

Exploring the Implementation of Unpredictability in the Field of Aviation Security

Hridayansh Gupta

Student of BBA in Aviation Management, School of Business, Galgotias University

Abstract

Regulations for aviation security have tended to be reactionary, responding to terrorist attacks by implementing more stringent measures. This has resulted in a more predictable system that can make it easier for unlawful interference. To address risks from both external (terrorist attacks) and internal (insider threats) sources, introducing unpredictability – such as varying security controls – proactively could be beneficial. A study conducted semi-structured interviews with security experts in order to explore how and why unpredictability is implemented at airports. The results revealed that European airport stakeholders apply unpredictable measures for various reasons: complementing the security system, outmaneuvering opponents, and improving human factor aspects of the security system. Unpredictable measures are applied at different locations by various controlling authorities across different forms; however, their deployment lacks systematic evaluation. Additionally, findings indicated that varying security controls may help mitigate insider threats by reducing insider knowledge. Further research should focus on evaluating the deterrent effect of unpredictability and providing recommendations on how unpredictable measures can be effectively realized proactively to address emerging risks.

Keywords: Unpredictability, Security measures, Insider threats, Aviation security, Qualitative research

1. INTRODUCTION

Civil aviation has been a target of terrorism for over half a century. (e.g., Refs. [\(Malik, 1998\)](#),²). In light of terrorist attacks, aviation security measures have undergone ongoing enhancements and improvements (e.g., Ref.). These efforts primarily aimed to reduce the risk posed by recognized threats. Each security-related incident led to the identification of vulnerabilities in the system, prompting adjustments to existing measures or the introduction of new ones for enhancing aviation security (e.g., Ref. [\(Wong & Brooks, 2015\)](#)). Most national and international standards and regulations have historically been reactive measures in response to previous incidents. The issue with a purely reactive approach is that security constantly lags behind, as perpetrators may already develop new threats by exploiting vulnerabilities in the system. Unpredictability, which involves changing security measures to heighten their deterrent effect and effectiveness, enables a more proactive strategy. It introduces uncertainty about the timing, location, reason, and method of control. This makes it harder for an attacker to prepare and carry out an assault. Moreover, unpredictability has the potential to improve security by better distributing and utilizing existing resources [\(Wong & Brooks, 2015\)](#).

Thirdly, it can be utilized to counter internal security risks, a topic of increased importance in light of recent incidents like the bombing on Daallo Airlines Flight 159 [\(BaMaung et al., 2016\)](#). Our research investigated the reasons for and methods of implementing unpredictability at airports, as well as its

effectiveness in addressing insider threats. In the following section, we provide a brief overview of the historical development of aviation security measures before examining the concept of unpredictability and its role in mitigating insider threats.

1.1. Brief history of aviation security measures

Terrorists have been targeting civil aviation since the 1960s. Prior to that time, the aviation sector faced technical safety challenges in the skies. Between 1968 and 1972, there was a significant shift in the situation as a total of 326 hijacking incidents took place ([Holden, 1986](#)), which were primarily driven by political agendas at the time. The Tokyo Convention of 1963, the Hague Convention of 1970, and the Montreal Convention of 1970 established guidelines and suggested measures for global civil aviation to deter unauthorized interference with civil aviation ([Elias., 2010](#)). The ICAO Council initially approved them in March 1974, marking them as Annex 17 to the Chicago Convention ([ICAO, 2020](#)). Furthermore, the ICAO Aviation Security Manual was created to aid member states in the implementation of Annex 17 by offering guidance on applying its standards and recommended practices. Since that time, Annex 17 and Doc 8973 have been regularly reassessed and modified to account for emerging threats and advancements in technology ([ICAO, 2020](#)). The Federal Aviation Administration of the United States implemented a program to prevent hijacking in 1973. This involved thorough screening of all passengers and their baggage at airports.

