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Proposal of a Matrix to Measure the Perceived Level of Safety in a Terminal Control Area

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ABSTRACT

The airspace is constantly adapting to efficiently absorb the growing traffic demand in the coming years and may therefore present bottlenecks for safety maintenance, especially in the Terminal Control Area (TMA), where the concentration of aircraft causes them to fly closer to each other. This paper presents a matrix of safety parameters to assess the perception of the safety level after modifications to the airspace, using the TMA from the state of São Paulo/Brazil, as an example for validation, following the implementation of the new airspace circulation in 2021. Through theoretical review, it was possible to delimit the study area and link related research to the presented matrix. The results indicated points of divergence among the surveyed stakeholders, such as speed adjustments which resulted in significant improvements for controllers, while for pilots, improvements were seen in traffic flow and waiting times. Overall, there was a positive perception regarding the decrease in workload in complex airspace, which translates into increased operational safety. Finally, areas for improvement were identified for future terminal designs, particularly regarding the need to reduce potential conflicts.

Keywords: Indicator Matrix; Terminal control area; Safety.

INTRODUCTION

According to the International Civil Aviation Organization (ICAO 2013), organizations linked to the aviation industry must be able to measure and ensure ongoing safety performance monitoring. Thus, continuous monitoring of parameters related to efficiency and safety is a key element for the success and continuity of business in the aviation industry. Following the premises of a Safety Management System (SMS), its objective is to prevent accidents from happening, and for this purpose, different tools and methodologies can be used.

Continuous monitoring is crucial so that, upon observing any factor that deserves attention, mitigating measures can be implemented in time to prevent an accident from occurring. In this perspective, in May 2021, the busiest portion of airspace in Brazil – the São Paulo Terminal Control Area, in this work referred to as (TMA-SP), underwent restructuring aimed at several objectives, such as: a) ensuring a 10% capacity increase above the predicted demand in the next decade; b) reducing the workload of controllers and pilots; c) decreasing waits and delays related to airspace capacity; d) reducing potential conflict crossings between aircraft, among others (Brasil 2021).

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The literature presents some possibilities for measuring the efficiency of airspace, such as the works of Murça *et al.* (2020) and Szenczuk *et al.* (2020). These actors carried out their work, focusing on efficiency related to the flight trajectory and the need for deviations/replanning of these trajectories. However, there is still a great difficulty in evaluating the safety of airspace. The use of performance indicators has proven to be an important tool for controlling and managing performance and efficiency in aviation industry systems. In this sense, ICAO has defined key performance indicators (KPIs) divided into 11 performance areas, known as key performance areas, with one of them being Safety (Brasil 2020).

Despite the existence of this quantitative metric for assessing a system, it is noted that Safety, for the most part, focuses on human elements, as it is based on reports and presents itself as the major contributing factor in accidents and incidents. Thus, measuring this sensitivity regarding Safety by the human element can be a challenging task. This (human factor) is the focus of this work. For Rodrigues *et al.* (2022), the human factor is challenging, despite all technological support. Decisions, and consequent actions, depend on the perception and expertise of human factors

The restructuring of the TMA-SP, resulting from the TMA-SP Neo Project and which occurred in the 1st semester of 2021, practically had no studies published regarding safety, not due to its robustness, but due to the fact that after a change, it is necessary to wait for a period until the environment is consolidated. In addition, the aviation sector was heavily affected by the COVID-19 pandemic, so the feasibility of using data related to safety up to that point was affected and may not reflect reality. Thus, the topic is relevant as it offers significant parameters regarding efficiency and safety of the busiest airspace in Latin America (Brasil 2021). This airspace is responsible for hosting three of the most important airports in the country and other connections.

Therefore, this study, using the Delphi method as a data collection technique, aims to provide a matrix approach to the perception of users and air traffic experts to evaluate whether the restructuring of the TMA met the requirements relating to operational safety.

To achieve this objective, through a matrix of efficiency and safety parameters, we sought to verify whether the operational performance indicators intended in the conception of a new air circulation presented a favorable scenario and advancement in relation to the old structure, and how these indicators were perceived by professionals and experts after its implementation.

To address the proposed objective, this work is divided into the following sections: the next one presents the theoretical framework on the themes that support the work and a literature review with research related to the topic; the following section presents the materials and methods used in conducting the work; then, the results and respective analyses are presented, and finally the conclusions, recommendations, and suggestions for future work.

Theoretical review

To aid in the understanding of the topics addressed, it is opportune to provide a brief historical context of aviation navigation milestones to the present day, which over time have also contributed to modifications in the TMA-SP. Subsequently, factors impacting airspace efficiency are presented, an overview of TMA-SP, and finally, research related to the work.

Brief history of navigation

Technological evolution introduced equipment into air traffic control systems and aboard aircraft that allowed for new controls and better system safety. There are two navigation systems: a) conventional navigation; and b) performance-based navigation. Conventional navigation has been losing ground to performance-based navigation, not only in Brazil but worldwide, as its techniques have become obsolete and inefficient. The latter is capable of delivering the level of precision, accuracy, and availability necessary to allow for increased capacity of a TMA (Rodrigues *et al.* 2022).

In its mission to support and enable the global air transport network, ICAO implemented five strategic objectives, which are the pillars of performance assessment: safety; air navigation efficiency and capacity; aviation safety (security and facilitation); economic development of air transport; and environmental protection. To achieve these objectives within the new aviation systems, it was realized that some elements within the industry were obsolete. Thus, a task force was created to enhance navigation, communication, and surveillance systems.

According to ICAO (2023), with the continuous increase in aviation as a means of transportation, the need arose for specific procedures to meet operational and performance requirements for its execution. Thus, the American satellite navigation program, the Global Positioning System (GPS), was adopted, with similar programs to Russia's constellations (Global Navigation Satellite

System – GLONASS), China (Beidou), Japan (Quasi-Zenith Satellite *System* – QZSS), and Europe (Galileo), forming an integration that provides the system with greater reliability and precision (Nolan 2011).

