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The Use of Artificial Intelligence in Air Traffic Control: A Theoretical Review

Hava Trafik Kontrolünde Yapay Zeka Kullanimi: Teorik Bir İnceleme

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Abstract

Aviation is a growing industry critical to commercial and military operations worldwide. This growth brings with it more complex and intensive air traffic management requirements. Air traffic control is a critical service operating within airports and airspace to ensure aircraft's safe, efficient and orderly routing. However, as the traffic density in the airspace increases, human operators are more likely to make mistakes and existing air traffic management systems may be inadequate. At this point, applying artificial intelligence (AI) technologies in air traffic control offers a significant innovation to the sector. This paper examines how AI technologies are used in air traffic control. The opportunities offered by technologies such as machine learning, deep learning, unmanned aerial vehicles (UAVs) and blockchain in air traffic control are discussed, and the role of these technologies in reducing human errors, increasing efficiency and optimizing decision-making processes is discussed. In particular, the integration of UAVs into the airspace and the contributions of AI in managing this process were emphasized. In addition, the benefits of blockchain technology in terms of data security and traceability are evaluated.

Keywords: Air traffic control, artificial intelligence, air transportation

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Özet

Havacılık, dünya çapında ticari ve askeri operasyonlar için kritik öneme sahip, büyüyen bir sektördür. Bu büyüme, daha karmaşık ve yoğun hava trafik yönetimi gereksinimlerini de beraberinde getirmektedir. Hava trafik kontrolü, uçakların güvenli, verimli ve düzenli bir şekilde yönlendirilmesini sağlamak için havaalanları ve hava sahası içinde faaliyet gösteren kritik bir hizmettir. Ancak hava sahasındaki trafik yoğunluğu arttıkça, insan operatörlerin hata yapma olasılığı artmakta ve mevcut hava trafik yönetim sistemleri yetersiz kalabilmektedir. Bu noktada, hava trafik kontrolünde yapay zekâ teknolojilerinin uygulanması sektöre önemli bir yenilik sunmaktadır. Bu makale, yapay zekâ teknolojilerinin hava trafik kontrolünde nasıl kullanıldığını incelemektedir. Makine öğrenimi, derin öğrenme, insansız hava araçları (İHA) ve blok zinciri gibi teknolojilerin hava trafik kontrolünde sunduğu fırsatlar ele alınmakta ve bu teknolojilerin insan hatalarının azaltılması, verimliliğin artırılması ve karar alma süreçlerinin optimize edilmesindeki rolü tartışılmaktadır. Özellikle İHA'ların hava sahasına entegrasyonu ve bu sürecin yönetilmesinde yapay zekânın katkıları üzerinde durulmuştur. Ayrıca blockchain teknolojisinin veri güvenliği ve izlenebilirlik açısından faydaları değerlendirilmiştir.

Anahtar Kelimeler: Hava trafik kontrolü, yapay zeka, hava taşımacılığı

Introduction

The aviation industry is a vast sector that includes numerous conventional fields, holding a critical global position as a conduit between nations and performing a distinctive function in executing each flight (Ukwandu et al., 2022; Kabashkin et al., 2023). The contemporary air traffic management system revolves around air traffic controllers and pilots, and its human-centric design has significantly enhanced aviation safety. Nevertheless, the proliferation of flights and the diversification of aircraft utilising European airspace are pushing this system to its limitations (Ortner et al., 2022). With the rise in flight traffic, conventional air traffic management techniques cannot address present practical requirements (Sui et al., 2022). Congestion presents substantial issues, including diminished flight safety, elevated expenses, prolonged delays, increased emissions, and dwindling airspace resources, hence amplifying the necessity for advanced air traffic management systems (Ortner et al., 2022; Tang et al., 2022).

According to Zaoui et al. (2024), digital transformation will be crucial in the aviation industry. Creating computer systems capable of mimicking human intelligence (AI) is a significant technological step. According to Abdillah et al. (2024), AI is utilised in air traffic control to support many parts of the system. Companies in the aviation industry are creating a plethora of fresh, groundbreaking products and services by leveraging AI technology. Production lines, image identification for maintenance, demand forecasting using machine learning and numerous indicators, chatbots for simple consumer concerns, assistance with check-in requests, and flight information are all examples of areas that use AI. There is no shortage of evidence that AI is good for business and can revolutionise the airline sector and customer service. The aviation industry is seeing a rise in the interest in AI research and development from airports, aircraft, airlines, and manufacturers (Zaoui et al., 2024). Despite these advantages, the continual growth of air traffic poses substantial security risks to aviation networks, affecting the industry's ability to operate safely (Lu et al., 2023).

Kabashkin et al. (2023) note that computer science, particularly AI, plays a key role in air traffic management, which is facing rising complexity and requires advancements to assure aviation safety. Due to its complexity and criticality for multiple stakeholders, including passengers, airlines, regulators, and air traffic controllers, air traffic management has been extensively studied across several domains. The number of AI methods proposed and developed for air traffic management has increased dramatically in recent years (Tang et al., 2022).

The literature study acknowledges the necessity to rethink aviation education in light of the revolutionary effects of AI on the aviation industry. The best ways to incorporate AI into aviation programs responsibly and efficiently and the fundamental skills that AI users in the aviation industry must possess are still up for debate (Kabashkin et al., 2023). It is of clear importance that investments in the aviation systems of countries or organizations will add value to them in a short period of time (Kanat, 2023). The increasing intensity of air travel (Blasch. et al., 2019) once again emphasizes the importance of incorporating AI into air traffic control (Abdillah et al., 2024). By delving into questions like "What is the overview of AI in air traffic control?", "How can AI in air traffic control provide benefits?" and "What are the limitations arising from the use of AI in air traffic control?" this research hopes to fill a gap in the current literature on the topic and suggest avenues for further study.