The era of electronic security screening started with the introduction of the magnetometer, now known as the walk-through metal detector, becoming a standard procedure for passenger screening ([Brodsky, 1975](#)),¹⁵. A certain proportion of travelers (referred to as quota) received more thorough screening by undergoing a complete body pat-down in addition to this search, an early implementation of uncertainty. As a result of electronic security screening, the incidence of hijackings decreased significantly ([Haas, 2010](#)). During the 1980s, there was a transition from negotiation to intentional aircraft crashes, which culminated in December 1988 with the tragic events of Lockerbie, where an improvised explosive device was detonated in the cargo hold of Pan Am Flight 103 ([Smart, 1997](#)). The tragic event led to the loss of all 259 passengers and crew on board, as well as 11 individuals on the ground ([Smart, 1997](#)), gained substantial media presence ([Malik, 1998](#)),¹⁸.

As a result, standards were established for hold baggage screening, which included the global deployment of explosive detection systems for hold baggage ([Malik, 1998](#)). The September 11, 2001 terrorist attack had a more significant impact, leading to the deaths of thousands (e.g., Ref. ([Elias., 2010](#))). The terrorists utilized knives, which were easily brought onto an aircraft at that time, to gain control of the cockpit (as cockpit doors were not reinforced) and seize multiple planes, which they then used as weapons for mass destruction ([Bhaum, 2018](#)). The period after 9/11 saw rapid adjustments to both legal and security frameworks; For instance, after the terrorist attack, knives were banned and reinforced cockpit doors were installed. Significant resources were also allocated to improve screening technology and train personnel. These changes in security protocols and rules directly followed the terrorist attack, leading to enhanced aviation security for all passengers (not based on risk; reactive regulation). In 2006, British authorities uncovered a plot by eight terrorists to bomb seven airplanes bound for the U.S.A. and Canada using improvised liquid explosive devices before it could be carried out ([Enerstvedt, 2017](#)), ([Wetter, 2014](#)). This led to limitations on liquids in carry-on bags, as well as the advancement and use of new detection technology. While the introduction and uniformity of security procedures and new protocols improved overall security, it also brought about a greater predictability within the security system ([Haldimann, 2018](#)). Aviation security systems have been customized to respond to previous incidents and threats through the

adoption and improvement of standardized measures in order to achieve security objectives effectively ([Kirschenbaum, 2015](#)). Two outcomes of a defensive security strategy were identified: “(1) the decrease in the frequency of assaults from a current form of danger and (2) The development of fresh risks that are likely unfamiliar to the system. In essence, as long as new norms and procedures stem from known incidents, aviation security systems will continue to lag behind. Thus, a more proactive approach based on unpredictability has become crucial ([Haldimann, 2018](#))”

1.2. Unpredictability in aviation security

The ICAO ([ICAO, 2020](#), p. 3) defines unpredictability as: “Enhancing security measures to maximize their deterrent effect and effectiveness by employing them at irregular intervals, various locations, and/or using different methods within a specified framework” Ref. ([Haldimann, 2018](#)) It is noted that introducing unpredictability in implementation does not always demand extra resources. Instead, it focuses on enhancing the effectiveness and efficiency of security controls by diversifying them. This diversity makes it challenging for individuals to anticipate when or how they will be checked. Intentionally creating a state of heightened uncertainty leads to the belief that everyone can be subject to checks at any given moment, which is expected to act as a deterrent ([Singhe, 2019](#)).

Unpredictable security measures, such as random searches, have been a consistent aspect of security systems for many years (e.g., occasional full body pat-downs since the introduction of magnetometers/walk-through metal detectors). see Ref. [14], but have recently gained more attention through explicitly formulated concepts of unpredictability (for example, the TSA's Playbook). A classic security system employs a multi-tiered strategy ([Wigginton et al., 2014](#)) multiple opportunities for potential weaknesses or errors to align, allowing a threat to breach the system; ([Reason, 1995](#)) representing weaknesses in the system. These security vulnerabilities may stem from the system being too predictable or not having adequate security controls in place. Introducing unpredictability through diversified security controls could help address these loopholes. While this idea seems rational in theory, international authorities have already proposed various regulations and suggestions to mitigate such risks, including mandatory measures like random passenger checks with explosive trace detection (ETD; ([EUR & , 2015](#))), and others with a voluntary nature, like increasing the element of unpredictability further ([ICAO, 2020](#)).