Measuring the safety level of an air traffic control facility

Measuring the safety level of any organization linked to aviation materializes the perception or feeling about the safe condition of the environment and directly influences SMS management activities. Thus, a set of tools and methods organized to support decisions to be made by a Civil Aviation Service Provider (CASP) regarding the risk of their activities is necessary.

There are three methods for managing information regarding hazards: reactive, which responds to events that have occurred, such as accidents and incidents; preventive, which actively seeks potential hazards through organization analysis, such as safety inspections; and predictive method, which documents performance through programs and computer systems.

Implementing changes in Air Navigation Services (ANS) activities may pose a risk to operational safety, as they interface with existing procedures, systems, and operational environments. A significant change can only be implemented after a safety assessment has demonstrated to be at an Acceptable Level of Safety Performance (ALoSP) – expressing that the existing risks in the operation have been considered, managed, and accepted by the Departamento de Controle do Espaço Aéreo (DECEA), which is the organization responsible for controlling Brazilian airspace (Brasil 2012). Always reinforcing that the study was developed in the Brazilian context.

Safety analysis is supported by concrete information, safety research, observations, and interviews. Data are collected, classified, and ordered so that appropriate analytical methods are selected and applied, which may include statistical analysis, trend analysis, situational comparison, ATC simulation, and expert committee (Brasil 2012).

Among the tools for hazard identification and risk management, a risk assessment matrix is used, which combines the severity and probability of the event occurring in the air traffic control (ATC) system. Risks are classified as high risk, medium risk, and low risk.

Efficiency of an airspace

As important as the conceptualization and measurement of safety in an airspace is the assessment of the efficiency of this space. However, safety levels must always remain high, so an alignment between safety and airspace efficiency must be sought.

ICAO (2005), through DOC 9854 – Global Air Traffic Management Operational Concept, introduces the idea of continuous improvement in ATM systems through the measurement of some parameters using 19 KPIs monitored in different areas, such as additional fuel burn, on-time departure, airport arrival capacity, among others.

Brazil, in turn, has a routine for monitoring this efficiency through the ATM indicators methodology of Sistema de Controle do Espaço Aéreo Brasileiro (SISCEAB), which allows for comparing situations between locations or at different periods of time in the same location (Brasil 2022).

This comparison enables important management control to verify the effectiveness and efficiency of the service provided in a particular airspace. In addition to the 19 KPIs developed by ICAO (2013), Brazil has created six BR IDs (performance indicators created by Brazil) with the aim of monitoring also some parameters that are not of interest to ICAO but that are relevant for the national scenario.

Through the analysis of these indicators, it is possible to direct future management and, more importantly, analyze the impact of these changes made to understand the real benefits in achieving the desired objectives. Ultimately, the combination of efficiency and safety translates into the services provided by airspace management and control, culminating in the perception of users. This ideal combination is also the driving force behind the pursuit of continuous improvements, which have been implemented in various phases and modifications of the TMA-SP until reaching its current state. Since 2013, this portion of airspace has undergone significant modifications with the aim of improving the efficiency of the service provided to users.

TMA-SP Neo

By definition, a TMA is an airspace control area, surrounding one or more aerodromes, situated at the confluence of Air Traffic Service (ATS) routes, with the primary objective of providing different levels of service to aircraft in arrival, departure, and instrument, area navigation (RNAV), or conventional approach procedures, as well as routes departing and arriving under visual flight rules. The controlling body responsible for this area is the approach control (APP).

With the need to accommodate traffic from a specific sector, a new restructuring of the TMA-SP (comprising the airports of Campinas, Congonhas, and Guarulhos) came into effect in 2017 to allow for more direct routes and ATC capacity gains. This modification led to a new sectorization of airspace, creating a new entry point for the TMA-SP, especially for Guarulhos Airport, through the northwest sector, channeling and interleaving the demand with traffic from the north sector – which is the busiest sector in transferring traffic to São Paulo.

Observing the structure of the country's largest TMA, to efficiently absorb the growing air traffic demand, efforts were made to modernize and optimize the airspace, maintain high levels of operational safety, establish routes for greater economy, and address obstacles found in circulation such as continuous descents and smoothing out climb and descent gradients (Brasil 2021).

As the development of the new circulation was based on the "in-out" concept, the initial focus was on defining the best trajectories within the TMA and subsequently adjusting the network of routes around it to keep them as direct as possible, developing an independent circulation. It is worth noting that this led to a redesign of all TMA adjacencies, allowing for the smoothest possible departures and improving the distribution of arrivals traffic for São Paulo.

Since the TMA-SP is the country's main hub and houses some of the largest and busiest airports, the priority for building the circulation was given to airports with the highest traffic: Guarulhos, Congonhas, and Campinas. Based on this principle, new departure and arrival sequencing profiles were created for Guarulhos Airport (SBGR) – such as the Point Merge System, to allow for unimpeded climb in Continuous Climb Operation (CCO) and alternatives for low and high-performance aircraft (Brasil 2021). With this technique, it is expected that the controller will be able to sequence a large number of aircraft with few vectors, little frequency occupation, and thus expedite flights to fly directly to the merge point as soon as possible (Brasil 2021).

Arrival procedures for Congonhas Airport (SBSP) remained similar to the current circulation, with the difference in the entry point of the flow from the south sector. However, descent gradients were reduced, and initial procedure altitudes were lowered to provide better management of aircraft energy, thereby avoiding unstable approaches. Departure procedures allow for unimpeded climb in CCO and with alternatives for lower-performance aircraft (Brasil 2021).

Campinas Airport (SBKP) also had its descent gradients reduced and initial procedure altitudes lowered, while departure procedures had elevated level restrictions, allowing for more direct climbs. Finally, São José dos Campos Airport (SBSJ) underwent few changes, only a compatibility adjustment with the new TMA-SP circulation (Brasil 2021).