Aviation Industry And Air Transportation

Cooperation among several people is essential in aviation for efficiency and safety (Ortner et al., 2022). The conventional sectors of the aviation industry can be better understood by first identifying them and then describing them. Airlines best exemplify the aviation sector. Commercial airlines use large planes to transport both people and commodities. The internal and international networks of significant airlines are extensive. Regional carriers can transfer Customers from smaller cities to big airline hubs. Charter flights can be scheduled according to your needs. Airline profits are mainly derived from ticket sales and cargo fees. Another vital part of the aviation industry is the production of aircraft. Boeing and Airbus are two of the major civil aircraft manufacturers. Bombardier and

Gulfstream are two business jet manufacturers catering to individual and corporate clients. Small piston-engine aircraft manufacturers cater to personal flying and flight training. Airports make up a third of the conventional industry. Commercial airports are utilised by both general aviation and airlines. Terminals, runways, air traffic control towers, navigational aids, and more are all taken care of by airport operators. A large airport is similar to a small city. Revenue is generated by fees collected from tenants, passengers, and airlines. Kabashkin et al. (2023) state that analysing the aviation business requires first identifying and comprehending these traditional industries. When it comes to reaching economic independence, the aviation sector is crucial. To make long-term investments in economies, we need reliable predictions of future air transport demand (Alam et al., 2024).

Air traffic management encompasses a wide array of intricate tasks to ensure air travel's safety and efficiency. Air traffic management seeks to optimise the utilization of various resources, including airspace, airfields, and runways, by resource users such as aircraft and airlines at any specific moment (Degas et al., 2022). The International Air Transport Association (IATA, 2023) said "In 2023, the global aviation industry is experiencing a robust recovery." In December 2023, it was stated that industry-wide paid passenger kilometres climbed by 25.3% compared to 2022. In 2023, air traffic attained 94.1% of the pre-pandemic levels observed in 2019. Seat-kilometers rose 24.1% year-over-year, reaching 94.4% of the pre-pandemic capacity 2019. The global passenger occupancy rate was 82.3%, just below the pre-pandemic level of 2019. Total domestic traffic surpassed pre-pandemic levels of 2019 by 3.9%. International traffic experienced a significant rebound in 2023, achieving 88.6% of pre-pandemic levels. (SHGM, 2023).

Air Traffic Control

A part of air traffic services, air traffic control works to keep planes from crashing into one another or into obstacles in the sky, and it also helps keep things running smoothly and safely (Ortner et al., 2022; Tang et al., 2022). According to SHGM (2024), Air Traffic Controllers are defined as “the professional group responsible for managing all phases of aircraft flights from one destination to another, primarily ensuring the safe execution of these flights, which entails maintaining the safe, orderly, and efficient flow of aircraft traffic in the air and at airports.”

It used to be that human air traffic controllers did these tasks. Maintaining the aircraft's safe flight path requires the controller to ascertain its location and altitude using the flight plan and the pilot's in-flight position report. Radars for primary and secondary monitoring were installed after 1945. Using the radar screen, controllers can see precisely where every plane in the radar wave coverage area is. But the system is getting overwhelmed by the ever-increasing number of flights. The FAA responded by implementing computer-based tools to aid controllers in performing certain air traffic control duties in the 1980s. Automation is used for air traffic control (Tang et al., 2022).

The air traffic management system includes air traffic control as one of its bigger components that connects with aircraft and satellites. Connected to the internet are data centres and ground networks, which are linked to air traffic control. Networks on the ground are responsible for managing components like air and satellite networks. Connectivity between aircraft and ground stations is crucial to the aviation system. In most cases, the responsibility of contacting an approaching aircraft lies with the ground station. An air traffic control centre and the link to auxiliary ground units are located at the ground station (Dave et al., 2022).

According to Kabashkin et al. (2023), air traffic controllers are responsible for directing the flow of aircraft safely by monitoring approach control facilities, route centres, or control towers. As air traffic increases, so does the data that air traffic controllers must process. Consequently, mental and physical health can be severely compromised by information overload and the stress it causes, leading to diminished cognitive performance and impaired decision-making abilities. The usage of airspace is still another obstacle. Airspace in Europe is segmented along national borders and into several regions. The air traffic controllers oversee specific sectors within each area. Surveillance systems use methods including primary and secondary surveillance radio detection and ranging to keep tabs on planes both in the air and on the ground. Tactical interventions and essential flight crew information are communicated directly via highly high-frequency and high-frequency radio (Ortner et al., 2022). More people are taking to the skies, which means more labour for air traffic controllers (Abdillah et al., 2024).

Regulating the flow of air traffic for flights presents a number of challenges for air traffic management. Unanticipated weather conditions were the biggest problem. Aircraft schedule slips are a direct result of this problem. There is also the possibility of flight conflicts, as the likelihood of accidents increases owing to increased air traffic density. Determining flight routes is one of the issues that must be carefully considered (Abdillah et al., 2024). Air traffic controllers can discover and resolve potential conflicts based on traffic flow. However, as traffic increases, so will the amount and frequency of disputes. This may increase the burden of air traffic controllers, potentially causing traffic flow limits and aircraft delays and jeopardizing flight safety. Sui et al. (2023) state that air traffic controllers will have to put in less work if decision-support systems can detect problems automatically and suggest ways to resolve them. Air traffic control benefits from advances in computer technology and AI (Tang et al., 2022).

