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EFFICIENCY SUSTAINABILITY OF AIR TRAFFIC CONTROL AND MANAGEMENT SYSTEM IN AVIATION SECTOR

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Abstract

The rapid advancement of cutting-edge technology has reshaped the global dynamics of the airline sector, elevating the significance of service quality, effectiveness, and protection. As a vital contributor to national economic growth and a public utility, aviation's expansion has directly impacted businesses in the service sector, leading to increased operational opportunities for hotels, restaurants, and travel agencies. This article addresses the challenges within Air Traffic Management (ATM), focusing on the aviation industry's primary concerns. With the continuous growth of aviation traffic, there is a pressing need to enhance security, productivity, and environmental sustainability. The article aims to stimulate business innovation and collaboration in advanced study areas such as dynamic airspace management (DAM), air traffic flow management (ATFM), and collaborative/non-collaborative surveillance. The proposed frameworks, based on Clean Sky and NextGen, incorporate 4D Trajectory Optimization techniques, advanced surveillance technologies, and data link connections to establish a foundation for ATM industry development. Additionally, the research explores adaptive Human-Machine Interface and Interaction (HMI2) forms to automate the assessment and negotiation of aircraft intentions, thereby improving the efficiency and security of ATM operations. The study also addresses specific requirements for cooperative and non-cooperative Detect-and-Avoid (DAA) systems for Remotely Piloted Aircraft Systems (RPAS) within the evolving CNS+A process, ensuring their safe and unrestricted access to all airspace types.

Key words: Aviation Sector, Safety, Efficiency, Air Traffic Control and Management System

1. Introduction

Thailand's tourism and airline industries, particularly in 2018, have surged, driven by technological advancements in aviation. The emerging market promises further growth, influencing sectors like restaurants, tourism, and hospitality. Rui's DARA model introduces a novel approach, addressing time limits and unexplored factors, employing a two-step heuristic algorithm with real ATC data from Beijing [1] [2]. The analysis extended to assessing the sensitivity of key coefficients in the DARA model. Traditionally, airspace planners rely and airport on SIMMOD, a widely used two-dimensional activity network in Simscript, employed by the US Federal Aviation Administration. This tool, applied globally, evaluates airport capacities, including runway and terminal capabilities, and facilitates the study of specific operations like ice removal during snowstorms [3] [4]. TAAM and SIMMOD simulators offer accurate representations of the flight paths of aircraft, considering factors like traffic, aircraft characteristics, weather, and flight plans. These tools provide detailed observations of gate-to-runway-to-destination movements, allowing for meticulous testing of aircraft activity feasibility under specific circumstances. However, their educational use comes with substantial costs, making them more suitable for strategic-focused applications. Different modeling guidelines and techniques are employed to study airport operations, aiding in strategic planning. Hemanth (2017) and Norin (2009) delve into airline interoperability, airport operations and air traffic control, investigating a range of commercially available simulation tools for analysis and modelling. They employ mathematical programming models, integrating them with simulations for scheduling icing operations and ground activities. Snowdon (2000) utilizes ARENA to simulate passenger and baggage movements in airport terminals. Horstmeier and de Haan (2001) employ ARENA to optimize Airbus A380 rotations, identifying time-saving opportunities through configuration and process adjustments. Yan (2002) investigates optimal gate activities using mathematical, heuristic, and Fortran 90-based simulations, addressing stochastic effects [2].

