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INCREASING THE EFFICIENCY AND CAPACITY OF AIRPORT SECURITY CHECKING BY ARTIFICIAL INTELLIGENCE

Summary. Airports face significant pressure to meet various interconnected performance objectives, including ensuring security and capacity. This aspect of airport operations is crucial regardless of the airport's size. The solution to the security dilemma is the implementation of new technologies combined with the use of artificial intelligence (AI). Artificial narrow intelligence (ANI), mostly based on machine learning, is being introduced in most areas of security inspections. This usually starts with personal identification with biometric verification, followed by passenger profiling, where ANI is also already being applied. The effective security screening of people, luggage, and shipments relies on imaging and volume detection technologies using electromagnetic radiation spectra. ANI with machine learning is beginning to be used in imaging technologies for image analysis, in metal detectors for signal analysis of wanted contraband, in classical spectrometric trace particle detectors, and in optical spectrometric methods for the spectral detection of wanted substances. At the same time, computerized scanner cooperation with occupant profiling is beginning to be promoted as part of the risk-based approach. This paper analyses the potential for introducing advanced AI into airport security processes and their potential impact on the capacity of a connected queuing system according to Jackson Networks. This study presents a vision of the implementation of multimodal AI into security screening processes. This AI would gather detailed data from individual scanners operating on different physical principles and synthesize and compare comprehensive information about detected suspicious objects with databases of harmless and dangerous items. Subsequently, it would decide on the next steps, potentially considering the passenger's security profile. This paper demonstrates that implementing AI into airport security screening processes can significantly improve the efficiency and reliability of these processes. AI can help reduce the time spent by individual passengers at security checkpoints while increasing the reliability of detection, contributing to the overall improvement of the airport security screening process.

1. INTRODUCTION

As the annual number of air transport passengers continues to rise [1], the need for smooth airport operations becomes increasingly pressing. Globally, the annual count of air passengers, including a small cargo portion, continued its upward trajectory, reaching 4.5 billion journeys [2]. This surge poses challenges for ensuring the security and facilitation of air cargo and mail. Therefore, it is imperative to uphold or enhance all facets of air cargo safety, as well as security and safety measures for air passenger transport [2]. Furthermore, as technology continues to advance, safeguarding the population against

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criminal acts is becoming increasingly challenging [3]. This necessitates the continual development and implementation of innovative technological solutions. Enhancing airport efficiency and elevating passenger service quality stand out as imperative objectives. Among technological trends, artificial intelligence is prominently featured for its role in predictive analytics and enhancing overall airport operational performance [4]. At its essence, AI embodies the capacity of a computer to react to specific stimuli with a semblance of human intelligence [5, 6]. Throughout the 21st century, artificial intelligence (AI) has emerged as a crucial area of study across numerous disciplines, such as engineering, science, education, medicine, business, accounting, finance, marketing, economics, stock market analysis, and law [7, 8].

Following the terrorist attacks in the last 35 years, research has expanded across various domains within the field of passenger security checking [9, 10] to enhance the capability to identify potential threats. Artificial intelligence can be the best answer to the modern requirements of airports while maintaining sufficient capacity and comfort.

One potential solution to enhance the efficiency of the process could involve integrating an AI-tailored model for passenger security checking. Dedicated software could aid airport security teams in pinpointing particular behaviors that warrant further scrutiny, thus enabling more targeted and effective security checks on individuals. Most importantly, AI has the potential to make individual passenger and baggage scanning technologies faster and more efficient, both independently and when working together.

2. CURRENT SECURITY CHECKS

From a security perspective, the arrival of passengers at the airport and their movement in the check-in halls still falls within the area of soft target protection. The actual air transport of passengers already falls under the protection of hard, well-protected targets. The beginning of this protection can be considered the identification at the self-service counter or manned counter, accompanied by the check-in and surrender of large (checked-in) baggage in order to obtain a boarding pass. This part of the check-in process is followed by a security check of passengers and their cabin baggage and, separately, a security check of their checked-in baggage bound for the hold.

There are considerable differences in the level of data exchange between the point of identification and the point of security screening of passengers and their baggage by country and flight direction. Passengers cannot fail to notice that in an EU country, when flying within the Schengen area, the exchange of information between these two points is usually zero, although the foreign police have access to police databases. This means that databases on the passenger and some other forms of passenger profiling are not standard in these security searches of people and their luggage.