Use Of Artificial Intelligence-Based Technology In Air Traffic Control

More and more people are pushing the aviation industry to use AI to boost productivity, security, and overall competitiveness. To revolutionize operations and tackle issues, prominent aviation organisations have demanded using AI (Kabashkin et al., 2023). AI is a relatively young field that is expanding rapidly thanks to advancements in IT. The fundamental idea is to program computers to mimic human cognitive processes and transfer them into the many ways conventional professional computers process data and run simulations (Tang et al., 2022). Computationally intelligent agents that can directly assist humans in their daily duties are the goal of AI, a field that explores and implements transdisciplinary principles (Ogunsina and DeLaurentis, 2022). A system is said to have AI if it can correctly understand data from outside sources, learn from it, and then adapt to new situations to accomplish predefined goals (Nikitas et al., 2020). This field studies and develops computer systems that can reason, perceive visually, recognise the voice, learn and the program automatically, make decisions, and translate between languages, all typically associated with human intelligence (Tselentis et al., 2023). AI is the subfield of computer science that studies how to make computers act more like the brain. Its primary function is to adequately resolve problems that conventional computational methods have failed to explain (Abduljabbar et al., 2019).

From 1940 to 1970, AI mostly focused on algorithms and research obstacles. From the 1970s through the 1990s, a plethora of new technologies emerged. These included statistical machine learning, computer vision and multimedia, and natural language processing. Engineers and researchers developed many AI concepts after the 90s to address problems in various fields. Computer vision, AR/VR, cloud computing, machine learning, predictive maintenance, big data and analytics, cloud computing, autonomous systems, and cloud computing are some of the new scientific innovations that AI has integrated into the industrial value chain (Zaoui et al., 2024). The present field of AI includes numerous sub-fields. Many of these subfields address difficulties linked to the understanding and abstraction of certain human behavioural features and patterns commonly regarded as markers of intelligence, as well as attempts to replicate the same behavioural patterns in machines. Recently, there has been an emphasis on developing AI methods to conduct various air and ground duties in air traffic management, mainly air traffic services, airspace management, air traffic flow management, and flight operations. These functions ensure that aeroplanes move safely and efficiently during all operation phases (Tang et al., 2022).

Recently, AI has found its way into two areas of the aviation industry, as reported by Kabashkin et al. (2023): aviation technology and operations and aviation education and training. Aviation education programs must be reformed to create two important competencies to incorporate AI into the industry.

There are two main goals in this area: first, to understand AI and its uses in aviation (NextTech), and second, to interact with AI systems (NextGen) effectively. As the aviation sector adopts innovative new technologies and adjusts to evolving needs, the term "NextGen" describes the upcoming generation of workers and experts who will be needed. Many new AI tools, such as machine learning, neural networks, NLP, and others, are becoming popular in the aviation sector, and the term "NextTech" describes these technologies (Kabashkin et al., 2023).

An essential tool for the development of innovative services and solutions, AI has been used for decades in air traffic management to improve the operational efficiency of air traffic and airspace (Abduljabbar et al., 2019; Zaoui et al., 2024; Xie et al., 2021). It offers unprecedented opportunities to enhance transportation sector performance. New AI methods show great promise for aviation technology's recent effective and speedy advancement (Tang et al., 2022). According to Kabashkin et al. (2023), the primary domains of AI in the aviation sector are the optimization and planning of flights, control of air traffic, enhancement of the passenger experience via chatbots and virtual assistants, and investigation of safety incidents and accidents. According to Abdillah et al. (2024), AI technology can assist with various elements of air traffic control, such as managing traffic flows, predicting abnormal flows, making traffic forecasts, improving air traffic controller situational awareness, and detecting and resolving conflicts. According to Abduljabbar et al. (2019), AI assists with technology, software/hardware, and implementation; it also helps with flight trip management, and airlines can save money on cancellations by using AI to predict weather and congestion.

The many benefits that AI can offer to air traffic control systems are highlighted by Abdillah et al. (2024). AI has the potential to significantly enhance air traffic control operations in several ways, including traffic flow prediction and management, airspace capacity optimisation, controller situational awareness, and the resolution of aircraft disputes. Ortner et al. (2022) created an AI-powered digital support system to identify air traffic issues by methodically examining data from aircraft surveillance systems. The outcome has enormous promise for accurate air traffic monitoring and the processing, classification, and prediction of conflicts in sequential flight data. This study offers a practical approach to incorporating explainable AI into AI-based air traffic management decision-support systems, which is intended to enhance the trustworthiness of these systems among human operators by making their reasoning more transparent and easier to understand (Xie et al., 2021).

According to use case results, big data analytics, autonomous intelligent systems, predictive analytics, machine learning, and robotics are the most recurring technologies. Zaoui et al. (2024) reported that aerospace companies are increasingly interested in integrating AI technologies. In addition, he discovered that businesses are driven to incorporate AI into their operational and industrial processes for various reasons. These include improving decision-making, enhancing security, saving time, reducing costs, improving efficiency, and enhancing customer satisfaction. Moreover, he discovered that AI has a positive effect on business performance. Al Radi et al. (2024) state that AI applications' primary domains include self-driving vehicles, robotic assistants, automated Unmanned Aerial Vehicles (UAVs), computer vision, deep learning, robotics, and expert system techniques. While this is not an exhaustive list, we have covered some of the most prevalent uses of AI in the transportation industry, including UAVs, blockchain, the Internet of Things (IoT), machine learning, deep learning, and computer vision systems.