The proposed algorithm focuses on optimizing taxi routes for efficient plane positioning during arrivals and departures, considering scheduled fuel times. The decision support system (DSS) for airport planning integrates individual strengths models, consolidated databases, and domain-specific analytics tools through human-machine interfaces. In air traffic control, controllers dynamically prioritize arrivals, assigning lanes based on urgency. While typically following a first-come, first-served (FCFS) basis, adjustments are made for system voltage. The airspace planning model, running on an FCFS basis, mimics airline and controller behavior, adapting time and routes for aircraft separation. Smith et al. (2011) demonstrated heuristic scheduling improvements over FCFS in river transport systems, using a step-by-step queue with a priority shift mechanism for equality [5]. The attribute of prioritizing entities in queues is crucial in transport and logistics, particularly when faced with physical constraints. In aquatic environments, optimizing performance without hindering various boat types is advantageous. The burden of delay shifts among user classes based on the density of priority shifts. Innovations in air traffic management (ATM) technology, driven by global initiatives like SESAR in Europe, NextGen in the USA, OneSky in Australia, CARATS in Japan, SIRIUS in Brazil, FIANS in India, and others, converge on integrated and collaborative automation. These programs aim to enhance airspace resource utilization through increased automation and information sharing, anticipating significant improvements in safety, capability, and efficiency in the CNS/ATM and Avionics domains, aligning with ICAO's FANS evolution [6]. CANSO estimates global Air Traffic Management (ATM) efficiency at 92-94%, with non-recoverable factors limiting improvements to 95-98%. In contrast, IATA reports a 12% fuel inefficiency compared to ATMs. Advanced CNS + A technology aims to enhance operational efficiency, environmental sustainability, safety, and interoperability. Key innovations include Performance-Based Communication, 4D Trajectory-Based Operations, Surveillance for CNS Performance-Based Operations, Navigation, Enhanced Line-of-Sight, System Wide Information Management, and Beyond LoS aeronautical communications, Avionics, Ground, and Satellite-Based Augmentation Systems supporting GNSS as the primary means of navigation, and improved surveillance. Additionally, advancements in Human-Machine Interface, Air Traffic Flow Management, and concepts like Collaborative Decision Making contribute to a more efficient and sustainable air traffic system [7] [8].

Thailand has emerged as one of the rapidly growing countries in the Asia-Pacific region, particularly in tourism, airline industries, and its economy. The airline industry in Thailand showed significant growth in 2018, propelled by advancements in technology that have reshaped global aviation dynamics and heightened the demand for quality service and passenger aviation. Beyond its role as an air transport, public utility plays a vital role in national economic development, influencing supply chain industries like hospitality, restaurants and travel agencies tourism. Global trends indicate a continuous increase in worldwide passenger air transport, with growth rates of 4.8%, 5.9%, and 6.3% in 2013, 2014, and 2015, respectively. However, the aviation sector is sensitive to economic, political, and social factors, facing challenges such as natural disasters, fuel crises, and epidemics that impact cost control and intensify competition. To thrive in this dynamic environment, global airlines, including those in Thailand, must adapt by evolving mechanisms, altering operations, and enhancing human resource management. Ensuring service quality is crucial for meeting passenger needs, ultimately contributing to the survival and success of the aviation business [1]. Thailand's Don Mueang International Airport (DMK) stands out as a hub for Low-Cost Airlines (LCAs), excelling in international point-to-point routes. While LCAs compete on pricing, studies caution against long-term reliance on price competition. Airlines globally, including in Thailand, focus on delivering excellent yet cost-effective services, meeting evolving passenger expectations. Amid economic and socio-political sensitivities, airlines adapt to challenges like natural disasters, fuel crises, and epidemics. Artificial intelligence in Air Traffic Control (ATC) emerges as pivotal for safety, efficacy, and sustainability in aviation. Global airlines must evolve operations, prioritize service quality, and innovate to stand out and compete effectively. Passenger satisfaction and loyalty hinge on service quality, with ground staff at DMK playing a crucial role. Clear communication of service standards aids passenger decision-making. The integration of Communication, Navigation, and Surveillance (CNS) systems is key for operational efficiency, sustainability, safety, and interoperability [13] [14].

2. Methodology

2.1 Evolution of Aviation Technology

There has been a rise in the need for efficient, high-quality service in the aviation business as a result of the changing global dynamic brought about by the fast growth of modern technologies. This paper aims to evaluate the influence of technology on Air Traffic Control (ATC) communications within the Civil Aviation Authority of Thailand (CAAT). The study emphasizes current technologies, their safety in the aviation industry, and the potential impact of future technologies, particularly those incorporating artificial intelligence (AI), on interpersonal skills.

2.2 Generic and Specific Elements

The research treats perceptions of current ATC technologies as generic, while considering future AI-based technologies as a specific element crucial for the growth and development of ATC.

2.3 Decision-Making Process and Trajectory Optimization

An essential component of the ongoing Joint Decision Making (CDM) process between the Air Navigation Service Provider (ANSP) and the Airline Operations Centre (AOC) is performance weighting, which is constantly changed while in flight.

Using a rule-based algorithm, the traffic management system generates many ideal 4D trajectories for each aircraft and determines a set of trajectories that are free of conflicts.