Two other improvements were implemented in the new TMA: the Final Approach Vectoring Area (FAVA) and omnidirectional departures (OMNI). FAVA is a predefined area near runway thresholds, based on radar equipment usage. In these areas, it is possible to conduct an aircraft descent to intercept the final approach of an IFR procedure, respecting minimum altitudes from radar surveillance charts. In this context, it is possible to reduce minimum vectoring altitudes when close to the final approach segment, reduce distances traveled in vectoring, decrease destabilized descents, and optimize the flow of final sectors (Brasil 2021).

Related research

According to the Federal Aviation Administration (FAA), one way to improve Air Traffic Management (ATM) is through collaborative decision-making initiatives, known as collaborative decision making (CDM), which bring together aviation authorities and industry in a single goal of exchanging information among the community and its stakeholders, as well as creating technology and solutions for the challenges and management measures of flow, also known as Air Traffic Flow Management (ATFM). Through data sharing, collective insight, and awareness of consequences, it is possible to achieve a common denominator that leads to a better decision-making process, improvement conditions, and global harmonization (FAA 2022).

Patriarca *et al.* (2022) support this idea, as they concluded that the ways Air Navigation Service Providers (ANSPs) perform and monitor safety performance are heavily influenced by international regulations, standards, treaties, and even local requirements.

Organizational policies and environmental considerations, using the Delphi method, were highlighted in the study by Efthymiou and Papatheodorou (2018), indicating that local studies are necessary to improve decision-making processes, ATFM architecture, and safety recommendations.

Chen and Li (2016) proposed a methodology for measuring safety performance and monitoring the safety management process of a civil aviation unit through a series of indicators – safety performance indicators (SPIs). These indicators would be arranged in a three-level model of Analytic Hierarchy Process (AHP), which allows incorporating the importance of different attributes in decision-making, combined with the Delphi method, calling it DAHP, allowing to extract extensive advantage from the combined knowledge of experts with quantitative calculation. The method was tested in civil aviation units in China and achieved success with real data.

This consideration of user perception within the air traffic environment is of great importance, as not always nominal trajectories will be executed by users, as it is a completely dynamic system, where lateral, vertical, and temporal deviations, as well as prolonged delays, can occur. Conclusions by Szenczuk *et al.* (2021) pointed out that even though those responsible for designing arrival and departure procedures seek expressed, ordered, and safe trajectories, real trajectories tend to deviate from standard routes, as the dynamics of air operations are complex.

The complexity of air traffic was defined by Homem (2020) as a subjective concept that expresses the level of difficulty of traffic control and the potential risk generated by increased workload for operators and control providers, being fundamental for sector capacity management.

Another important work was that of Oliveira *et al.* (2022), who developed a SWOT matrix through interviews with experts on Brazilian airspace, especially to analyze the migration of airport management to the private sector under the scope of the intelligence activity.

It is noted, therefore, that deterministic analyses performed through KPIs may point in a different direction from what is perceived by users and ATS service providers. Thus, it is expected that a perception assessment can assist the manager in decision-making on the best way to intervene, even positively, in a network of routes in a terminal area.

METHODOLOGY

This section outlines the procedures developed for data collection and analysis to support the achievement of the research objective.

Delphi method

The Delphi methodology seeks to facilitate decision-making when carried out by a group of experts without the need for personal interaction. It consists of a series of questionnaires that are sequentially answered individually by the participants. In the absence of consensus, a new round of iterations with summarized information on the group's responses to previous questionnaires seeks to establish a kind of dialogue among the participants and gradually build a collective response (Osborne *et al.* 2003).

According to Grisham (2009), the advantages of the Delphi method include: offering varied analysis and information on complex issues; highly objective thinking is formed; decisions based on expert opinions tend to be efficient; and finally, anonymous participation encourages creative input. Therefore, the Delphi method was used in this work to collect information from experts.

Data collection

In general, pilots have a more limited view of all food sectors and all traffic that is being sequenced and it is up to controllers to organize the arrival flow. Thus, data collection was carried out with these two segments of professionals, as they can understand whether there was an improvement after changing the airspace design.

According to ANAC (2023), the number of valid pilot licenses currently in Brazil is 50,423. However, it is known that not everyone ends up having contact with the portion of the airspace that is the subject of the study. Therefore, only pilots with a type rating were selected, a category that includes pilots who operate using instruments and in aircraft with more interesting characteristics for the research. Currently, the number of pilots with this valid qualification category is 7,917 (ANAC 2023).

Regarding controllers, according to Brasil (2021), considering the month of March 2022, there are 4,190 valid licenses, of which 3,549 are for air traffic controllers who are in operation and 641 who are away from their duties. In order for the research to better reflect the perception of air traffic controllers, it was decided to consider only those who actually had contact with the airspace that underwent modification. Therefore, to determine the size of the population, only controllers who have qualifications in the impacted agency were selected.

The anonymity of respondents was ensured through a liability agreement. The questionnaire was administered electronically, with participation being voluntary, after prior contact with each participant. The participants were chosen for convenience and ease of access, as the main author of the work works as a pilot in this airspace.

Data collection instrument

For data collection, a questionnaire was developed and sent via e-mail to respondents. The questionnaire consisted of objective questions, with responses in Likert scale format, where respondents could indicate their agreement on the proposed items in each question. At the beginning of the questionnaire, an informative text was presented, along with questions to identify the respondent's profile.

Eleven questions with specific content related to the research objective were part of the questionnaire. The questions were based on the eleven efficiency and safety parameters of the Global Air Navigation Plan (GANP) of ICAO and the interests of the Aviation System Block Upgrade (ASBU), which are as follows: traffic flow; sequencing understanding; workload; potential conflicts; reauthorizations; frequency occupation; speed adjustments; waits; vectoring; unrestricted departures; and finally other aspects related to efficiency and safety.

RESULTS

This section presents the results and corresponding analyses. Firstly, considerations are made regarding the population and sample, followed by the profile of the respondents, and then the results and analyses by respondent group. Finally, there are results and analyses for all respondents collectively.

Population, sample, and respondent profile

In calculating the sample size for finite populations, a confidence level of 95% and a margin of error of 5% were sought. However, due to the difficulty in engaging the participating public, the following margins were obtained for each audience, along with the following margin considering a single population. The data are shown in Table 1.