Unmanned Aerial Vehicles (UAV)

UAVs, frequently called drones (Tsao et al., 2022), are autonomous aircraft capable of flight without pilots. They represent a significant advancement in air transportation, integrating AI and wireless technologies into aviation (Nikitas et al., 2020). Currently, UAVs commonly employ AI methodologies. The primary components of a UAV include an airframe, a propulsion system, and a navigation system. Their scope encompasses many aircraft design configurations and ancillary tools that facilitate multiple applications (Al Radi et al., 2024). Due to recent technological advancements, UAVs are commonly employed in civil aviation and various other industries. They possess excellent mobility, cost efficiency, flexible deployment alternatives, and advanced technical frameworks (Yetgin and Baştuğ, 2023).

UAVs represent an emerging technology extensively utilised for package delivery, remote sensing, disaster management, search and rescue operations, traffic surveillance and management, innovative city initiatives, firefighting, agricultural applications, wind turbine and power line inspections (Allouch et al., 2021), drug delivery, humanitarian assistance, first aid, organ transplantation, and cargo transportation (Yetgin and Baştuğ, 2023), as well as remote monitoring of weather, traffic, and personnel, military surveillance, network relays, construction, and goods delivery (Tsao et al., 2022), alongside surveillance, traffic monitoring, agriculture, firefighting, videography, industrial inspection, and civil infrastructure monitoring (Al Radi et al., 2024). UAVs have widespread use in various fields, including intelligence gathering, reconnaissance, border patrol, target detection and designation, counter-insurgency, strikes, law enforcement, environmental monitoring, surveying, geospatial operations, and remote sensing. Aerial mapping, meteorology, traffic, movement of goods, reporting of accidents, emergency search and rescue, wireless coverage, cloud computing, communication relays, and weather monitoring are all made easier with this technology (Nikitas et al., 2020).

Developing a traffic control system for the heavily populated airspace, UAVs use is gaining significance (Keith et al., 2023). Monitoring, controlling, and automating the management of UAV flights will be essential to ensure safe flying and secure operation of UAVs as their applications grow ubiquitous (Allouch et al., 2021). The risk of manned aircraft accidents increases, and operations are disrupted when flights are too close to airports. People living on the ground have also been put at risk by unapproved aircraft in densely populated urban areas. Flying near nuclear power facilities or other prohibited areas is also risky. Last but not least, plane crashes and pilot mistakes can cause harm to people and their possessions. The coexistence of manned and unmanned aircraft in the airspace is critical to the safe UAV operational concept. Contrary to unmanned aerial vehicle automation, conventional approaches to air traffic control rely heavily on human intervention. Furthermore, the anticipated massive volume of operations is beyond the capabilities of current air traffic control systems. New control systems are required to ensure the safe operation of UAVs and other aircraft while allowing their efficient simultaneous operation. Unmanned traffic management systems are the name of these new systems (Carramiñana et al., 2021). Building this traffic management system with the triad of availability, integrity, and confidentiality in mind is crucial. According to Keith et al. (2023), an autonomous traffic management system is urgently needed to ensure the safe and effective management of UAV traffic in the airspace since the number of UAVs is projected to grow in the future.

Blockchain Technology

Blockchain technology is a crucial facilitator for reliable and open data transactions to take place. The distributed ledger, known as blockchain, ensures data accuracy (Kim et al., 2021). Not only are blockchains decentralised, but they also have unique properties like transparency, immutability, and irreversibility. It is impossible to alter or fabricate a block once it has been uploaded to the blockchain (Astarita et al., 2019). Fast and decentralised transaction processing is possible with a blockchain system. Blocks, which include transactions in a blockchain system, are validated and added to earlier blocks. No one entity has any say over the verification process because it is entirely decentralised. The immutability of data is a crucial characteristic of blockchain systems. The immutability of approved blockchain transactions results from the blocks' interconnected nature (Karger et al., 2021). Some significant advantages of blockchain technology for cybersecurity include its immutability and accountability (Keith et al., 2023). A popular method for system security, it offers auditable decentralised security without a trusted third party. It is popular, but it requires significant computational resources to process and store the ever-expanding chain of security blocks (Blasch et al., 2019).

Air traffic management challenges include safeguarding aviation from cyber-attacks, reducing aircraft delays or cancellations caused by overcapacity, and more appropriately allocating capacity in response to rising traffic demand. To make things safer, a lot of new systems and procedures have been put in place recently. Although airports benefit from centrally networked systems for managing several parties, more operators are at risk when these systems are compromised. A decentralized database can present opportunities to enhance information security compared to conventional centralised systems. Because of this, researchers have made great strides toward creating a framework for decentralised air traffic management. Air capacity can be more equitably distributed through a blockchain-based system, relieving strain caused by rising passenger volumes. Academic investigations into blockchain architecture, algorithms, and capacities are continuing, focusing on the aviation industry. Potential applications for blockchain technology include payment processing, identity management, customs clearance, air traffic control, monitoring, and maintenance due to its immutability, security, and lack of intermediaries. Some advantages of using blockchain technology in the aviation industry include improved air traffic control, digital administration, and track and trace capabilities (Li et al., 2021).