3. Experimental System

3.1 The CNS+A paradigm

The new automatic CNS+A system allows a properly installed aircraft to fly the best possible flight path the user needs, limiting human operator intervention and involving a high level of decision-making in the event of an emergency. The increased airspace flexibility allows for a more efficient and environmentally friendly flight profile. The CNS+A system will provide enhanced autonomous navigation, aided by optimal aircraft separation, to make full use of the available airspace and airport surface resources. An essential component of CNS+A systems is ground-based ATM systems and network-centric avionics, which work together to plan and execute 4D Trajectory (4DT) in real time. These systems also include MOTO-4D, which optimizes 4DT for various objectives and has negotiation and validation capabilities. NG-ADL, the Next Generation Air-to-Ground Data Link, is a secure, high-integrity, and high-throughput technology that links SWIM and other Collaborative Decision Making (CDM) stakeholders. Compliance with Clean Sky and NextGen standards is achieved through the optimization of online air traffic flows, utilizing CNS+A technologies, technologies for Remotely Piloted Aircraft Systems, and integrated health management systems for both ground-based and airborne systems [15].

Overall, 4D Trajectory (4DT) decisions are significantly enhanced by utilizing an automated negotiation plan and validation process. This involves the exchange of constraints and operational parameters between 4DT planning and the Next Generation Flight Management System (NG-FMS) through the Negotiation and Validation (4-PNV) system via the Next Generation Air-to-Ground Data Link (NG-ADL) [14, 16, 17, 15, 18, 19, 20, 21, 22, 23]. Figure 1 illustrates the concept of CNS+A-enabled 4DT validation and negotiation. In this process, the 4-PNV system receives 4DT Intent from each of the NG-equipped unmanned and manned aircraft via the NG-FMS. If an optimal conflict-free trajectory is identified, the 4-PNV system instructs each aircraft to follow the verified trajectory, and the aircraft then sends a confirmation to the ground [23]. The 4-PNV system is capable of computing a new set of appropriate trajectories based on performance weights determined by the Air Navigation Service Provider (ANSP) and the Airline Operations Center (AOC). It uploads this information to the respective aircraft in the event that the intended potential trajectory of the NG-FMS cannot be determined. Once the intended trajectory is established, the onboard NG-FMS notifies the 4-PNV system with a confirmation. A sub-case of this scenario involves a negotiation loop initiated by the 4-PNV system itself, for instance, due to air traffic or conflicting information from the ANSP or AOC.

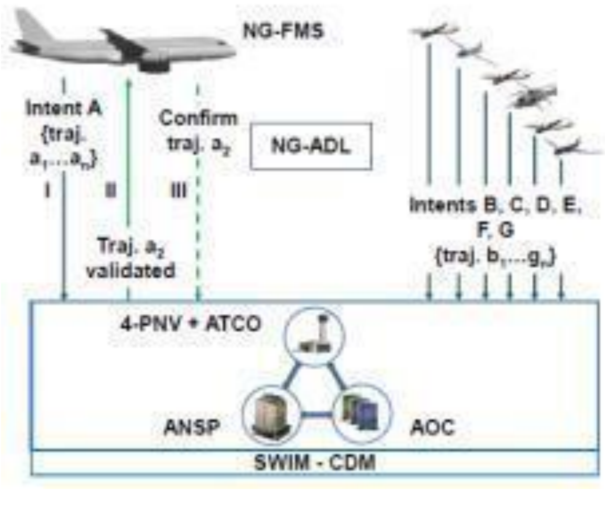

Fig. 1 CNS+A enabled intent negotiation and validation scenario.

3.2 Trajectory optimization

The trajectory of each aircraft is influenced by various operational and environmental factors. Traditional flight plans, based on initial horizontal route selection for the shortest path, have inherent limitations. This approach considers ascending winds, followed by appropriate vertical planning based on aircraft performance. The major environmental impacts include Nitrogen Oxides (NOX), Carbon Oxides (COX), Unburned Hydrocarbons (UHC), Sulphur Oxides (SOX), as well as condensation paths (contrails) and noise, as illustrated in Figure 2 [23]. This research is dedicated to the development of efficient and multi-purpose route planning, along with real-time mission management algorithms. These advancements are intended for integration into both air and ground CNS+A systems. The foundation of future Air Traffic Management (ATM) systems will be a network-centric information environment. In this setup, ground and aircraft/Remotely Piloted Aircraft Systems (RPAS) act as nodes, exchanging data and communicating intentions across an interconnected network of systems. Key aspects such as interface management, communications, protection, and enterprise service management represent some of the interoperable and compliant services that enable seamless operations across different platforms.