From an operational perspective, increasing "unpredictability" could potentially have a positive effect on certain important performance measures. For instance, if fewer resources are used to screen all passengers at the security checkpoint and additional random checks are conducted elsewhere, it could lead to improved efficiency (throughput), effectiveness (security), and passenger satisfaction. However, initial research on perceived passenger experience has indicated that conventional security checks (where everyone is screened equally) are seen as fairer and more secure compared to security checks based on random schedules screened; ([Scurich & John, 2013](#))), but are also less convenient ([Nguyen & John, 2017](#)). In a study by Ref. ([Stotz et al., 2020](#)), Research has demonstrated that individuals tend to view traditional security checks as more secure than randomized ones, regardless of the proportion of people subjected to screening. As a result, implementing randomized security checks could diminish the perceived level of safety. It is essential to have a thorough understanding of the mechanisms behind unpredictability in order to harness its potential effectively and avoid undesirable outcomes such as reduced feelings of security. The implementation of unpredictable elements in security measures should be carefully planned and assessed. Additionally, an unpredictable security system may also aid in mitigating various threats by

addressing not only external attacks but also internal risks within the airport security infrastructure ([Wallace & Loffi, 2014](#)).

1.3. Internal security risks

In the not so distant past, there was suspicion that "insiders" were taking on a more significant role in carrying out terrorist attacks ([Bhaus, 2018](#)). The term "insider" denotes individuals who are currently or were previously authorized users of the system and have valid access to sensitive or confidential information. These individuals may be familiar with the weaknesses in the operating systems and business procedures (Ref. ([Homoliak et al., 2019](#)), p. 2). An "insider threat" refers to one or more individuals who possess access to critical infrastructure and/or internal information, enabling them to exploit system vulnerabilities and inflict harm on the organization ([Homoliak et al., 2019](#)). The insider threat in the field of information security has been extensively studied (e.g., Refs. ([Homoliak et al., 2019](#))) Surveys indicate that approximately 27% of cybercrime incidents are believed to be perpetrated by insiders ([Homoliak et al., 2019](#)); ([Loffi & Wallace, 2014](#)). The field of science differentiates between the intentional and unintentional non-malicious insider threat. Both have negative impacts on the organization, but only the deliberate insider acts with malicious intent. The functioning of an airport involves the utilization of a large workforce, with some individuals having access to sensitive security zones and working in close proximity to aircraft. Therefore, any airport staff members with such access or knowledge regarding security protocols could potentially pose an insider threat.

Upon closer examination, various types of malicious insider activity could occur: For example, an employee may become radicalized after being hired or be influenced by an external entity not within the airport system. Additionally, it is also plausible to imagine that an airport worker might accept bribes to smuggle a bag (containing restricted items) through security without realizing they are aiding in placing a bomb onboard the aircraft ([Baus, 2018](#)). Typical actions of a malicious insider involve "surveillance, disclosure of information, undermining, manipulation, posing as someone else, stealing, illegal trade and terrorism". In February of 2016, an explosion occurred on Daallo Airlines Flight 159 traveling from Mogadishu to Djibouti. (e.g., Ref. ([BaMaung et al., 2016](#))), The suicide bomber was given a laptop-like device by at least one airport employee after getting through the security check, putting the passengers and crew in grave danger ([BaMaung et al., 2016](#)). Additionally, there is suspicion that the bomb explosion on Metrojet Flight KGL9268 above Sinai may have been aided by someone working within Sharm el-Sheikh International Airport (e.g., Ref. ([Baus, 2018](#))).

The accidental non-malicious insider is also important because the person "has no intention of causing harm with his/her action (or inaction), which resulted in harm or significantly increased the chances of future serious harm to the organization's information confidentiality, integrity, or availability Security concerns may arise from various incidents such as unintended exposure of sensitive data and social engineering tactics, where an outsider manipulates an insider to access restricted areas or plan attacks. The aviation industry considers insider threats a significant issue requiring the implementation of preventive measures [[Wallace & Loffi, 2014](#)], ([Loffi & Wallace, 2014](#)).