The combination of distributed systems and blockchain technology can make UAV operations safer, more secure, and more flexible, according to Allouch et al. (2021). Blockchain's decentralised nature and traceability make it a good fit for improving privacy and security. Li et al. (2021) state that to resolve traceability concerns, the solution lies in blockchain supply chain management in the context of air logistics. As a result, it has the potential to be a helpful technology that can provide handlers with greater control over luggage and cargo by correctly tracking its whereabouts in real-time from loading to unloading. Throughput time optimisation, automation of the transfer procedure, and efficiency improvement in baggage handling are all possible with a permissioned blockchain-based tracking system. As a result of its immutability and transparency, blockchain technology can also give clear records of aircraft parts' tracking status. Implementing blockchain technology into building "smart airports" could be advantageous. An e-passport that stores biometric data could allow passengers to be automatically identified. With further digitisation, an improved and more streamlined experience for travellers is possible (Li et al., 2021).

Internet of Things (IoT)

According to Shah et al. (2022), the term "Internet of Things" (IoT) describes a network of interconnected computing devices that may gather and transmit data to make smart judgments. The expansion of M2M communication over the past decade has brought about a paradigm shift in communication, allowing for always-on device connectivity and the capacity for devices to converse amongst themselves without any human input whatsoever. M2M communication has progressed over the years to become acknowledged as the technology that paves the way for the real-world implementation of the IoT. IoT is a system of interconnected computing devices that can sense its environment and exchange data wirelessly or through a network without a human operator or a computer program. IoT is seen as the natural progression of our current grid networks. Communication between machines has progressed to the Internet of Things. The IoT aims to link many physical items together through IP-based solutions so that they may exchange data and instructions with one another and other devices online (Kimani et al., 2019). Connecting physical and virtual items is central to the IoT, which aims to make available many services that would be inconceivable without it. New devices can be produced and connected to the ubiquitous network thanks to the motivation from the growth of the IoT in information communication technologies (Samir Labib et al., 2019).

Many sensors and actuators make up an IoT network. Robot or drone operation controls in innovative industries produce massive amounts of data that necessitate a high degree of dependability. IoT networks built on a blockchain architecture are very trustworthy. Extremely high data security is guaranteed by the shared ledger and open data validation between users (Kim et al., 2021). With its one-of-a-kind characteristics, blockchain technology offers a potential answer to the IoT's security issues. It enhances IoT systems regarding security, decentralisation, adaptability, and identity management. Due to its decentralised design, problems with interoperability, scalability, and flexibility are inherent in the present IoT deployment. Blockchain can eliminate decentralised traffic flows and single points of failure by providing a safe platform for IoT networks (Shah et al., 2022).

An era of widespread automation is predicted to be ushered in by the smooth connection of gadgets with the IoT. Smart grids, homes, transportation, environments, and cities are just a few new frontiers where the IoT is an indispensable tool (Kimani et al., 2019). According to Shah et al. (2022), the IoT shows that it can turn the real world into a massive data system.

Machine Learning

A subfield of AI, machine learning relies on statistical models to generate forecasts (Pérez-Castán et al., 2022). Despite the challenges, well-timed predictions have the potential to impact choices significantly. Predictions about scheduling, resource allocation, production decisions, and output levels are all affected by forecasts, which is why they are crucial to managers. For accurate forecasting, machine learning is a great tool to have on hand. According to Alam et al. (2024), even a little increase in the accuracy of forecasts can result in substantial advantages. Modern data availability has given birth to the AI subfield known as machine learning. Instead of teaching computers everything, machine learning involves programming them to mimic brain functions. It allows computers to access large amounts of data, which they then use to solve complicated issues by extracting relevant aspects (Abduljabbar et al., 2019).

More automation, along with the use of AI and machine learning capabilities, is required to accommodate the expected increase in conventional air traffic and operations involving unmanned aircraft systems, especially in low-altitude airspace (Xie et al., 2021). More automation and AI and machine learning capabilities are required to accommodate the expected increase in conventional air traffic and operations involving unmanned aircraft systems, especially in low-altitude airspace. can be utilised in air traffic control to enable systems to learn from data and enhance their performance over time (Abdillah et al., 2024). Most accidents or occurrences result from a confluence of interacting elements rather than a singular cause. Machine learning models can effectively classify accident reports in the aviation setting, provided they receive sufficient and suitable training (Ziakkas and Pechlivanis, 2023). Aviation is a sector particularly susceptible to applying AI techniques owing to the substantial volume of available data. Recent applications of machine learning techniques include trajectory prediction, airspace performance assessment, and atmospheric modelling. Machine learning approaches are utilised for conflict identification in air traffic control (Pérez-Castán et al., 2022). Machine learning and AI have a huge impact on air traffic management and are absolutely necessary for it. Machine learning and AI have many potential uses, such as in data analysis, anomaly identification, and forecasting (Abdillah et al., 2024).