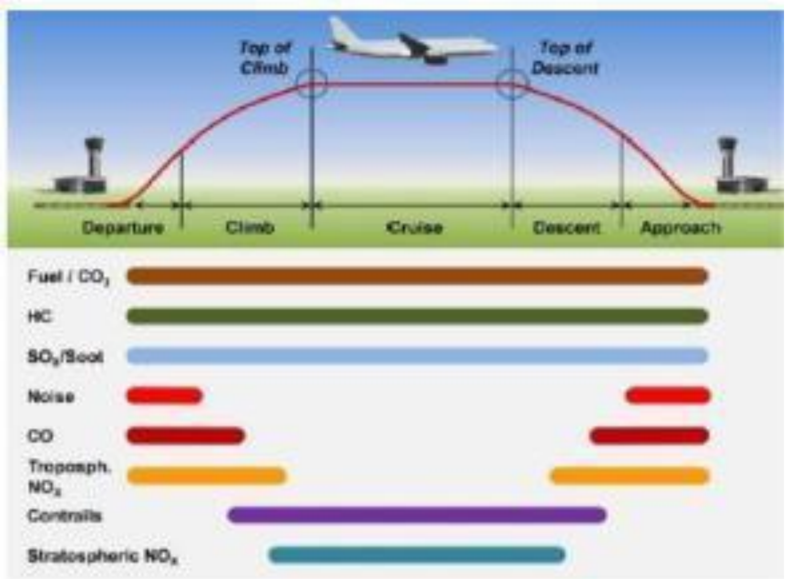

Fig. 2 Multi-objective optimization criteria.

3.3 Air traffic flow and dynamic airspace management

Departure delays represent unforeseen complications that may arise during aviation procedures. Factors such as unscheduled traffic, unexpected wind and weather variations, and tactical Air Traffic Control (ATC) interventions for separation can impact the Air Traffic Flow Management (ATFM) system. The primary objective of Demand-Capacity Balancing (DCB) is to address these challenges and achieve a balance between demand and capacity. ATFM Decision Support Systems (DSS) cope with uncertainties by differentiating representations of actual demand and making forecasts based on trust standards. This approach enables flow managers to handle excess forecasting to some extent, provided there is a redistribution strategy in case of actual occurrences [24, 25].

DCB can benefit various aviation resources, including airports, sectors, and remediation efforts. Implementation can be gradual, involving actions such as airline schedule planning and collaboration with organizations like the International Air Transport Association (IATA) to establish a strategic DCB. Traditional Air Traffic Management (ATM) automation assists with airport lanes, airspace layout, capacity analysis, and performance prediction. However, the evolution of ATFM Decision Support Tools (DST) operations introduces new capabilities and enhanced algorithms for demand prediction.

Key features of ATFM DST operations include what-if replication, improvements in Human-Machine Interface (HMI2), enhanced situational awareness (considering factors like weather, airspace restrictions, NOTAMs, etc.), Collaborative Decision Making (CDM) negotiation mechanisms, compliance reporting, and post-incident analysis. Significant aspects to explore for ATFM DST include integrating metrics with sequencing, utilizing the HMI2 factor to depict complexity and fluid density concepts, and integration with Arrival Manager (AMAN) and Departure Manager (DMAN) activities, among others. The continued growth of ATFM in various Air Navigation Service Provider (ANSP) regions further underscores the importance of these developments.

The Air Traffic Flow Management (ATFM) system effectively tackles a majority of the demand-side concerns. Currently, the capacity to alter power factors is restricted to tactical and pre-tactical measures. The implementation of the adaptable and changing airspace concept was devised as a solution to address the inflexibility inherent in traditional, distinct civil and army airspace frameworks. According to the standard Adaptable Use of Airspace concept, adjustments can be made to the geographic scope and activation times of Special Use Airspace (SUA) to minimize disruptions or optimize its utilization. However, there have been no changes in the Air Traffic Control (ATC) sector regarding Special Use Airspace (SUA). The SUA is unable to enhance the capacity of the ATC sector; its impact is limited to reducing capacity. Dynamic Airspace

Management (DAM) enables the temporary augmentation of air traffic control (ATC) sector resources by modifying the geographic boundaries. Propose adjustments to the geographic limits of regions and traffic patterns to efficiently deal with evolving patterns of traffic, changing weather conditions, and other relevant factors.