In a tightly regulated security environment that primarily responds to past incidents, insider threats are extremely important. This is because insiders have knowledge of possible security weaknesses as a result of their proximity in daily operations and could use this information for both malicious and non-malicious purposes. In particular, the predictability arising from the consistent implementation of security measures poses a concern ([Haldimann, 2018](#)) increases the system's susceptibility, which is why it is important to take proactive steps to address insider threats with innovative security approaches like unpredictability.

In principle, incorporating unpredictability into security measures appears rational and uncomplicated. Nonetheless, bridging the gap between theory and implementation can be challenging, especially considering that most research on unpredictability has been carried out in controlled laboratory environments. ([Singhe, 2019](#)), ([Scurich & John, 2013](#)) ([Stotz et al., 2020](#)), The reasons for using unpredictability at airports and its application to address insider threats remain unclear. This forms the basis of the current study and its related research queries. 1.4. The current research focuses on three main inquiries:

1. What is the rationale behind implementing unpredictable measures at airports?
2. In what manner are these unpredictability measures put into practice at airports?
3. Can unpredictability help to reduce insider threats, as perceived by practitioners?

To capture diverse viewpoints from stakeholders, we have adopted a qualitative research approach with a semi-structured interview study design ([Creswell, 2017](#)).

2. METHODS

We referred to data of interviewed specialists and carried out on-site visits at airports to investigate the research queries. We categorized an expert as someone with extensive knowledge and/or privileged information in the realm of airport security practices, who is willing to share it according to the definition of expertise Ref. ([Littig, 2009](#)), p. 98ff). To conduct purposeful sampling ([Creswell, 2012](#)), we sought to involve professionals from a variety of relevant national aviation security regulatory authorities, large airport police organizations, airline representatives, as well as managers from both large and small airports. Leveraging the extensive network of contacts belonging to the third and final authors and their respective institutions, we reached out to 22 experts across different European countries via email. In our initial outreach, we provided a brief overview of the research project and requested an off-the-record personal exchange. Eighteen respondents expressed interest by email and sought further details. Subsequently, detailed information about the study was shared with them during telephonic conversations. After internal discussions within their respective organizations, eight experts consented to participate in semi-structured interviews and on-site visits at airports. All participants provided informed consent before taking part in this engagement. We crafted an interview guide for semi-structured interviews based on recommendations by Refs. ([Creswell, 2017](#)); ([J Brown, 2012](#)). The Interviews took place at the airport and lasted between 60 to 90 minutes. One interviewer conducted the interview while a second one created an interview protocol. After giving a brief project overview and explaining the interview process, anonymity was assured. Participants then provided written consent before discussing general concepts of unpredictability in the first part of the interview. The experts brainstormed about applying unpredictability in general during the second part, followed by collecting data on applied unpredictability measures at airports without specific implementation details in part three.

In part four, detailed questions were asked about how stated measures were implemented with focus on what happens where, when, how and why they are used along with responsible parties and lessons learned. The fifth segment addressed how these measures address insider threats.

Finally, participants shared further insights and prospects for future work related to unpredictability (refer to Table 1).

To supplement information from interviews, the two interviewer also conducted on-site observations with experts for 15-90 min (at all except one airport) using initial interviews as guidance. After finalizing their protocol, which included observational information it was reviewed by lead interviewer. Throughout this

process consistency was maintained. In cases of discrepancies clarified them or made necessary adjustments after sending protocols for review, experts could request alterations or deletions if need be. For analyzing data from finalized protocols, content analysis approach employing an inductive method will be used (Kuckartz, 2019) and MAXQDA 20.0.2 was utilized for developing the coding scheme. The two interviewers individually coded one interview and resolved any differences through discussion to advance the coding scheme. Following this, both interviewers separately coded all interviews, and we assessed intercoder reliability as recommended by Ref (O'Connor & Joffe, 2020). We achieved a Cohen's Kappa value of .80, which is considered to be good (Landis & Koch, 1977).