Two types of profiling fall under the general term “passenger profiling”: data-based passenger profiling (including profiling of past passenger behavior) and behavioral passenger profiling (analysis of their current, in-the-moment behavior). Data-based passenger profiling is the basis for risk-based screening and is d by airports in the USA, for example. Well-known Israeli airlines are active in behavioral passenger profiling. The results of this type of profiling could be effectively used for risk-based passenger screening. Higher-risk passengers should be screened more thoroughly and vice versa.

Data-based passenger profiling, including profiling of past passenger behavior, has been highly automated since its inception. The use of police databases, in the form of encrypted data, to assess the level and type of riskiness associated with a given passenger is proposed. Similarly, the exchange of passenger data between airlines is proposed. AI could also use other data, but the use of passenger data tends to be in breach of General Data Protection Regulation (GDPR), especially in EU countries. The introduction of AI in this area also faces political resistance, as it is assumed that AI would start to assess the riskiness of passengers on the basis of faith (atheism), race, gender, age, etc.

Effective security screening of people, luggage, and shipments relies on imaging and volume detection technologies using the electromagnetic radiation spectrum. The usable spectroscopy ranges from the X-ray to the terahertz region. These technologies are complemented by the detection of trace explosive particles. Metal detectors are widely used for the security screening of persons. Due to the need to detect non-metallic items, the screening of persons is now extended by whole-body imaging scanners operating in the millimeter and terahertz wave bands (also backscatter X-rays outside the EU). For baggage screening, either dual-energy (multi-energy) multi-view X-ray systems or CT X-ray systems operating without conveyor belt stopping are being introduced. After many years, the introduction of detection of liquid explosives and their precursors is on the horizon. Artificial Narrow Intelligence (ANI) with machine learning is beginning to be used in imaging technologies for image analysis, in metal detectors for signal analysis of the contraband of interest, in conventional spectrometric trace particle detectors, and in optical spectrometric methods for spectral detection of the substance of interest. At the same time, the computerized interaction of scanners with passenger profiling is beginning to be promoted as part of the risk-based approach. More important, however, is the collaboration between the different physical principles of AI detection. Such AI, which can be described as multimodal AI, would reduce waiting times while increasing the reliability of security checks.

3. METHODOLOGY

For modern security inspection, we cannot use simpler models, such as the M/M/1 queue model, whose relationships can be easily expressed by equations. This model assumes a single server, but modern security inspections are multi-stage. Far from all passengers or their luggage are screened at higher levels. Since this system has interconnected queues, it is appropriate to use Jackson networks. In this paper, the necessary variables will be denoted as follows:

λ, the average passenger's arrival rate;

μ, the average screening service rate;

ρ, utilization factor: $\rho=\mu / \lambda$. This represents the fraction of time the server is busy;

L, average number of passengers in the system;

L^Q, average number of passengers in the queue;

L^C, average number of passengers in the checking (screening) service;

W, average time spent in the system (W_i);

W^Q, average waiting time in the queue;

W^C, average time spent in the screening service.

Assume that arrivals are external and follow a Poisson probability distribution and that service times are exponentially distributed. In Jackson networks, each security inspection stage is represented by node i. Each node i is described by relevant quantities such as the arrival rate λ_i, service rate μ, utilization ρ_i, average number of passengers in the system of the node (L_i), average time in the system (W_i), etc. Assuming that the conditions for a Jackson network are met, the total average time spent by a passenger across all nodes can be computed by summing the average time spent at each node:

$$W_{total} = \sum_{i=0}^{n} W_i, \tag{1}$$

where W_i is the average time a job spends at node i, calculated as:

$$W_i = \frac{1}{\mu_i\,(1-\rho_i)}, \tag{2}$$

with $\rho_i = \frac{\lambda_i}{\mu_i}$ being the utilization at node i, μ_i being the service rate at node i, and λ_i being the effective arrival rate to node i.

The effective arrival rate λ_i for each node can be determined using the following traffic equation:

$$\lambda_i = \lambda^e{}_i + \textstyle\sum_i \lambda_j\, P_{ji}, \tag{3}$$

where $\lambda^e{}_i$ is the external arrival rate to node i, and P_{ji} is the probability that a job completed at node j will require service at node i next.

It is desirable to reduce W_{total} while at least maintaining (but preferably increasing) the reliability of security searches and, if possible, not increasing the required number of security staff. The following hypothesis is analyzed in this paper: the introduction of not only ANI but also multimodal AI in airport security systems will reduce the total average time spent by a passenger across all nodes (W_{total}) while maintaining or increasing the reliability of security checks.