The possibility of temporarily reducing the size of nearby Air Traffic Control (ATC) sectors is a more flexible concept than merging or splitting a sector into an ATC position. However, potential regulatory constraints on changes to sector boundaries include considerations such as Air Traffic Controller (ATCO) rating and the mix of traffic. An experimental study on Flexible Airspace Management (FAM) and an early dynamic sector survey, validated in the context of NextGen, demonstrate that both Air Navigation Service Providers (ANSPs) and airline operators stand to benefit significantly from reduced interference. ANSPs have the potential to enhance ATCO efficiency and manage staffing levels, while airline operators can potentially reduce Demand-Capacity Balancing (DCB) measures such as transitions and holding. The emphasis is on critical aspects, including the size, frequency range, schedule, and foresight of sector changes. Shifts involving heavy traffic, substantial flow, or reversing directions (up or down) were found to be particularly detrimental to job pressure and situational awareness. It's important to note that Letters of Agreement (LOA) governing cooperation at international borders impose significant limitations on Dynamic Airspace Management (DAM), as ATCOs are aware. These limitations need to be considered when implementing changes in the airspace structure.

On the other hand, additional efforts to facilitate data sharing and enhance compatibility across Air Traffic Management (ATM) systems should simplify the process of forming cross-border agreements. Investigating the dynamics of collaboration between different sectors and centers requires in-depth study. In the long run, Dynamic Airspace Management (DAM) should not be limited exclusively to Air Traffic Control (ATC) and Special Use Airspace (SUA) sectors. Instead, the algorithmic adjustment of Air Traffic Service (ATS) classification for SUA and ATC sectors based on the latest Decision Support Tools (DST) input is advisable. The DAM system should automatically update its lexicon to consider the current levels of Communication, Navigation, and Surveillance (CNS) performance, influencing its assessment and decision-making logic. Due to these functionalities, DAM plays a crucial role in Performance-Based Operations (PBOs).

3.4 Integrated vehicle health management systems

In the realm of integrated aviation systems, the Integrated Vehicle Health Management System (IVHM) serves as a valuable tool, providing comprehensive data on the "health" of an aircraft, its systems, and its components. This information proves essential for various purposes, including maintenance and support tasks. The IVHM system contributes to optimizing logistics, facilitating restoration processes, and adapting aircraft designs. Simultaneously, it enhances efficiency and autonomy in monitoring health status. The IVHM system offers numerous advantages, such as minimizing system and component duplication, improving accessibility, ensuring security dependability, establishing a minimum operating baseline, and reducing annual expenses.

The common practice involves aggregating and analyzing health data collected from a network of dispersed sensors. These sensors, ranging from simple to highly sophisticated, employ intelligent and wireless communication for data collection. The assessment module evaluates the current health condition, performing tasks such as failure detection, diagnosis, and isolation. The prediction module analyzes historical data to anticipate future issues. Following the comprehensive data collection, a thorough evaluation is conducted to determine the necessary aircraft support activities. Management support personnel utilize these activities as evaluation criteria or inputs for in-flight rescue systems. In many cases, mathematical frameworks such as Neural networks, statistical analysis (including regression and correlation methods for particle filtering), Bayesian networks, Fuzzy logic, and Hamilton's dynamic estimation techniques are employed for diagnosis and prognosis.

3.5 Datalink evolutions

To transmit limitations from the ground system to the Flight Management System (FMS) of aircraft, the Aircraft Address Notification and Communications Reporting System (ACARS) serves as a medium for Future Air Navigation System (FANS) 1/A Controller-Pilot Data Link Communications (CPDLC) communications. Updated 4D Trajectory (4DT) scenario data sharing is crucial for ensuring compatibility between the 4-PNV and NG-FMS systems. While current FANS-1/A technology allows for this, adjustments to the interchange path should be minimized and tailored to the required deviation, disregarding the unmodified section of the route after rerouting. The following circumstances contribute to these restrictions: ATM systems may not be as accurate as FMS systems in predicting future aircraft locations, and they often extend the intended flight path by adding waypoints to establish the aircraft's route (e.g., ADS-C, projections, inter-sectoral coordination, downlink route element-response, Top of Climb (TOC), Top of Descent (TOD)).