3. RESULTS

The study results are outlined in this section, in accordance with the suggestions of Ref. (Levitt et al., 2018). We will start by examining the reasons for the application of unpredictability [finding 1] before listing the implemented security precautions [finding 2]. We will further examine the different aspects of the identified security measures in greater depth [finding 3] Prior to considering the possibility of unpredictability as a means to counter insider threats [finding 4]. At the conclusion of this results section, we provide three viewpoints on the integration of the mentioned measures into a security system [finding 5].

Table 1. Covered topics of the research.

Section	Topic	Example questions
1	Concept of unpredictability	What do you [as an appropriate national authority/police organization/airline security manager/airport security manager] understand by the term «unpredictability»?
2	Application in general	What role/value does unpredictability play/have in general when applying/realizing security measures at the airport?
3	Overview of applied measures	What measures are already in use that you think have an unpredictability component?
4	Implementation of applied measures	How was this measure concretely implemented?
		Why was this measure concretely implemented?
5	Contribution to insider threats	How does your organization address the issue of insider threats?
6	Future prospects of unpredictability	How do you assess the future development of unpredictability measures?

3.1. Finding 1: Reasons for applying unpredictability

While examining the data, we initially identified all the factors contributing to unpredictability using an inductive method. Next, we condensed these into meaningful units to streamline the data and further categorized them. Subsequently, we established four primary categories that enabled us to group the subcategories. The frequency of mentions determines the order of reasons listed in Table 2.

3.2. Findings 2 and 3: Unpredictability measures and their varying elements

The examination of the interview protocols yielded ten measures of unpredictability, which are organized by application locations in Table 3. These measures were explicitly mentioned and described, unlike other security measures such as air marshals and explosive detection dogs, which were briefly mentioned but not elaborated on and therefore omitted from Table 3. We then analyzed the diverse elements of these identified security measures based on specific questions related to time, location, type, and authority. Our data collection also included an assessment of whether unpredictability measures are evaluated systematically. It was found that these measures were generally not subject to systematic evaluation; however, one measure (assignment to security lanes) was evaluated for operational efficiency while another measure (patrol activity) was assessed in terms of employee implementation variation.

3.3. Finding 4: Unpredictability's contribution to mitigate insider threats

As indicated in Table 3, a number of measures designed to address unpredictability focus on groups with inside information (such as airport staff, crew members, and suppliers). To delve further into this aspect, we conducted a detailed analysis of our data specifically related to insider threats based on our coding system. This led to the following possibilities:

Diminished insider knowledge. In comparison to outsiders, the experts mentioned during interviews that insiders benefit from being part of the security system and possess crucial knowledge about its operations. This presents a risk especially if security processes and procedures are standardized and predictable. By introducing unpredictability into security procedures and processes, it is intended to make the system less transparent which reduces the value of insider knowledge. Furthermore unpredictable variations in security procedures make it challenging for attackers to plan or execute an attack.

Reduced impact from insiders. The experts highlighted that unpredictability has the capability to decrease individual impacts on the security control process through randomization. For instance algorithms controlling passenger and bag allocation using randomness for screening operators (e.g., multiplexing combined with remote screening) (M, 2017), serves as a preventative measure for the system since it does not allow for manipulation of the controlled passenger and their belongings, nor can anyone take advantage of it.

Increased deterrence. Randomizing procedures and processes also has the added benefit of discouraging insiders, according to experts. When security measures are randomized, the likelihood of successful unlawful interference is reduced, which could dissuade insider actions.

Increased flexibility. Interviews have revealed that unpredictability may require airport staff to demonstrate greater adaptability and flexibility in carrying out their duties, potentially reducing monotony and boredom at work. Varying procedures, processes, and team arrangements could provide employees with more diversity and challenges.

Increased security awareness. Unpredictability was cited by interviewed experts as a method for boosting and sustaining security awareness among employees while encouraging them to remain vigilant. Implementing unpredictable measures described in Table 3 could enhance ongoing employee knowledge about insider threats; consequently necessitating additional security controls aimed at employees. With heightened awareness regarding insider threats, employees would be more observant towards one another thereby increasing chances of identifying unusual behavior.

Table 2. Main and subcategories of reasons for applying unpredictability measures.