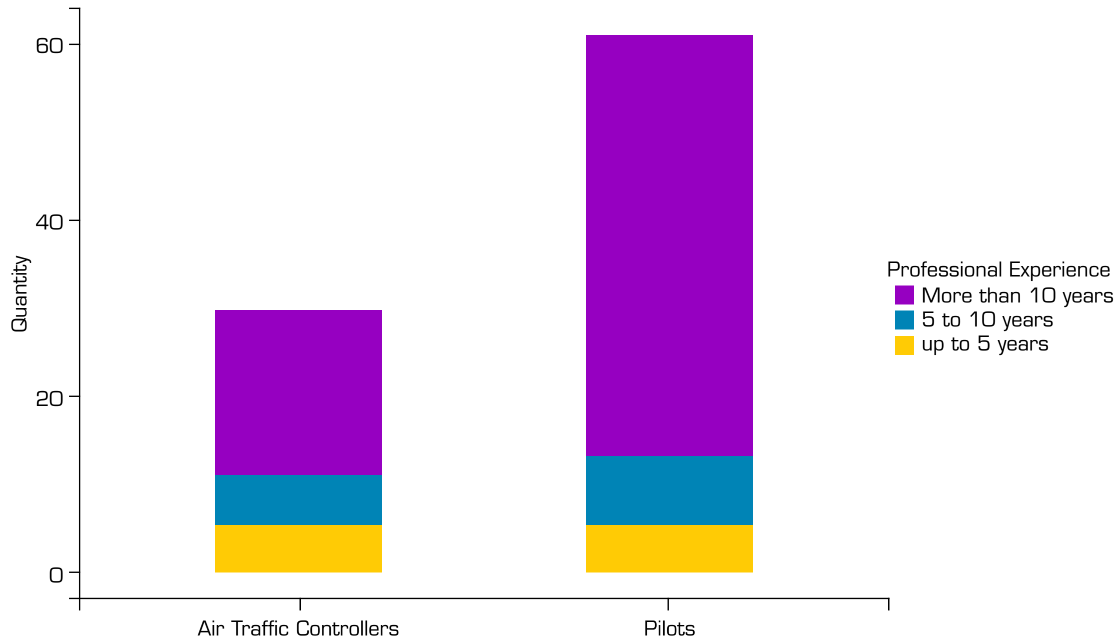
Table 1. Confidence level and margin of error.

Confidence level	Pilots 61 responses	Controllers 30 responses	Total 91 responses
Confidence level of 80% with margin of error	8.2	11.1	6.7
Confidence level of 85% with margin of error	9.2	12.5	7.5
Confidence level of 90% with margin of error	10.6	14.3	8.6
Confidence level of 95% with margin of error	12.5	17.0	10.2

Source: Elaborated by the authors.

According to the results of the social questionnaire, Fig. 1 presents the data of the population participating in the research.

In terms of function, 65.6% of the responses came from the pilot group and 32.3% were responses obtained from the TMA-SP controllers group. Regarding the professional experience of the participants, 74.2% of the responses came from professionals with more than 10 years of experience, while 15.1% were responses obtained from professionals with 5 to 10 years of experience, and 10.8% had professional experience of up to 5 years. As for having had contact with the TMA-SP before and after the modification, 100% of the interviewees answered yes.



Source: Elaborated by the authors.

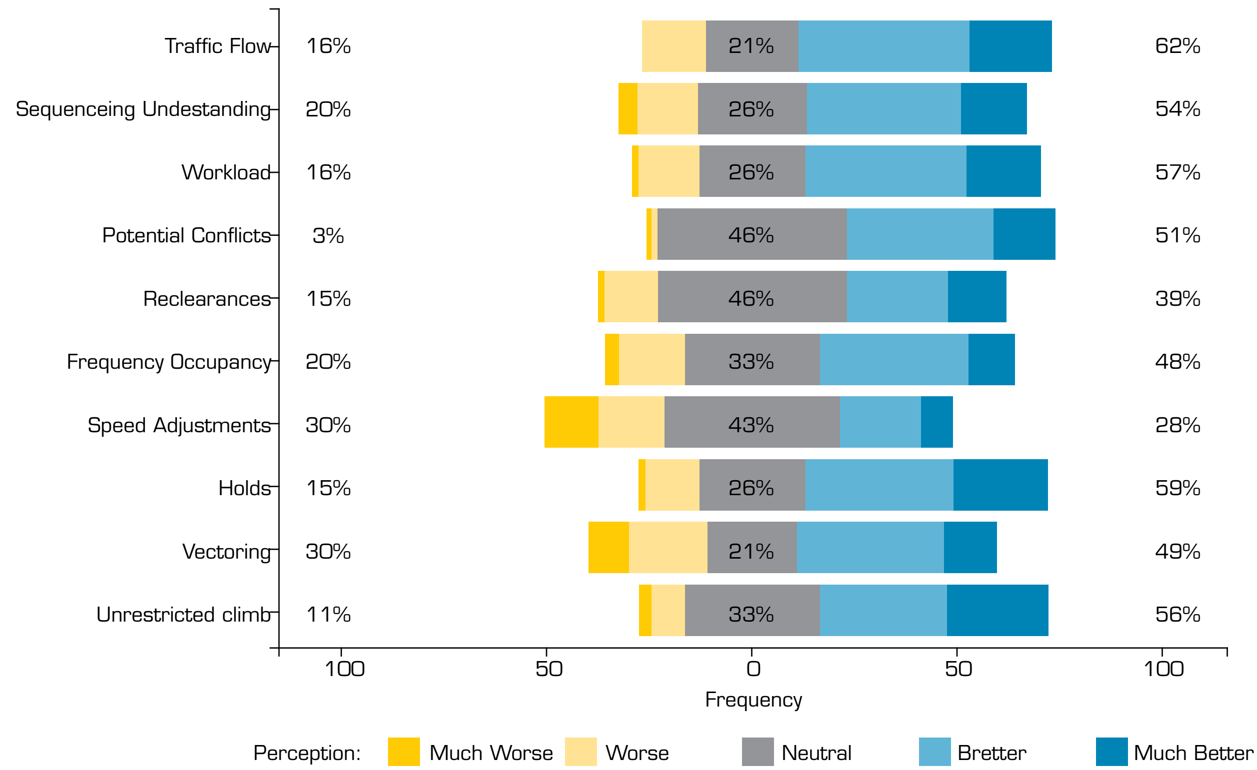
Figure 1. Social questionnaire of the expert participants in the research.