The FANS-1/A route clearance parameters allow for 128 reference points based on identity, latitude-longitude geographic coordinates, or range and heading. It's important to note that both aerial platforms have constraints in terms of connectivity and processing power, with terrestrial restrictions further limiting their use. Additionally, the FANS-1/A route clearance parameter's reference point does not include elevation, necessitating that CPDLC signals or text components properly indicate altitude changes, similar to voice clearances. The recently introduced B2 Aviation Telecommunication Network (ATN) protocol has the potential to impact the ADS-C message set. Forecasting is expected to improve with the B2 ATN profile, which is similar to FANS-1/A. The Next Generation Air-to-Ground Data Link (NG-ADL) can project 2 to 128 waypoints with latitude, longitude, and altitude information, showcasing its compatibility with FMS/ATM. However, optimizing bandwidth for 4-PNV-NG-FMS communication remains crucial. Another technique involves a centralized, decentralized separation control system, such as NG-FMS and NG-ATM co-processing.

3.6 System-wide information management

The current research program is tackling the challenge of establishing a secure, integrated, and reliable interoperable ground-air communication system. The goal is to enhance both the frequency and information connection spectrum while developing performance-driven solutions that meet the functional needs of TBO (Trajectory-Based Operations) and other applications. This encompasses achieving performance standards in accessibility, minimizing delays, and ensuring signal fidelity. Initiatives like NIS3 (Network Integration Services for Security Technologies) and NWSKY (Networking the Sky) are actively working on ground and aerial communication technologies to support the deployment of SWIM (System Wide Information Management). The SANDRA project, standing for "seamless aeronautical networking," focuses on integrating data links, radio broadcasts, and antennas. To promote greater sharing of Air Traffic Management (ATM) data, including climate information, operational status, airport functioning data, flight schedules, airspace status, and limitations, the Australian government has undertaken various infrastructure projects. These projects include the development of a high - integrity, high-throughput, secure Line-of-Sight (LOS) and Beyond-Line-of-Sight (BLOS) data link, a ground network for civilian-military pairing, and SWIM applications.

SWIM is composed of infrastructure and governance standards that facilitate ATM data management and qualified inter-party exchanges through SESAR (Single European Sky ATM Research) data-driven interoperability services. The aim is to enable network-centric ATM operations, providing quick delivery and efficient communication to the intended destination. The foundation of future ATM systems is envisioned as a network-centric information environment where ground and aircraft/Remotely Piloted Aircraft Systems (RPAS) systems function as nodes exchanging data and communicating intentions over an interconnected network. Various platforms offer a range of interoperable and compliant services, covering enterprise management, emails, privacy, and interface management. Among SWIM's guiding principles are the application of open norms and service-based design, the separation of data collection and consumption, and the use of loosely connected systems. An integral part of SWIM involves leveraging Business Intelligence (BI) and big data to enhance data mining capabilities.

3.7 CNS+A -technologies for RPAS

Significant changes are anticipated in controlled airspace and the architecture of the Communications, Navigation, Surveillance + Automation (CNS+A) system due to a shift in Air Traffic Management (ATM) regulations allowing Remotely Piloted Aircraft Systems (RPAS) unrestricted access to non-isolated airspace. Standardization committees such as RTCA SC-203, ASTM F 38, and EUROCAE WG 73 play a crucial role in monitoring the integration of RPAS into non -segregated airspace by establishing aviation system performance standards. The Minimum Aviation System Performance Specification (MASPS) for RPAS, highlighted by the International Civil Aviation Organization (ICAO) in its Aviation System Block Upgrades (ASBU) framework, is a significant performance enhancement. Basic operational tasks in non-isolated airspace involve implementing detection and avoidance capabilities for RPAS operations. Integrating RPAS into air traffic requires a comprehensive moderation procedure addressing missing links and enhancing Digital Advertising Alliance functionality. RPAS Transportation Management focuses on utilizing RPAS for operations on airport surfaces and within non-isolated airspace, similar to unmanned aircraft. The proposed approach emphasizes the integration of cooperative and non-cooperative surveillance systems to enhance operational capabilities in networked situations. This includes combining collision avoidance and collective conflict resolution functionalities. Additionally, the integration of Detect and Avoid (DAA) capabilities in RPAS and Next Generation Flight Management Systems (NG-FMS) is explored.