Deep Learning

Deep learning is a neural network that continuously adapts to novel situations using data-driven learning. It consists of three layers: input, hidden, and output. Always remember that there can be precisely one input and output layer. An infinite number of hidden layers is possible, while the actual number might vary. A layer's depth is defined by its arrangement of layers, and the number of neuron-like cells defines the width it may include (Ortner et al., 2022). Deep learning is an advanced kind of AI that aims to extract features from organized and unstructured data, particularly useful for classification and regression issues. Unstructured text analysis, message decoding, and commonality recognition are all tasks at which deep learning excels. Deep learning effectively addresses intricate issues that are typically challenging for conventional machine learning methods, including the recognition and realistic reproduction of diverse data types such as text, images, audio, and video, applicable across various contexts and technical issues (Zaoui et al., 2024). The intricate mechanisms analogous to brain operations and the vast data volume may account for the efficacy of deep learning. Conventional machine learning methods exhibit satisfactory performance that varies with the volume of data available. Nonetheless, the effectiveness of deep learning algorithms markedly improves with substantial data volumes (Yazici et al., 2023). Deep learning, a subset of AI and machine learning, is a biologically inspired programming paradigm designed to enhance automation and autonomously execute analytical and physical activities (Ortner et al., 2022). Deep learning has been utilised across various domains, including aviation, transportation, industry, and medicine. In aviation, deep learning algorithms enhance efficiency in analysing intricate data, including photos and videos, to identify anomalies or damage to cargo (Zaoui et al., 2024). Deep learning relies less on manually generated features, as it autonomously extracts features through its internal processes and facilitates end-to-end learning, necessitating reduced domain expertise. This characteristic renders them appealing for extensive implementations (Yazici et al., 2023).

Cyber Security

Despite the fact that air traffic management-cyber physical systems are now more efficient and effective thanks to AI and other information network technologies, the safety of these systems is severely impaired owing to a plethora of information network vulnerabilities. As a result, to achieve comprehensive information security assurance of networked air traffic management, it is necessary to conduct security risk assessments and vulnerability assessments based on cyber-physical integration, set up a systematic assurance system, and implement the findings (Lu et al., 2023). If an attacker gains access to permission or data through cyber-attacks and physically targets the air traffic control cyber-physical system, it could lead to significant consequences (Wu et al., 2022).

Ensuring aviation cybersecurity is vital as more devices and systems are digital and networked, with several services and conversations occurring wirelessly. Nonetheless, the wireless aspect of communications may be susceptible to malicious attacks. Instances of communication-related assaults encompass those aimed at communication signals. GPS spoofing, signal jamming and eavesdropping, jamming assaults, single-tone frequency attacks, and navigation modification attacks are all examples of attacks connected to navigation. Attacks pertaining to surveillance encompass unauthorized or unlawful monitoring of aircraft and their movements as well as signal interference, alteration, and deletion (Dave et al., 2022).

Cybersecurity risk management is managing the risks associated with running and using information systems. However, the hazards to these systems are getting more intricate as information systems get more linked and complicated. The secure operation of air traffic control depends on robust cyber defences. Air traffic management systems are vulnerable to new security threats due to the growing reliance on onboard platforms for integrated electrical, energy, positioning, communications, and satellite systems (Bernsmed et al., 2022). Core services in most countries are now integrated into cyberspace networks due to the growing usage of technology. The allure and strategic use of cyberspace are thus greatly enhanced (Kimani et al., 2019).

Flight safety is in jeopardy due to the possibility of accidental interception, unauthorised access to, or manipulation of data pertaining to air traffic management systems, which is crucial to aviation safety. To guarantee the security of air traffic management systems and human lives, it is essential to meet security requirements that protect information from unauthorised disclosure, maintain its integrity, and make sure it is available when needed. Understanding and mitigating cybersecurity threats in air traffic management systems is crucial for their long-term viability and each system's design, implementation, and operation (Bernsmed et al., 2022).

According to Bernsmed et al. (2022), the primary goal of air traffic management has consistently been and will continue to be safety. As confirmed by Ukwandu et al. (2022), the primary objective of cybercriminals targeting the aviation industry is to observe, penetrate, and obstruct the capabilities of other countries. Additionally, they seek to acquire intellectual property and intelligence to enhance their aviation capabilities. The sheer amount of air travel only heightens the difficulty of guaranteeing aviation cybersecurity. Cybercriminals are showing a growing interest in the aviation industry due to its increasing reliance on wireless technologies and digitisation. To illustrate the point, malicious actors can take advantage of security holes in the many interconnected devices and their code and overall design (Dave et al., 2022).

Conclusion And Recommendations

There are two primary areas where AI is being used in the aviation industry: first, in aviation systems, and second, in aviation education. Thus, it is necessary to have theoretical understanding of important AI principles and practical experience with AI tool implementation and management to create suitable AI capabilities. In addition, aviation experts need to be cognizant of the social, legal, and ethical consequences of depending on AI technology for vital transportation infrastructure and operations (Kabashkin et al., 2023). Further automation of traffic management systems is necessary due to the ever-increasing quantity of aircraft and levels of automation. Automation has the potential to relieve air traffic managers of some responsibilities, freeing them up to concentrate on matters about the safety of the airspace. Hence, much study is still required to guarantee that AI-powered automated systems can fulfil aviation systems' stringent security and safety criteria (Tang et al., 2022).