4. AI CAPABILITIES FOR PASSENGER IDENTIFICATION AND PROFILING

In a time where efficiency and customer satisfaction reign supreme, airports worldwide are seeking innovative solutions to elevate the passenger experience. Among these advancements, artificial intelligence (AI) has emerged as a pivotal force, poised to revolutionize how airports assist passengers at every stage of their journey, spanning from trip booking to their arrival at their destination [11].

4.1. AI and passenger identification

A crucial measure at airport security checkpoints is to verify a passenger's identity when passing through. Traditional airport security systems relied heavily on manual processes and human judgment, which were often time-consuming and susceptible to errors [10]. Passenger identification and validation are key measures in protecting civil aviation from illegal acts.

The use of AI in the biometric verification of passenger identity is spreading rapidly and slowly becoming standard. During the initial phase of its integration into airport security, AI played a pivotal role in luggage screening. Utilizing AI algorithms, X-ray images of baggage were scrutinized to detect prohibited items like weapons and explosives. Additionally, AI was employed for access control to authenticate the identities of individuals entering secure airport zones. This was achieved through biometric systems, including facial recognition and fingerprint scans. Biometric screening, which leverages unique physical characteristics such as fingerprints, facial features, and iris patterns, is increasingly being embraced in airports to bolster security and streamline passenger verification. Unlike conventional methods like ID cards or boarding passes, which are susceptible to loss or forgery, biometric screening is lauded for its reliability. By offering a more precise and dependable means of identity verification, biometric screening enhances security measures [12].

4.2. AI and active behavioral profiling

The active behavioral passenger profiling of Israeli airlines is based on screening interviews with skilled staff who speak multiple languages, can read body language, and can identify inconsistencies in people's responses [13].

Obviously, this type of profiling is relatively invasive of passenger privacy and time-consuming for both passengers and experienced security personnel with excellent language skills. Replacing security staff with AI is possible but would be challenging. More significant disadvantages are the invasion of passenger privacy and the time-consuming nature of checking passengers.

Active behavioral passenger profiling, in particular, also involves the observation and analysis of the passenger's body language (e.g., facial expressions, hand, foot, head, and torso movements, eye movements, and perspiration).

4.3. Risk-Based Passenger Screening

Passenger profiling, especially data-based passenger profiling, can be used for risk-based passenger screening. Efforts are also being made to use so-called positive passenger profiling to make security screening more efficient. Airline databases can be used to identify passengers who, for example, are frequent travelers, are well-versed in security screening, and have been trouble-free. These passengers can be expected to cooperate effectively and knowledgeably with the security check. This can be used to speed up the screening process for them.

5. POTENTIAL APPLICATIONS OF AI FOR PASSENGER PROFILING AND LUGGAGE SECURITY CHECKING

Airports operate under high demands and strive to satisfy many diverse, interrelated performance goals. Airport areas such as security and safety also involve detecting hazardous materials inside passengers' luggage [14]. AI can significantly enhance these areas through its implementation in various advanced methods, such as AI-powered walk-through metal detectors for improved threat detection, AI-enhanced full-body scanners for precise identification of hidden objects, AI-integrated X-ray systems for carry-on luggage to analyze hazardous materials, AI in optical and particle explosive detectors for sensitive chemical identification, and AI-based liquid explosives detectors for analyzing potentially dangerous substances. These innovations can enhance accuracy, efficiency, and passenger satisfaction.

5.1. AI for walk-through metal detectors

AI greatly improves the reliability of detecting electrically conductive, mainly metallic, possibly ferromagnetic, contraband against the background of the human body while minimizing false positive alarms.

The basic principles of machine learning detection of contraband of interest by a walk-through metal detector are simple. For example, suppose we have a certain type of gun and do not want it to be able to be carried onto an airplane, not even manually disassembled into multiple parts smuggled in piecemeal by multiple terrorists. So, we're going to manually disassemble the pistol for learning purposes. We'll take one of the largest parts—for example, the barrel. First, a figure without contraband passes through the detector, and the device remembers the excited electromagnetic response of his body. Then, the subject puts the programmed contraband (in this case, the barrel) in a certain position in a certain part of his clothing and passes through the detector. The device memorizes the signal response at which to trigger a positive detection alarm. It also remembers not to trigger the alarm at slightly lower response levels. The dummy then repeats these steps many times for different barrel rotations and locations [15].