Results and analysis by groups

The exploratory analysis of the results involved interpreting the data from the Likert scale response graphs, where the positive percentages ("better" and "much better") and negative percentages ("worse" and "much worse") are summed on the sides of the graph. For the descriptive analysis, a heatmap was also developed for each group, allowing for better visualization of the results by assigned degree, separately. Heatmaps are often used to visualize patterns and variations in datasets. The data is presented in a grid, assigning different colors to different values, allowing for quick identification of areas with high or low values. Stronger colors indicate a higher expressiveness of responses for a particular parameter, enabling verification of which degrees were most selected. Considering the possibility of heterogeneity in the responses since these professionals may have different viewpoints regarding the same parameters, the analysis was divided into three phases, first considering only the pilot group, then considering the responses of the controller group, and finally an analysis of a single population, considering pilots and controllers belonging to the same group.

Group of pilots

Figure 2 presents the results obtained from the pilot group. It is noted that out of the 10 parameters evaluated, there was a perception of improvement in eight of these parameters and a tendency towards neutrality in two. The parameters where improvement was noted, in order of relevance, are Traffic Flow (62%), Waits (59%), Workload (57%), Unrestricted Departures (56%), Understanding of Sequencing (54%), and Potential Conflicts (51%), where the majority of the surveyed audience positioned themselves as "better" or "much better." Regarding the parameter Vectoring, although 49% of the participants indicated improvement by responding as "better" or "much better," 30% provided "worse" or "much worse" responses. The parameter Reauthorizations showed a majority of neutrality (46%) regarding the improvement or worsening of the scenario, as well as Speed Adjustments, where the majority of pilots remained neutral regarding the change (43%). Among the parameters, despite the majority being neutral during the evaluation, Speed Adjustments had the worst performance, with 30% of the group providing "worse" or "much worse" responses. Considering Frequency Occupancy, 48% of the group provided "better" or "much better" responses, 33% were Neutral, and 20% were "worse" or "much worse".



Source: Elaborated by the authors.

Figure 2. Responses from the pilot population. The numbers that appear next to the columns (according to the Likert scale response) are the sum of all responses, negative and positive, respectively.

Through the heatmap (Fig. 3), it is possible to correlate the most resonant items for each of the Likert scale grades. The results obtained support the analysis of the bar graph, highlighting Traffic Flow, Waits, Workload, and Unrestricted Departures as parameters that showed positive perceptions ("better" or "much better"), while Speed Adjustments, despite the majority of the group being neutral, exhibited a negative perception ("worse" or "much worse"). The heatmap in Fig. 3 was calculated according to the most resonant items in each degree of the Likert scale.

Group of air traffic controllers

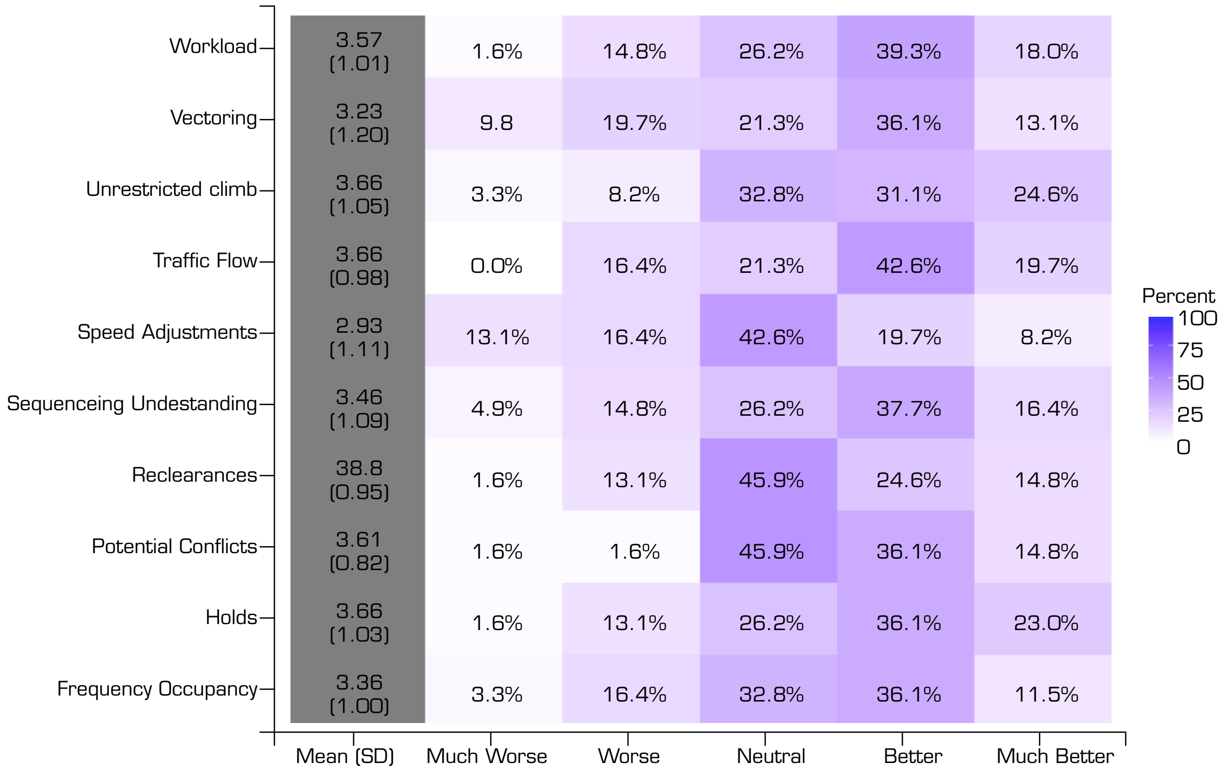
The results from the group of air traffic controllers are presented in Fig. 4 through the Likert chart, highlighting the evaluated parameters. The graphical analysis reveals that, out of the 10 parameters assessed, there was a positive perception of improvement in eight of them, a neutral perception regarding one parameter, and an identification of worsening in one parameter.