Standards must also change to ensure that autonomous technologies are used safely and regulated. Innovation and caution must be balanced moving ahead. The ethical application of AI in aviation is the only way to bring about a new era of safety, sustainability, and passenger-centricity. AI has enormous potential in the aviation business but needs quick investment and careful planning to reach its full potential. The aviation community is expected to collaborate to develop an AI flight plan to benefit all parties involved (Kabashkin et al., 2023). Like any other, the aviation sector always looks for ways to serve its customers better and go the extra mile. There will be ongoing cybersecurity concerns caused by the mix of digital transformation, connectivity, segmentation, and the industry's complexity, all resulting from increased worldwide travel. The aviation industry faces severe operational integrity challenges, but there is also clear potential to develop AI-based cybersecurity solutions. There is a wealth of possibilities in the avionics infrastructure protection measures since the automation of these systems is on the rise, leading to more attack surfaces (Ukwandu et al., 2022).

Air traffic control centres should start integrating AI-based automation systems into their existing systems. AI systems, especially those supported by machine learning and big data analytics, can significantly predict traffic density and detect potential conflicts in advance. In transitioning to new systems that work with AI technologies, comprehensive training programs should be organised for personnel to adapt to these technologies. Cooperating with AI will enable human operators to make more accurate and faster decisions.

More resources should be allocated to R&D on AI and other advanced technologies used in air traffic control. Governments should incentivise R&D activities and support projects in collaboration with the private sector to support innovation in the aviation sector. Large amounts of data are required for AI technologies to function correctly. Governments should develop policies that encourage secure data sharing and ensure data privacy. They should also take stricter measures to protect AI-enabled systems against cybersecurity threats.

More scientific research should be conducted on AI-enabled air traffic control systems. Academics should conduct extensive studies on the performance and reliability of these technologies and their impact on the human factor.

The effective use of AI-based solutions in air traffic control has the potential to increase the safety and efficiency of airspace operations and minimise human errors. In this context, it is suggested that AI technologies should be adopted more widely in air traffic control in the future, and international standards should be established in this field.

Finally, Kabashkin et al. (2023, p.29) make the following statement on AI in the aviation industry: "The future lies not in choosing between human expertise and AI, but in organising harmonious cooperation between the two." To achieve this equilibrium, aviation professionals must undergo continuous training and upskilling.

References

Abdillah, R. E., Moenaf, H., Rasyid, L. F., Achmad, S., & Sutoyo, R. (2024). Implementation of Artificial Intelligence on Air Traffic Control-A Systematic Literature Review. (s. 1-7). 18th International Conference on Ubiquitous Information Management and Communication (IMCOM) IEEE.

Abduljabbar, R., Dia, H., Liyanage, S., & Bagloee, S. A. (2019). Applications of artificial intelligence in transport: An overview. Sustainability, 11(189), 1-24.

Al Radi, M., AlMallahi, M. N., Al-Sumaiti, A. S., Semeraro, C., Abdelkareem, M. A., & Olabi, A. G. (2024). Progress in artificial intelligence-based visual servoing of autonomous unmanned aerial vehicles (UAVs). International Journal of Thermofluids, 21(100590), 1-15.

Alam, M. S., Deb, J. B., Al Amin, A., & Chowdhury, S. (2024). An artificial neural network for predicting air traffic demand based on socio-economic parameters. Decision Analytics Journal, 10(100382), 1-13.

Allouch, A., Cheikhrouhou, O., Koub, A., Toumi, K., Khalgui, M., & Nguyen Gia, T. (2021). UTM-Chain: Blockchain-Based Secure Unmanned Traffic Management for Internet of Drones. Sensors, 21(3049), 1-20.

Astarita, V., Giofrè, V. P., Mirabelli, G., & Solina, V. (2019). A review of blockchain-based systems in transportation. Information, 11(1), 1-24.

Bernsmed, K., Bour, G., Lundgren, M., & Bergström, E. (2022). An evaluation of practitioners' perceptions of a security risk assessment methodology in air traffic management projects. Journal of Air Transport Management, 102(102223), 1-18.

Blasch, E., Xu, R., Chen, Y., Chen, G., & Shen, D. (2019). Blockchain methods for trusted avionics systems . In 2019 IEEE National Aerospace and Electronics Conference (NAECON) (pp. 192-199). IEEE.

Carramiñana, D., Campaña, I., Bergesio, L., Bernardos, A., & Besada, J. (2021). Sensors and Communication Simulation for Unmanned Traffic Management. Sensors, 21(927), 1-29.

Dave, G., Choudhary, G., Sihag, V., You, I., & Choo, K. K. (2022). Cyber security challenges in aviation communication, navigation, and surveillance. Computers & Security, 112(102516), 1-14.

Degas, A., Islam, M., Hurter, C., Barua, S., Rahman, H., Poudel, M., . . . Aricó, P. (2022). A Survey on Artificial Intelligence (AI) and eXplainable AI in Air Traffic Management: Current Trends and Development with Futuure Research Trajectory. Appl. Sci., 12(1295), 1-47.

IATA. (2023). Air Passenger Market Analysis. 1-5. https://www.iata.org/en/iata-repository/publications/economic-reports/air-passenger-market-analysis-december-2023/ adresinden alındı

Kabashkin, I., Misnevs, B., & Zervina, O. (2023). Artificial Intelligence in Aviation: New Professionals for New Technologies. Applied Sciences, 13(11660), 1-33.

Kanat, Ö. Ö. (2023). The Significance of Unmanned Aerial Vehicles (UAVs) in Strategic Contexts. Anadolu Strateji Dergisi, 5(2), 75-87.

Karger, E., Jagals, M., & Ahlemann, F. (2021). Blockchain for Smart Mobility—Literature Review and Future Research Agenda. Sustainability, 13(13268), 1-32.