5.2. AI full-body scanners

Whole-body scanners image all objects concealed in or under the clothing of persons under inspection, even non-metallic and large objects. X-ray scanners that image transmitted radiation can also detect contraband hidden in body cavities [16]. Full-body scanners operate using different parts of the electromagnetic spectrum, and they can be classified according to their operating frequencies, as shown in Table 1.

Table 1

Classification of Body Scanners According to Operating Frequencies [17]

<table>
<tr><th>Radio wave</th><th>Type of scanner</th><th>Name</th><th>Frequency</th><th>Wave-length</th></tr>
<tr><td rowspan="2">X-ray</td><td>Transmission</td><td>Transmission</td><td rowspan="2">30–3.000 PHz</td><td rowspan="2">10–0.01 nm</td></tr>
<tr><td>Backscatter</td><td>Backscatter</td></tr>
<tr><td rowspan="2">Millimeter-wave (MMW)</td><td>Passive</td><td>Passive MMW</td><td rowspan="2">30–300 GHz</td><td rowspan="2">10–1 mm</td></tr>
<tr><td>Active</td><td>Active MMW</td></tr>
<tr><td rowspan="2">Sub-millimeter-wave (SMW or THz)</td><td>Passive</td><td>Passive SMW</td><td rowspan="2">0.3–3 THz</td><td rowspan="2">1–0.1 mm</td></tr>
<tr><td>Active</td><td>Active SMW</td></tr>
</table>

The EU does not recommend the use of X-ray scanning systems for passengers at airports due to health concerns, although the ionizing radiation doses are low, and the concerns are more due to public opinion. For this reason, whole-body scanners imaging millimeter and terahertz radiation are used at airports in EU countries. Full-body scanners that display millimeter and terahertz waves can also be of the "stand-off" type, which detects contraband under clothing and individuals at distances of several meters. These systems are suitable for the protection of soft targets (in this case, airport terminals). Systems capable of detecting even smaller contraband are needed for the protection of hard targets for scanning people boarding aircraft. This is made possible by systems that scan a person standing alone [15].

All full-body scanners require sophisticated image analysis. The vision of using AI for this analysis is quite optimistic. *Current computer vision techniques have limited functionality when it comes to analyzing images. However, recent breakthroughs in neural networks (frameworks for machine learning algorithms that power AI) and high-capacity computer chips have allowed AI systems to flourish. A walk-through scanner that uses AI and space technology to reveal hidden security threats is being trialed at Cardiff Airport in the UK. It is the result of a collaboration between Sequestim Ltd. and a scientist from Cradiff University. The scanner used the human body as a source of "light," in contrast with the existing scanner, which processes reflected and scattered millimeter waves while the passenger is required to strike a pose. The system only needs a few seconds to do its work. Passengers walking normally through security would no longer need to take off their coats and jackets or remove personal items from their pockets. Machine learning allows the scanner to distinguish between threats and non-threats without requiring the passenger to keep still* [18]. The vision is overly optimistic in that it suggests AI-controlled people will not have to remove objects from their pockets. Given the scanning principles used, it is important to keep in mind the discriminatory capabilities and also that contraband may be covered by an innocent item of equal or greater area. Artificial intelligence is capable of developing skills related to the recognition of prohibited items as the information processed increases. The embedded and processed data is used to train the model in recognizing and identifying objects of interest to aviation security. The increased volume of data and machine learning analysis and threat identification will enable faster information processing and responses.

5.3. AI X-rays for onboard luggage

AI analyzes the acquired X-ray images to detect the outlines of mainly firearms but also cold weapons. In terms of firearms detection, it also learns to detect the outlines of parts of disassembled weapons. This is complicated by the fact that contraband can be rotated in different ways. This is an easy task for the AI. Weapon searches conducted by AI will be very reliable.

AI will also greatly help in detecting explosives and flammables based on the detection of a substance with a risky CT density in an unusual location. More generally, AI can highlight an unusual density in some location of a known, ubiquitous object (e.g., deodorant, cell phones). However, detecting explosives in this way is very unreliable, and using AI will not drastically enhance reliability. However, it will relieve operators from monotonous work.

For the above purposes, it is advisable to use X-rays that provide a 3D view of the checked baggage. It is not just about getting a 3D image of the item just examined by the AI; these X-rays are also better able to deal with the degradation of the influence of items above and below the item under examination.