The parameters where improvement was noted, in order of relevance, are Traffic Flow (90%), Sequencing Understanding (90%), Vectoring (87%), Waits (70%), Speed Adjustments (67%), Unrestricted Departures (60%), Workload (60%), and Frequency Occupancy (50%), where the majority of the survey participants positioned themselves as "better" or "much better."

Regarding the Frequency Occupancy parameter, although 50% of the participants indicated that there was improvement by responding as "better" or "much better," 43% provided responses with a "neutral" perception regarding the changes in the terminal design.

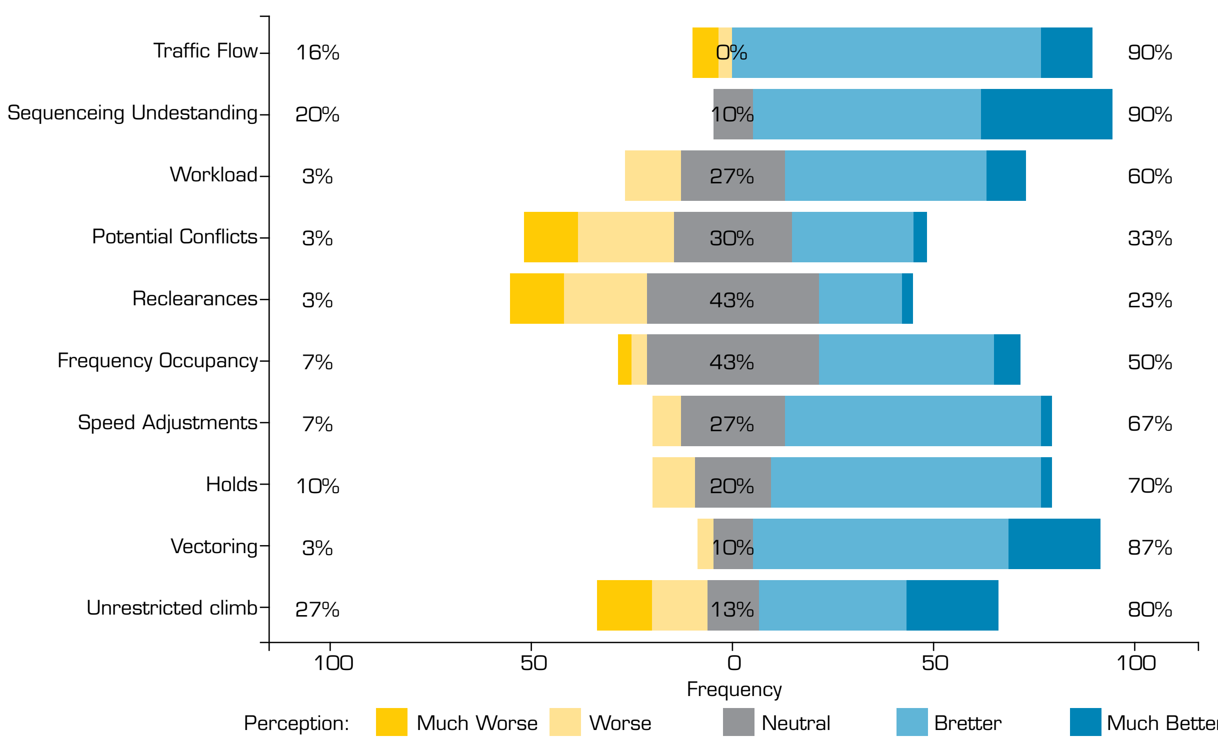
The Reauthorizations parameter showed a majority neutral response (43%) regarding improvement or worsening of the scenario, although 33% provided "worse" or "much worse" responses, and 23% provided "better" or "much better" responses.

Potential Conflicts had the worst performance, with 37% of the group providing "worse" or "much worse" responses.



Source: Elaborated by the authors.

Figure 3. Heatmap of the pilot population.



Source: Elaborated by the authors.

Figure 4. Responses from the population of air traffic controllers. The numbers that appear next to the columns (according to the Likert scale response) are the sum of all responses, negative and positive, respectively.

With respect to the heatmap of this group (Fig. 5), it is possible to observe an overall perception of improvement among the observed parameters. It is noteworthy that some of the parameters did not even receive "much worse" perceptions from the Likert scale.

Traffic Flow, Wait Times, Vectoring, and Speed Adjustments received the best positive perceptions ("better") – above 60%, while Potential Conflicts showed a negative perception ("worse" or "much worse").

Source: Elaborated by the authors.

Figure 5. Heatmap of the population of air traffic controllers.