Keith, A., Sangarapillai, T., Almehmadi, A., & El-Khatib, K. (2023). A Blockchain-Powered Traffic Management System for Unmanned Aerial Vehicles. Applied Sciences, 13(10950), 1-27.

Kim, J.-H., Lee, S., & Hong, S. (2021). Autonomous Operation Control of IoT Blockchain Networks. Electronics, 10(204), 1-16.

Kimani, K., Oduol, V., & Langat, K. (2019). Cyber security challenges for IoT-based smart grid networks. International journal of critical infrastructure protection, 25, 36-49.

Li, X., Lai, P. L., Yang, C. C., & Yuen, K. F. (2021). Determinants of blockchain adoption in the aviation industry: Empirical evidence from Korea. Journal of Air Transport Management, 97(102139), 1-11.

Lu, X., Dong, R., Wang, Q., & Zhang, L. (2023). Information Security Architecture Design for Cyber-Physical Integration System of Air Traffic Management. Electronics , 12(1665), 1-29.

Nikitas, A., Michalakopoulou, K., Njoya, E. T., & Karampatzakis, D. (2020). Artificial intelligence, transport and the smart city: Definitions and dimensions of a new mobility era. Sustainability, 12(2789), 1-19.

Ogunsina, K., & DeLaurentis, D. (2022). Enabling integration and interaction for decentralized artificial intelligence in airline disruption management. Engineering Applications of Artificial Intelligence, 109(104600), 1-18.

Ortner, P., Steinhöfler, R., Leitgeb, E., & Flühr, H. (2022). Augmented Air Traffic Control System—Artificial Intelligence as Digital Assistance System to Predict Air Traffic Conflicts. AI, 3, 623–644.

Pérez-Castán, J., Pérez Sanz, L., Fernández-Castellano, M., Radiši´c, T., Samardži´c, K., & Tukari´c, I. (2022). Learning Assurance Analysis for Further Certification Process of Machine Learning Techniques: Case-Study Air Traffic Conflict Detection Predictor. Sensors , 22(7680), 1-14.

Samir Labib, N., Danoy, G., Musial, J., Brust, M. R., & Bouvry, P. (2019). Internet of unmanned aerial vehicles—A multilayer low-altitude airspace model for distributed UAV traffic management. Sensors, 19(4779), 1-22.

Shah, Z., Ullah, I., Li, H., Levula, A., & Khurshid, K. (2022). Blockchain Based Solutions to Mitigate Distributed Denial of Service (DDoS) Attacks in the Internet of Things (IoT): A Survey. Sensors, 22(1094), 1-26.

SHGM. (2023). Sivil Havacılık Genel Müdürlüğü Faaliyet Raporu. 1-122. https://web.shgm.gov.tr/documents/sivilhavacilik/files/kurumsal/faaliyet/2023.pdf adresinden alındı

SHGM. (2024). https://web.shgm.gov.tr/tr/havacilik-personeli/2129-hava adresinden alındı

Sui, D., Liu, K., & Li, Q. (2022). Dynamic Prediction of Air Traffic Situation in Large-Scale Airspace. Aerospace, 9(568), 1-15.

Sui, D., Ma, C., & Wei, C. (2023). Tactical Conflict Solver Assisting Air Traffic Controllers Using Deep Reinforcement Learning. Aerospace, 10(182), 1-24.

Tang, J., Liu, G., & Pan, Q. (2022). Review on artificial intelligence techniques for improving representative air traffic management capability. Journal of Systems Engineering and Electronics, 33(5), 1123-1134.

Tsao, K. Y., Girdler, T., & Vassilakis, V. G. (2022). A survey of cyber security threats and solutions for UAV communications and flying ad-hoc networks. Ad Hoc Networks, 133(102894), 1-39.

Tselentis, D. I., Papadimitriou, E., & van Gelder, P. (2023). The usefulness of artificial intelligence for safety assessment of different transport modes. Accident Analysis & Prevention, 186(107034), 1-10.

Ukwandu, E., Ben-Farah, M., Hindy, H., Bures, M., Atkinson, R., Tachtatzis, C., . . . Bellekens, X. (2022). Cyber-Security Challenges in Aviation Industry: A Review of Current and Future Trends. Information, 13(146), 1-22.

Wu, Z., Dong, R., & Wang, P. (2022). Research on Game Theory of Air Traffic Management Cyber Physical System Security. Aerospace, 9(397), 1-19.

Xie, Y., Pongsakornsathien, N., Gardi, A., & Sabatini, R. (2021). Explanation of Machine-Learning Solutions in Air-Traffic Management. Aerospace, 8(224), 1-25.

Yazici, İ., Shayea, I., & Din, J. (2023). A survey of applications of artificial intelligence and machine learning in future mobile networks-enabled systems. Engineering Science and Technology, an International Journal, 44(101455), 1-40.

Yetgin, M. A., & Baştuğ, M. (2023). Sivil Havacılık Şirketlerinin İnsansız Hava Aracı Stratejileri. Türkiye İnsansız Hava Araçları Dergisi, 5(2), 72-80.

Zaoui, A., Tchuente, D., Wamba, S. F., & Kamsu-Foguem, B. (2024). Impact of artificial intelligence on aeronautics: An industry-wide review. Journal of Engineering and Technology Management, 71(101800), 1-19.

Ziakkas, D., & Pechlivanis, K. (2023). Artificial intelligence applications in aviation accident classification: A preliminary exploratory study. Decision Analytics Journal, 9(100358), 1-14.