Main category	Description of the main category	Subcategory	Description of the subcategory
Security system focused (46%)	Unpredictability is applied because it is mandated by (inter)national regulations and/or is seen as a proactive approach complementing baseline security measures.	Regulation (n = 9)	Unpredictability measures (e.g., random inspections of passengers, staff, and items being screened) are mandated by international and national regulations. Compliance with these regulations is important and therefore a reason for applying unpredictability measures.
		Closing gaps (n = 8)	A specific vulnerability of the system (i.e., a security gap) can be addressed by random checks (i.e., with unpredictable measures) that cannot be covered within the regular security measures. For example, a small size airport does not necessarily have explosive detection dogs (EDD) in use. This lack can be addressed with additional explosive trace detection (ETD) usage, which are carried out randomly on passengers and staff.
		Quality control (n = 4) Proactive security (n = 1)	Unpredictability measures and tests can be used for quality control purposes to ensure that security measures are conducted effectively and provide feedback to employees on their performance. Unpredictability is seen as a proactive approach that complements baseline security measures that have been implemented as reactions to incidents.
Opponent focused (31%)	Unpredictability is applied to defeat the opponent of the security system through deterrence, confusion, and by impairing planning and collaboration.	Deterrence (n = 6)	The irregularity of controls can lead to a state of uncertainty for persons with malicious intentions in information gathering, in the planning of a criminal activity, and in the criminal act itself. It is assumed that the implementation of unpredictability and its appropriate communication to passengers and staff increases the deterrent effect of the security system.
		Confusion of the opponent (n = 5)	The irregularity of applying security measures aims at confusing potential opponents who are presumably observing security processes to identify regularities, vulnerabilities, and weaknesses.
		Prevention of planning and collaboration (n = 2)	If security measures are conducted in an unpredictable way, planning an attack becomes difficult. Moreover, an act of unlawful interference involving different persons from in and/or outside the system (e.g., a screener working at a checkpoint and a passenger with a bomb in carry-on baggage) becomes difficult.
		Visibility of security (n = 2)	Overt security measures (e.g., patrolling police officers) increase the visibility of security for passengers, staff, and visitors of an airport.
Human factors focused (23%)	Unpredictability is applied to enhance human factors by increasing awareness, training, and motivation of security staff.	Security awareness (n = 5)	Unpredictability measures can increase security awareness because security employees are more often confronted with the fact that something could happen. Therefore, it is assumed that random tests, for example, raise security awareness.
		Training (n = 3) Flexibility (n = 2)	Some procedures, which are rarely carried out due to operational reasons, can be trained by applying them at an irregular frequency.
		Flexibility (n = 2)	Implementation of unpredictability measures can increase the cognitive flexibility of security employees as workflows and processes vary more.
		Variety/diversification (n = 1)	Boredom and monotony have a negative impact on work motivation and performance. Unpredictability measures reduce boredom and monotony by introducing variety in security processes, which could result in better work motivation and performance.

3.4. Finding 5: Perspectives on the application of unpredictability

Three viewpoints on incorporating unpredictability into an established security system were discovered based on the interview data. Unpredictability was seen as a variation of standard security measures (1). In this view, measures of unpredictability are not viewed as separate or independent. Unpredictability, which involves the use of randomness, serves as a method for implementing and diversifying an existing security measure. For instance, controlled areas have incorporated randomness into the process of inspections (order, timing, and frequency). This utilization of unpredictability is practical when seamless control is unattainable (e.g., patrol activity; refer to Table 3). Unpredictability along with standard security measures (2). Unpredictability is frequently characterized as an extra layer of security on top of the standard security measures. It serves to fill in security gaps by complementing conventional measures, making it a valuable addition for addressing inadequacies in regulatory provisions (e.g., implementing additional security controls airside, refer to Table 3). Unpredictability can be used as an alternative to regular security measures (3). An alternative viewpoint on unpredictability is not currently being utilized but may show promise in the future, pending successful testing. To improve economic efficiency, occasional and targeted unpredictable measures should replace traditional methods (e.g., quota-based checks on goods; refer to

Table 3). Additionally, from this standpoint, the implementation of unpredictability could be based on risk assessment.

Table 3. Unpredictability measures ordered by locations where they are applied.