5.4. AI in optical and particle explosive detectors

For optical explosives detection methods, such as terahertz spectrometry or Raman spectrometry, AI is primarily used to recognize the spectrum of the substance of interest against the background of the many different substances present in the measured area. While the spectra of cover materials (clothing, packaging) can be ruled out to some extent, it is worse with unknown materials with which the explosive may be mixed [15]. The reliability of detection will be determined primarily by the parameters of the physical method used. AI will speed up the measurement while somewhat reducing the number of negative and positive false alarms. Alternatively, it will estimate the probability of the presence of the substance of interest at a given measurement location. Assuming the use of a combination of several different physical detection methods simultaneously, there are additional challenges for multimodal AI.

For spectrometric methods of explosives trace detection, such as IMS, MS, and GC/MS, AI is primarily used to recognize the spectrum of the substance of interest against the background of the many different substances present in the sample [15].

5.5. AI for specialized liquid explosives detectors

For specialized liquid explosives detectors, AI excels particularly in inspecting liquids in metal containers, such as beverage cans. Neither optical nor microwave methods can work through metal packaging. The type of liquid in the can is then most often determined by the mass density of the liquid. This is determined by weighing and optically measuring the volume of the can. At the same time, the type of container must be entered manually, and the weight of the container must be obtained from a stored database for correction purposes. Simply reading the barcode of the item, retrieving the data from the database, checking the printing inscriptions, and comparing the density of the controlled liquid not only with the liquid explosives database but also with the density of the liquid proclaimed by the package are tasks for AI [19].

6. THE DEGREE OF AUTONOMY OF AI IN TERMS OF LEGISLATION

The European Union Aviation Safety Agency (EASA) is planning to implement AI in passenger and baggage security screening: “AI is integrated with airport security systems such as screening” and “ML techniques are used to automatically analyse data for threats, including explosives and firearms” [20, 21]. However, the EASA does not allow fully autonomous decision-making by AI in the area of critical security decisions: “The AI guidance is driven by both the level of AI (as an output of the characterisation of the AI application) and the criticality of the application (as an output of the safety and security assessments)” [20]. Currently, the degree of AI autonomy in the field of passenger and baggage security screening is restricted by the provision: “EASA will initially accept only applications where AI/ML constituents do not include IDAL A or B / SWAL 1 or 2 / AL 1, 2 or 3 items” [21] (p. 12).

The abbreviations in the above statement mean:

- IDAL = item development assurance level (specifies the required level of confidence and safety assurance for individual system components, such as an AI module).
- SWAL = software assurance level (level of confidence for software components, typically used in the aviation domain, such as traffic management, ATM/ANS).
- AL = assurance level (simplified designation of safety assurance level according to the EASA’s classification for AI – AL1 represents the highest criticality, such as explosions and fatalities, while AL5 represents the lowest).

Because explosive detection corresponds to AL1, artificial intelligence systems should not be entrusted with tasks requiring confidence levels associated with IDAL A or B, which correspond to higher autonomy levels, such as AI Level 3A or 3B. AI level 3A gives decision-making authority to the AI, with the human acting only as a remote monitor. In AI level 3B, the AI functions fully autonomously without any human involvement [21].

Legislative analysis conclusion:

Currently, the EASA does not permit fully autonomous (level 3) AI systems for explosive detection tasks. Therefore, the maximum acceptable level of AI autonomy for baggage screening is AI level 2B (human-supervised collaboration), with AI level 2A being preferable and more likely to be certified, where the AI may propose actions, but a human operator retains full control and oversight at all times. Moreover, these limitations may apply logically only to partial evaluations of the images of some scanners, such as X-rays and full-body scanners—and, above all, to the overall decision on the result of a comprehensive check. Human operators cannot interfere with the analysis of radio signals from metal detectors, analysis of spectra measured by trace particle detectors or optical detectors, etc. In the case of a positive signal on a metal detector, the operator can, for example, verify that the passenger has a metal joint. In the case of a positive signal on a trace particle detector of explosives, the operator can, for example, verify that the passenger may have been contaminated while working as a pyrotechnician, etc.

7. DISCUSSION

The possibilities of using AI in airport security checks have been described above. As mentioned above, when flying outside the Schengen area, passengers go through passport control, but their identity is not known during security screening. Thus, the screening staff approaches an "unknown" person. However, if the known identity of the passenger during the security screening is used for passenger profiling processed by the AI, it would make it possible to reduce both the service rates μ_i at some nodes and i is the probability P_{ji} that a screening completed at node j will require service at node i next. This approach aligns with the EASA's concept of contextual awareness in AI systems, where personalized data can optimize decision-making while remaining compliant with data protection laws such as GDPR [20].