Combined population

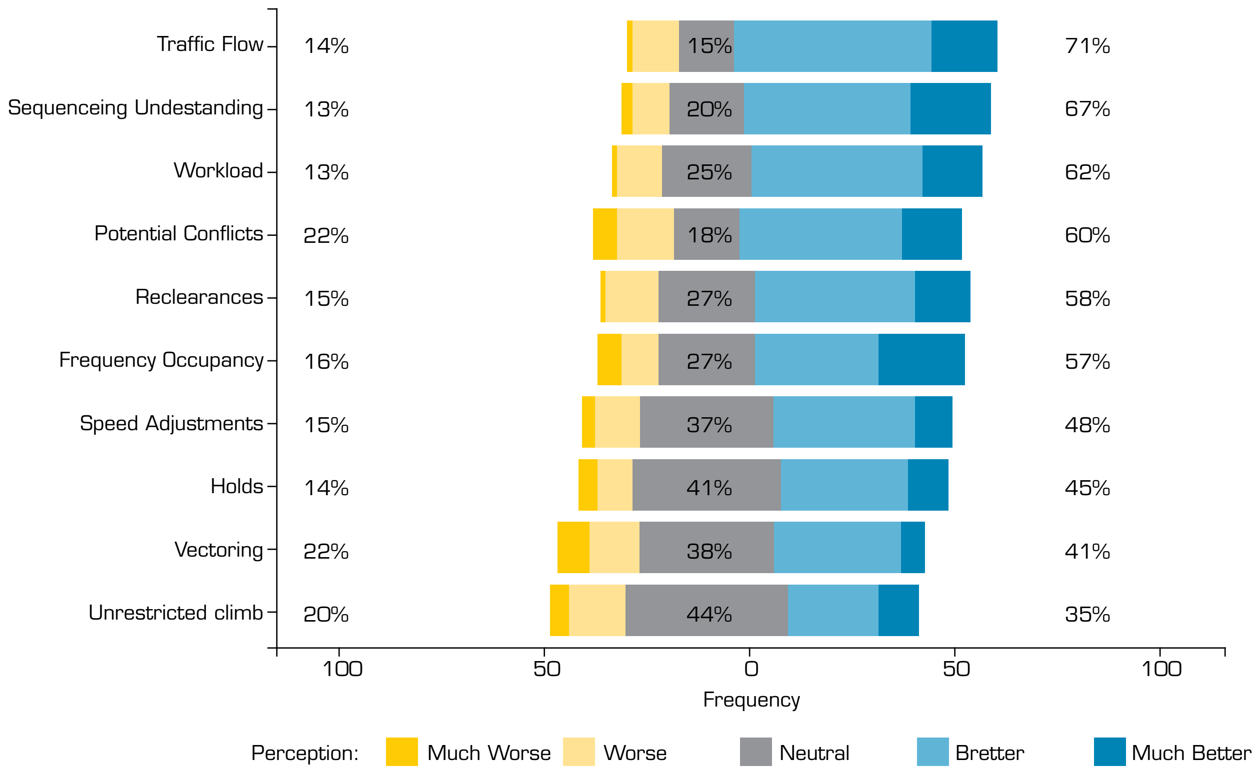
As described earlier, pilots and air traffic controllers groups may have different perspectives regarding the same parameter. Since the objective of the study is to conduct a global analysis of a group of experts, an evaluation considering both pilots and air traffic controllers belonging to a single population was also performed, the results of which are presented in Fig. 6.

The graphical analysis reveals that Traffic Flow Fluidity converges to 71% of perceptions of improvement ("better" and "much better"), followed by Sequencing Understanding (67%), Waits (62%), Vectoring (60%), Workload (58%), and Unrestricted Departures (57%) – with rates above 50%.

When analyzed globally, the Reauthorizations parameter had the lowest performance. Nevertheless, its most significant perceptions are around neutrality (44%), and when analyzed at its extremes, a more positive perception (35%) than negative (20%) is noted.

In an analysis focusing only on "worse" or "much worse" responses, it is noted that the parameters Speed Adjustments and Vectoring received the highest number of these responses (22%), despite both showing positive perception results, 41 and 60% respectively.

Frequency Occupation and Potential Conflicts showed positive performance, but with results that do not correspond to the majority of the group, counting with 48 and 45% of "better" and "much better" responses respectively.



Source: Elaborated by the authors.

Figure 6. Responses from the unified population. The numbers that appear next to the columns (according to the Likert scale response) are the sum of all responses, negative and positive, respectively.

From the heatmap for the unified population (Fig. 7), it is noticeable that participants mostly provided responses indicating "neutral" and "better" degrees. Traffic Flow showed 53.8% of responses as "better," being the parameter with the highest number of responses in this degree. Frequency Occupation, Traffic Flow, Waiting, Sequencing Understanding, and Workload each had less than 5% of responses with the "much worse" degree.

