers show. CNN. May 24, 2024. Atlanta, Georgia, USA.
- [5] Terenzi, M., O. Ricciardi and F. D. Nocera (2022). Rostering in Air Traffic Control: A Narrative Review. International Journal of Environmental Research and Public Health 19(8): 4625. DOI:10.3390/ijerph19084625.
- [6] Pavlović, G., R. Jovanović and M. Stanojević (2023). Rostering of air traffic controllers – current practices in Europe, key performance trade-offs and future opportunities. Journal of Air Transport Management 113(102472). DOI:10.1016/j.jairtraman.2023.102472
- [7] Mellett, U. and T. Licu (2023). Air Traffic Services Operations staff/personnel Rostering Best Practices and Tools Guidelines. NMD/SAF/2653. EUROCONTROL. Brussels, Belgium.
- [8] Socha, V., L. Hanáková, V. Valenta, L. Socha, R. Ábela, S. Kušmírek, T. Pilmannová and J. Tecl (2020). Workload assessment of air traffic controllers. Transportation Research Procedia 51: pp. 243-251. DOI:10.1016/j.trpro.2020.11.027
- [9] EUROCONTROL (2006). Complexity Metrics for ANSP Benchmarking Analysis. Performance Review Unit, EUROCONTROL. Brussels, Belgium.
- [10] Zhuoxi, S., C. Yangzhou, L. Zhenlong, Z. Defu and B. Hong (2013). A review for workload measurement of air traffic controller based on air traffic complexity. 25th Chinese Control and Decision Conference (CCDC). Guiyang, China, IEEE: pp. 2107-2112. DOI:10.1109/CCDC.2013.6561284
- [11] DLR (2025). IFAV3 Sol.1 V3 SPR-INTEROP/OSD – Part I. D2.8. Increased Flexibility of ATCO Validations - V3 (IFAV3). Braunschweig, Germany.
- [12] Majumdar, A. and W. Y. Ochieng (2002). The factors affecting air traffic controller workload: a multivariate analysis based upon simulation modelling of controller workload. Transportation Research Record 1788(1): pp. 58-69. DOI:10.3141/1788-08
- [13] Flynn, G., A. Benkouar and R. Christien (2003). Pessimistic Sector Capacity Estimation – Project COCA. EEC Note No 21/03. EUROCONTROL Experimental Centre. Brétigny-sur-Orge, France.
- [14] Nagaoka, S., H. Hirabayashi and M. Brown (2021). Towards Automatic Trajectory Modification for Reducing Air Traffic Complexity Using an ATC Difficulty Index. Air Traffic Management and Systems IV, Lecture Notes in Electrical Engineering 731. Springer Nature Singapore: p. 285–298. DOI:10.1007/978-981-33-4669-7_16
- [15] Isaac, A. R. and B. Ruitenberg (1999). Air Traffic Control: Human Performance Factors. Routledge. London, Great Britain. DOI:10.4324/9781315263076.
- [16] [Mihetec 2011] Mihetec, T., Z. Jakšić and S. Steiner (2011). Air Space Management Procedures in Europe. 14th International Conference on Transport Science (ICTS 2011). Washington, D.C., USA.
- [17] Çinar, E. and A. Tuncal (2024). A comprehensive analysis of competency and training perspectives among air traffic controllers. Aviation 28(2): p. 54-63. DOI:10.3846/aviation.2024.21501

- [18] Meier, J., M.-M. Temme, R. Hunger and M. Finke (2025). Unlocking potential: Enhancing air traffic controller deployment through dynamic competency-based rostering. 44th Digital Avionics Systems Conference (DASC 2025). Montreal, Canada.
- [19] Jaber, M. Y. and M. Bonney (1996). Production breaks and the learning curve: The forgetting phenomenon. *Applied Mathematical Modelling* 20(2): p. 162-169.
- [20] Murre, J. M., M. Meeter and A. G. Chessa (2007). Modeling amnesia: connectionist and mathematical approaches. *Statistical and Process Models for Cognitive Neuroscience and Aging*. Ed. M. J. Wenger and C. Schuster. Mahwah, New Jersey, USA: p. 119-162.
- [21] Renkhoff, J. (2025). Identifying Potential Conflicts and Corresponding Resolutions in the Upper Airspace from Historical Air Traffic Data. *Deutscher Luft- und Raumfahrtkongress (DLRK 2025)*. Augsburg, Germany.
- [22] Song, W. and X. Ye (2025). A Comprehensive Review of Advances in Civil Aviation Meteorological Services. *Atmosphere* 16 (1014): 17.
DOI:10.3390/atmos16091014