Meanwhile, risk-based passenger screening based on data-based passenger profiling does not add another node, nor does it increase the number of security personnel when executed by AI.

This is different for active behavioral passenger profiling, which requires the inclusion of an additional node. This also adds additional W_i time spent by passengers at that node. Moreover, replacing security personnel with AI would still be problematic in this case. According to the EASA, AI should not aim to fully replace human personnel in sensitive tasks involving behavioral interpretation, as such tasks may require ethical discernment and context-sensitive judgment beyond current AI capabilities [20].

In the area of passenger body scanning, some visions of AI use are overly optimistic, suggesting that AI will render it unnecessary for individuals being screened to remove items from their pockets. Due to the scanning principles used, it is essential to remember that contraband may be concealed by an innocent item of equal or greater area. AI is increasingly helping to automate the analysis of images taken of scanned persons to detect any larger foreign objects hidden under or in the clothing of scanned persons. Considering the monotony of such work for humans, AI increases the reliability of the searches—that is, it reduces the number of false negative detections (FNs). Compared to less experienced operators, AI also reduces the number of false positive detections (FPs) by slightly reducing the W_{ij} time spent at that node and/or the likelihood of P_{ji} sending the occupant and/or the removed larger foreign item to the next node as well, to the next, higher level of search. Additionally, it reduces the time W_j at the full-body scanner node, mainly by making the AI work faster than the operator.

In the case of implementing AI for onboard baggage X-rays, the AI searches for prohibited items based on shapes in conjunction with CT density. However, according to the same parameters, it can also search for atypical features in seemingly innocuous items, given the databases it has learned. The AI slightly increases the reliability of the scan but primarily reduces the W_i time spent by the onboard baggage at this node, similar to that of full-body people scanners. It should be noted that the scanning of the cabin baggage is done in parallel with the scanning of the person. However, the two processes are interdependent, and scanning onboard baggage requires at least initial and final assistance from the passenger.

For spectrometric optical methods of explosives detection such as terahertz spectrometry or Raman spectrometry, and similarly, for spectrometric methods of explosives trace detection such as IMS, MS, GC/MS, etc., AI is primarily used to recognize the spectrum of the substance of interest against the background of the many different substances present in the sample. Reducing the number of false negative detections will increase reliability, and reducing the number of false positive detections will reduce the likelihood of P_{ji} sending the passenger and/or their onboard baggage to the next node for the next, higher level of screening. This eliminates the W_i time spent at the higher level node.

By comparing the measured data of the inspected liquid container on the one hand and the data from databases on the other hand, AI for specialized liquid explosives detectors will reduce the number of false negative detections and, with that, increase reliability. Moreover, by reducing the number of false positive detections while reducing the number of impossible, infeasible detections, it will reduce the likelihood of P_{ji} sending the passenger and/or his/her onboard baggage to the next, higher level of inspection. This eliminates the W_i time spent at the higher-level node.

Scanning an object, piece of baggage, or person with a device based on a single physical principle will never be reliable, especially for detecting explosives. A combination of physical principles must be used to make the scan reliable [21]. In any case, the exchange of information between instruments is often inadequate and is still usually done only through security personnel [21]. There is a large field of application for multimodal AI in the future.

Table 2

AI and future technologies of airport control [15, 16, 23, 24]

	Document Verification	Personal Search	Baggage Search	Public Concerns
Conventional technologies	ID reader, barcode reader	Metal detector + ETD device	Dual Energy X-ray + ETD device	Time-consuming, privacy issues, ethical issues
Emerging technologies	Conventional + facial recognition	Conventional + mmW+THz imaging	CT X-ray + ETD device	Privacy issues, ethical issues
Next-generation technologies	AI passenger profiling	Emerging with AI + QR with AI (+THz spectroscopy, Raman spectr. etc.)	Emerging with AI + XRD with AI (+ neutron in – gamma out)	
	AI security gate			

In Table 2, ETD stands for explosives trace detection, QR stands for quadrupole resonance, and XRD stands for X-ray diffraction. Future reliable safety inspections cannot be done without QR and XRD, but this topic is beyond the scope of this paper [22, 25].