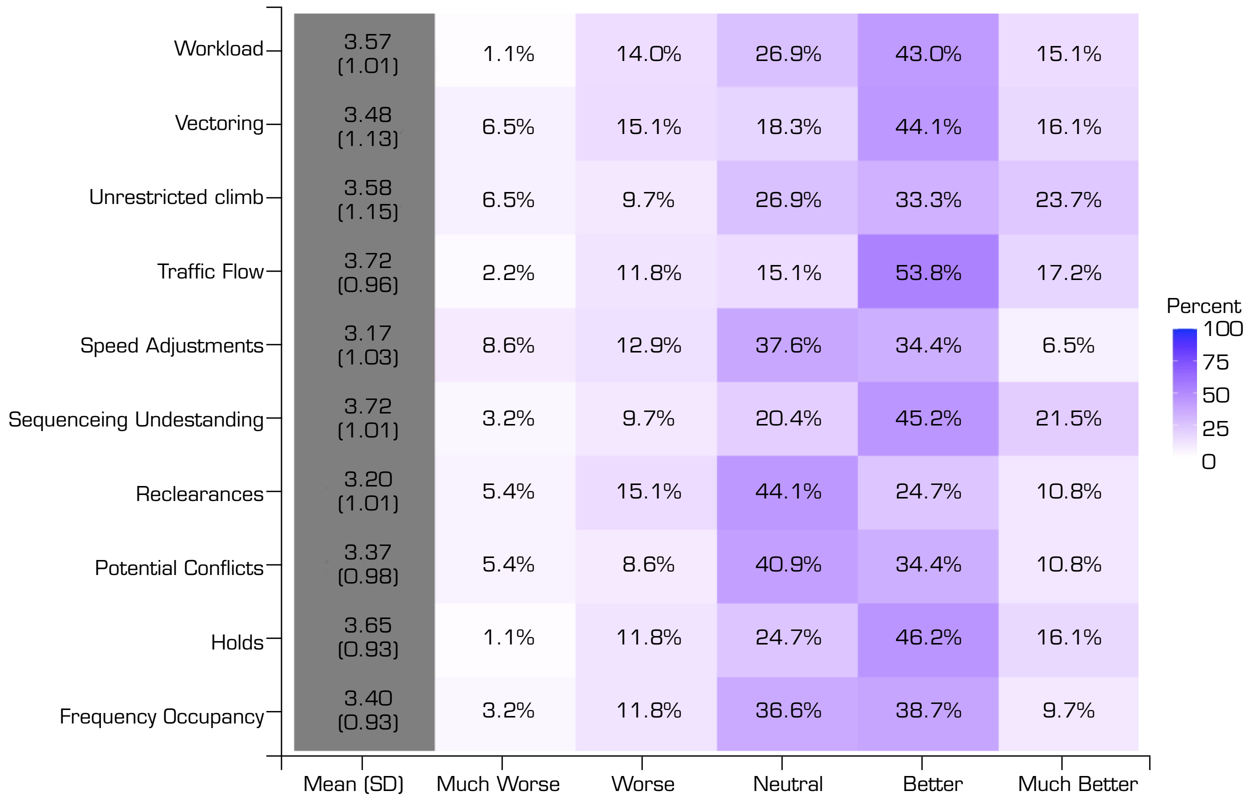
Comparative analysis and discussion

Through the field study, it was possible to obtain data on the perception of controllers and pilots regarding the modification of the TMA-SP, in order to evaluate the listed parameters, providing support to the study in question, pointing out potential improvements and identifying possible impacts and risks associated with this change.

Although with different percentages in some parameters, the results of perceptions regarding efficiency and safety were positive, converging to consensus, revealing the strengths of the modification and those that need attention. Through the obtained results, it was possible to observe the convergence of opinions on the overall improvement of TMA-SP Neo. Among the 10 parameters evaluated, we can highlight the following comparative points.

The parameters Traffic Flow (62% × 90%), Sequencing Understanding (54% × 90%), Workload (57% × 60%), Wait Times (59% × 70%), and Unrestricted Departures (56% × 60%) pointed out satisfaction rates above 50% in both groups. Thus, it is possible to understand that there was convergence in perceptions of "better" and "much better" in both groups.

Similarly, there was congruence in perceptions of neutrality regarding Reauthorizations (46% × 43%). This tendency toward the midpoint can be understood by the subjective interpretation of the public or by a respondent bias, since these are limitations of works that use the Likert scale, meaning that sometimes a lack of context causes the participant to tend towards neutrality in their response.



Source: Elaborated by the authors.

Figure 7. Heatmap of the unified population.

Regarding the feeling of worsening, it was possible to observe a divergence in the opinion of pilots and controllers. Around 30% of the former group believes in a worsening in Speed Adjustments, while controllers perceive a worsening in Potential Conflicts (37%). Based on the explanations presented, this can be attributed to their different work environments, awareness of the whole, and even the interrelation of some of the observed parameters.

The perception of pilots can be easily influenced by the time of arrival at the terminal, as well as by the sector of entry into the TMA. Speed Adjustments are commonly the first tool when it becomes necessary to sequence the traffic tactically, which is promptly perceived by pilots due to the immediate increase in workload.

Regarding controllers' perception, it is worth noting that before the modification of the Terminal, the Catarina Airport (SBJH), IFR operation at Jundiaí (SBJD), and approach procedures for Sorocaba (SDCO) and Amarais (SDAM) airports did not exist. The creation of these new structures may also have contributed to the Potential Conflicts being perceived more negatively, since all mentioned airports are mostly located in the northern region of the terminal, generating a greater possibility of interference with other routes, such as with Campinas Airport (SBKP), with possible conflicts that did not exist in the previous scenario.

CONCLUSION

The study successfully achieved its objective of providing an approach matrix for assessing the perception of users and air traffic specialists regarding whether the restructuring of the TMA met the requirements for maintaining operational safety. Overall, the results indicate that both pilots and controllers have a positive view and tend towards consensus regarding their perceptions of the modification of TMA-SP Neo. Within the presented context, the strengths of the new change were addressed by both groups and were further consolidated when analyzed as a unified population.

Based on the obtained results, it is evident that the proposed matrix demonstrated its ability to capture the sentiment of specialists, providing tangible data that aligns with the initial proposal of DECEA during the conception of the new design. Furthermore, the results from subjective comments were able to identify areas of concern for the new air traffic flow and potential improvements to enhance airspace safety and efficiency.

Finally, it can be observed that the new layout keeps Brazil in line with best international practices and policies, considering the agreements between States, ICAO's strategic objectives, and the ongoing pursuit of modernizing the SISCEAB through the SIRIUS Program, of which TMA-SP Neo was one of its endeavors.

As the matrix proved to be a valid alternative for capturing the sentiment of specialists and users, its application is recommended in other airspace areas undergoing modification where there is an interest in evaluating results that cannot always be measured through numerical indicators.

The following potential future works are proposed to continue the study: further utilization of the matrix through new iterations, aiming for consensus, and the development of new parameters with the potential to impact operational efficiency or safety.

It is also suggested that future data collection can overcome some possible limitations of this work, such as: not separating pilots by aircraft scope; not capturing working hours (higher frequency of respondents) and the frequency with which pilots use this airspace in data collection.

CONFLICT OF INTEREST

Nothing to declare.

AUTHORS' CONTRIBUTION

Conceptualization: Babinski PBO and Guterres MX; **Data Curation:** Babinski PBO; **Formal Analysis:** Babinski PBO; **Investigation**: Babinski PBO and Guterres MX; **Methodology**: Babinski PBO and Guterres MX; **Project Administration:** Babinski PBO, Guterres M, and Albano CS; **Resources**: Babinski PBO and Guterres MX; **Supervision:** Guterres MX and Albano CS; **Validation:** Babinski PBO; **Visualization**: Babinski PBO, Guterres MX, and Albano CS; **Writing – Original Draft Preparation**: Babinski PBO; **Writing – Review & Editing:** Babinski PBO, Guterres MX, and Albano CS; **Final Approval:** Albano CS.

DATA AVAILABILITY STATEMENT

Supplementary data are available in: https://data.mendeley.com/datasets/2xys947nwy/1

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