The interaction between Guidance, Navigation, and Control (GNC) loops and decision tracking and avoidance (TDA) loops is improved to enhance overall system performance. Various collaborative and non-cooperative solutions for Distributed Autonomous Agents (DAA) exist, but additional efforts are needed in the certification process to facilitate the growth of RPAS operations. Full integration of RPAS in conventional air traffic requires a comprehensive framework of regulations, procedures, and technology to secure airspace access. DAA technology is crucial for minimizing collisions and hazards and improving situational awareness. The development of Airborne DAA systems to handle various characteristics of airborne and terrestrial obstacles, both natural and man-made, is essential and is expected to have a significant impact on DAA airworthiness and the evolution of design standards [20-28].

3.8 Advances in HMI2

Current Air Traffic Management (ATM) systems are equipped with Human-Machine Interfaces (HMI2) designed to provide data in a standard format at predefined instances and predetermined numbers. However, the highly variable transmission geometry generates a random image pattern that can vary in ease of use for human operators. This variability has been shown to impact situational awareness and increase the rate of human error. The limitations of this fixed approach are particularly evident in terms of restricting the amount of traffic that individual human operators can safely handle. In response to this, there is a need for research to develop an adaptive HMI2 that combines automatic changes in function and control styles based on measured cognitive states and operational/environmental observations.

Applying bio-driven and biologically inspired design principles from relevant literature, cognitive models of HMI2 (CHMI2) will be developed. The innovative CHMI2 concept is designed to complement human operator decisions and actions, reducing errors, and enhancing human-machine collaboration. With the inclusion of CHMI2, the next generation of ATM systems is expected to: Increase the number of aircraft that can be safely controlled in current (rigorous) and future (flexible) airspace areas, thereby enhancing operational capacity and safety simultaneously. Enable air traffic controllers (ATCos) to quickly identify recurring problems, retrieve data, and make decisions/actions with critical cognitive aspects such as excessive data and fatigue in mind. Reduce HMI clutter by displaying only the information needed at the appropriate times for a wide range of ATCo decision-making tasks. Enable a higher level of HMI2 customization and individual adaptation to ATCo characteristics. The significant increase in airspace capacity brought about by the installation of the Communications, Navigation, Surveillance + Automation (CNS+A) system will directly contribute to the increased flexibility of ATM operations, making them more efficient and safer.

4. Questionnaire and Respondents

To gather insights, a questionnaire with 12 questions for each variable was administered to 81 respondents, comprising Air Traffic Controllers from Don Muang Airport and Suvarnabhumi Airport in Thailand. Responses were recorded on a five - point Likert scale.

4.1 Statistical Analysis:

Various statistical methods, including cross-sectional analysis, descriptive analysis, and regression analysis, were employed to analyze the collected data. Each method was selected to investigate the relationships between variables.

4.2 Research Approach

The study follows a cross-sectional research approach based on the guidelines outlined by Hussey and Hussey (1997).