One of the main ways to save time is to reduce the probability of P_{ji} sending a passenger and/or his/her onboard baggage to the next node as well as to the next, higher level of screening. However, this has largely been going on for quite some time, even without multimodal AI. However, data interconnectivity between nodes using multimodal AI will enable a substantial reduction in Wj times at higher-level nodes. Especially for volumetric imaging, the higher-level scanner will only be able to focus on the bottleneck from the upstream node, which will substantially reduce the actual scan time. AI can also utilize data from passenger profiling in decision-making processes. Its use can serve as a clue to speed up inspections during peak traffic times.

8. CONCLUSIONS

Implementing artificial intelligence into airport security screening processes can significantly improve the efficiency and reliability of these processes. Various aspects of AI use were analyzed, including the risk profiling of passengers, proactive passenger behavior, and the use of AI in detecting suspicious objects. The conclusion of the discussion shows that both ANI and multimodal AI can help reduce the time spent by individual passengers at security checkpoints while increasing the reliability of detection, thus improving the airport security screening process. However, it is also important to note that successful implementation of multimodal AI requires a comprehensive approach and an evaluation of all factors, including technical, ethical, and legal issues. According to the EASA's Artificial Intelligence Roadmap 2.0, AI systems used in aviation must comply with a human-centric design approach, prioritizing support for human decision-making over full automation [20].

The shift to using ANI for passenger security screening is not sudden but has been slowly evolving for decades in the form of various automation and ancillary analyses. However, current developments in information technology allow ANI to replace security personnel in the monotonous analysis of images obtained by instruments of various physical principles. The development of ANI even makes it possible to perform and evaluate rapid series of measurements that were previously practically unfeasible, as they would require lengthy manual measurements and subsequent lengthy analyses of the acquired data. Future challenges await multimodal AI in coordinating the multiple different physical principles of safety scanning. Such a scan will be almost perfect, even without profiling people. Passenger profiling can be used by AI, but it is not necessary from a security perspective. It can, however, be used to speed up during peak hours. The EASA emphasizes that AI's autonomy should evolve gradually [20]. Current use cases, like those mentioned, correspond to levels 1–2 of autonomy: AI supports or cooperates with human operators, but critical decisions must remain traceable and verifiable [20].

AI can reduce the service rate μ_i at node *i*. It can do this by processing the values obtained by a given scanner faster and more robustly using ANI. It can also achieve this by speeding up its own scanning by focusing on a specific part or problem based on the use and processing of data obtained at lower-level nodes using multimodal AI.

Multimodal AI also has the potential to reduce the probability P_{ji} that a scan completed at node *j* will require service at node *i*. In particular, multimodal AI can also reduce this factor by leveraging data from passenger profiling. For reliable database-based passenger profiling, biometric identification is essential, for which ANI also has applications (the EASA warns, however, that the use of biometric systems must be aligned with legal and ethical frameworks, particularly concerning privacy and data protection under GDPR [20]). The use of passenger profiling is particularly suitable during peak hours.

All this reduces the average time W_i in the system of each node and, thus, the total W_{total} time spent scanning and waiting in queues.

Nodes of multi-stage security inspections interact with each other in non-trivial ways. These interactions will become even more complex when driving multimodal AI. Therefore, an accurate overall "pen and paper" streamlining calculation is impossible. However, we can point to improvements in sub-variables. For example, a computer simulation method could be used to calculate the specific impact of introducing a particular AI into a particular security screening system. However, this computer simulation would also require the involvement of the AI in question, which would depend heavily on its level of learning. In any case, AI has significant potential to achieve very high efficiency of security searches within the limits set by the set of scanning technologies used.

In the future, there will be a need to implement not only ANI into individual scanners but also multimodal AI into the overall security check process. Multimodal AI will obtain more detailed data from individual scanners based on different physical principles, synthesize it, and compare complex data about the detected suspicious object with databases of both harmless and dangerous objects. Then, taking into account the passenger's security profile, it will decide on the next step. This will speed up security checks while increasing security.

This aspect holds considerable weight when assessing the human element, which can effectively manage only a limited number of areas at once. Moreover, notwithstanding pertinent technical training and courses, each security officer remains attuned to other factors that may be a premise for potential criminal activities [25]. The topic of AI and cybersecurity in civil air traffic presents numerous practical challenges amid rapid technological advancements and the potential for human error. Addressing these challenges requires collaboration and coordination at both national and international levels [26].

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