Where	Unpredictability measure	Short description of measure	Who	Target group	Variation/Randomization factor	Overt/covert application
In- & outside perimeter	Patrol activity	Patrols are executed in an unpredictable manner, whereby time entries and journals help to monitor the variation (the measure is often combined with "Badge/ identity check").	Airport security staff; security provider; police	Passengers/visitors; airport staff	Location of control Time of control Type of control	Overt Covert
Entire airport site	Badge/identity check	Random, irregular, and unexpected examination of an employee's identity and access rights for a certain area at the airport (without a quota; the measure is often combined with "Patrol activity"). This includes verifying that a badge/ID card is still valid.	Airport security staff; security provider; police	Airport staff	Location of control Time of control	Not mentioned
	Quality checks	Quality checks include the verification of compliance with security regulations/instructions among employees. These checks are not announced but defined by a system for random, uniform deployment.	Airport security staff; security provider; Airport security management	Airport staff	Location of control. Time of control Type of control Controlling authority	Overt Covert
Gates of goods delivery	Quota-based checks on goods	Quota-based application of checks on goods delivered by unknown suppliers. The randomness is defined by a quota algorithm.	Airport security staff	Supplier (unknown); Airport staff	Time of control Type of control	Not mentioned
Entire airport site; mainly at the security checkpoint	Switch of workplaces	Working stations must be switched unexpectedly (team/individual A switches workplace with a team/ individual B). The randomness is carried out from time to time (not structured or constantly).	Airport security management	Airport staff	Location of control. Time of control	Covert
Security checkpoint	Quota-based ETD checks	Quota-based application of explosive trace detection (ETD) tests on passengers or baggage at the security checkpoint. The quota is given by the authority and applied by an algorithm.	Airport security staff	Passengers; Airport staff; Crews	Time of control	Not mentioned
	Assignment to security lanes	Random assignment to a specific security control lane at the end of the passenger queuing. The assignment is based on capacity of the security lanes (efficiency).	Airport security staff	Passengers; Airport security staff	Location of control	Covert
	Additional checks on passengers	Additional controls (e.g., ETD, pat down) are carried out at the discretion of security employees. The selection of passengers can be risk-based (e.g., a passenger behaves suspiciously) or random.	Airport security staff	Passengers	Time of control Type of control	Covert
Airside; at the gate	Match of ID/boarding card	The measure includes the comparison of the personal identification document (ID) and the boarding pass for intra- Schengen flights. The flights are selected randomly, with an annual event-based number of executions.	Ground handling staff; airline	Passengers	Time of control	Not mentioned
	Security controls airside (abroad)	Various measures are commissioned unannounced to security providers at foreign airports which do not meet the airline's quality standards (e.g., additional ETD checks on passengers, observation, repeated X-ray screening). The frequency of the measure depends on the relationship of trust between airline and security provider.	Security provider (abroad); airline	Passengers; Security provider (abroad)	Time of control Type of control Controlling authority	Overt Covert

4. DISCUSSION

Aviation security regulations and measures have historically been primarily reactive responses to terrorist attacks. However, in the past decade, there has been a growing focus on implementing a more proactive approach that revolves around unpredictability. (Zeballos et al., 2023),(Singhe, 2019). Varying security measures are introduced to enhance their effectiveness as deterrents. Our research examines the implementation of unpredictability in airport security, discussing our findings, addressing limitations and potential further research before concluding.

4.1. Discussion of findings

The reasons for implementing unpredictable measures can be categorized into three main areas: focus on security systems, focus on opponents, and focus on human factors. Among these, the emphasis on security systems was most commonly cited. From this standpoint, unpredictability is utilized in adherence to (inter)national regulations or as a proactive strategy to augment baseline security measures (ICAO, 2020),