5. Results and Discussions

Table 1 provides a detailed breakdown of respondents based on technology concerning safety, efficacy, and environmental sustainability in the aviation industry. The study's results indicate that 62.96% of CAAT's air traffic controllers strongly agree on the usage of Air Traffic Flow Management for the safety, efficacy, and sustainability of aviation, with 22.22% in agreement, 1.23% in disagreement, and only 1.23% strongly disagreeing. Additionally, 12.36% of respondents remain undecided about the technology's usage. For Dynamic Airspace Management (DAM), 69.14% of air traffic controllers at CAAT strongly agree, 13.58% agree, 1.23% disagree, and 0% strongly disagree, while 16.05% are undecided about its usage. In the case of CNS+A PARADIGM, 75.32% of traffic controllers at CAAT strongly agree, 11.11% agree, 1.23% disagree, and 1.23% strongly disagree. Meanwhile, 11.11% of respondents are undecided. Trajectory Optimization sees 51.85% strongly agreeing, 27.16% agreeing, and 20.99% undecided, with no respondents disagreeing or strongly disagreeing. For Air Traffic Flow and Dynamic Airspace Management combined, 44.44% strongly agree, 23.46% agree, 1.23% disagree, and 1.23% strongly disagree, while 29.64% are undecided. Integrated Vehicle Health Management Systems have 46.91% strongly agreeing, 19.75% agreeing, 1.23% disagreeing, and 0% strongly disagreeing. Furthermore, 32.11% are undecided. Datalink Evolutions are supported by 50.62%, with 22.22% in agreement, 2.47% in disagreement, and 1.23% strongly disagreeing. Meanwhile, 23.46% remain undecided. System-Wide Information Management receives 56.79% strong agreement, 25.93% agreement, 2.47% disagreement, and 0% strong disagreement, with 14.81% undecided. CNS+A Technologies for RPAS are favored by 58.03%, with 13.58% in agreement, 1.23% in disagreement, and 1.23% strongly disagreeing. Additionally, 25.93% are undecided. Advances in HMI2 see 66.66% strongly agreeing, 13.58% agreeing, and 19.75% undecided, with no respondents in disagreement or strong disagreement. When considering all the technologies linked with Artificial Intelligence, 83.95% of traffic controllers at CAAT strongly agree, 11.11% agree, and 4.94% are undecided, with no respondents in disagreement or strong disagreement.

Table 1

Distribution of respondents based on technology for the safety, efficacy and environmental sustainability in aviation industry

Parameter	SA (%)	A (%)	DA (%)	SD (%)	UND (%)
I prefer the following technology would be good for the safety, efficacy and environmental sustainability in aviation industry (n=81)					
Air Traffic Flow Management (ATFM)	51 (62.96)	18 (22.22)	1 (1.23)	1 (1.23)	10 (12.36)
Dynamic Airspace Management (DAM)	56 (69.14)	11 (13.58)	1 (1.23)	0 (0.00)	13 (16.05)
CNS+A PARADIGM	61 (75.32)	9 (11.11)	1 (1.23)	1 (1.23)	9 (11.11)
Trajectory optimization	42 (51.85)	22 (27.16)	0 (0.00)	0 (0.00)	17 (20.99)
AIR Traffic Flow and Dynamic Airspace Management	36 (44.44)	19 (23.46)	1 (1.23)	1 (1.23)	24 (29.64)
Integrated vehicle health management systems	38 (46.91)	16 (19.75)	1 (1.23)	0 (0.00)	26 (32.11)
Datalink evolutions	41 (50.62)	18 (22.22)	2 (2.47)	1 (1.23)	19 (23.46)
System-wide information management	46 (56.79)	21 (25.93)	2 (2.47)	0 (0)	12 (14.81)
CNS+A -technologies for RPAS	47 (58.03)	11 (13.58)	1 (1.23)	1 (1.23)	21 (25.93)
Advances in HMI2	54 (66.66)	11 (13.58)	0 (0)	0 (0)	16 (19.75)
With all the above technologies linked with Artificial Intelligence to overall enhanced performance	68 (83.95)	9 (11.11)	0 (0)	0 (0)	4 (4.94)

Source of data: Survey SA= Strongly Agree, A= Agree, DA= Disagree, SD= Strongly Disagree, UND= Undecided

6. Conclusion

Global aviation, including Thailand, faces transformative shifts driven by technological advancements and the need for enhanced service quality. Thailand has emerged as a fast-growing player in the airline industry, driven by tourism and economic growth in the Asia-Pacific region. The industry, currently in its budding stages, anticipates significant growth in the coming years. Amidst economic and socio-political sensitivities, airlines worldwide are evolving operations to gain a competitive edge and establish world-class reputations. This study revealed satisfactory international terminal services, though check-in staff performance scored average satisfaction. The future of air transport focuses on environmentally friendly practices, with advancements in aircraft technology and air traffic management enabling more efficient airspace use. Automation and information sharing will play a pivotal role in dynamic scheduling optimization. Future research recommendations include improving prediction efficacy, negotiation strategies, human factors, and machine interoperability.

To enhance airline efficacy, safety, and passenger satisfaction, further studies should explore socio-economic status impacts, local services, and international comparisons. Embracing future technologies, particularly artificial intelligence in Air Traffic Control, is crucial for achieving safety, efficacy, and sustainability in the global aviation industry.

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