European (e.g., Refs. [\(EUR & , 2015\)](#)), several national laws already require certain actions [\(EUR, 2015\)](#) or suggest additional implementation of unforeseeability(e.g., Ref. [\(ICAO, 2020\)](#)). Security professionals see unpredictability as an effective method for addressing specific security system vulnerabilities, such as closing security gaps, by introducing variation. From another standpoint, unpredictability is used to outmaneuver adversaries of the security system by enhancing deterrence, causing confusion, and disrupting the planning and coordination of individuals with malicious intentions. This view aligns closely with prior research on the advantages of unpredictability [\(Haldimann, 2018\)](#),[\(Singhe, 2019\)](#). Interestingly, we have also discovered that introducing unpredictability can enhance the human factors of the security system. Using unpredictable variations in security controls is seen as an opportunity to train staff in carrying out these measures effectively, even those rarely utilized. Additionally, incorporating unpredictability is considered beneficial for enhancing and sustaining practical security awareness, which is acquired through hands-on experience[\(Nøkleberg, 2021\)](#), an unanticipated and thorough implementation of measures could indicate the potential for an imminent occurrence. Taking into account the comprehensive approach to security[\(Wigginton et al., 2014\)](#) where each security measure acts as a barrier to prevent illegal interference, the security-conscious human operator, who applies security measures in a less predictable manner and also pays attention to unusual behavior of passengers and employees, could serve as an extra layer of human obstruction; [\(Schouten, 2014\)](#) and improve security (by making better security choices); [\(Kirschenbaum, 2015\)](#)). From our point of view Ref. [\(Haldimann, 2018\)](#), Security protocols at airports are essential for maintaining unpredictability. Airport personnel need to undergo training and be motivated to report any security-related findings. (e.g., Refs. [\(Haldimann, 2018\)](#); for instance, in an unidentified employee reporting platform; [\(BaMaung et al., 2016\)](#)) and implementing unpredictability within their constraints.

Finding 2: Unpredictability is introduced through diverse security measures, which differ in terms of how they are implemented and where. Measures are carried out both land- and airside, with a focus on the security checkpoint. The landside area is considered vulnerable[\(Leese & Wildi, 2017\)](#),

Airport security received greater attention following the 2016 bombings at Brussels Airport, prompting immediate responses and enhanced security measures in non-secure areas. However, effectively securing the entire airport remains a significant and costly challenge. Introducing unpredictability could prove beneficial by allowing for more efficient allocation of limited resources. For instance, varying security presence through patrols with explosive detection dogs combined with camera surveillance can help detect individuals who react unusually to their unexpected presence.

In terms of practical implementation, it is worth noting that mostly defined algorithms are utilized to introduce randomness into security controls for a target group (e.g., ETD-checks). This approach is considered reasonable as humans tend to struggle with generating randomness manually[\(Treisman & Faulkner, 1987\)](#) and Fall into easily recognizable patterns. However, in some instances, the implementation of measures is not structured or planned but rather a result of operations (e.g., switching workplaces). This explains why assessments of unpredictability measures were not conducted on their effectiveness. Consequently, it is challenging to establish practical knowledge regarding how a measure should be applied (i.e., varied) to achieve the best effect under existing conditions without systematic evaluation. It is important to acknowledge that there remains limited understanding about the concept of unpredictability, which complicates assessment.

Finding 3: A common approach to unpredictable security measures involves introducing variability or randomness, often through the timing of security controls. By varying the time when these controls are

conducted, an entity can effectively introduce unpredictability into their security system. This allows for consideration of operational processes at the airport such as flight schedules and staff resources. For example, an entity could identify multiple possible time slots during business hours and randomly deploy unpredictable measures like quality checks. As long as the deployment planning cycle is changed periodically without following a predictable pattern, this approach remains effective in maintaining a level of unpredictability. The study also revealed that varying the location and type of security control is feasible based on airport characteristics such as layout and infrastructure; ([Polater, 2018](#)) Various types of executions are feasible. Smaller airports, in particular, may face limitations in terms of suitable locations. For instance, the allocation of passengers to different security lanes may not be highly effective if there is only a small number of lanes. However, certain measures can also be adjusted with respect to location at smaller airports, such as badge checking. The variation in the type of security controls also relies on infrastructure and available resources (e.g., availability of explosive detection dogs). An intriguing approach to introducing unpredictability is by varying the controlling authorities (similar to quality checks; see Table 3), for example, by involving the local police or the appropriate national authority as an additional control entity. In our opinion, this is a promising approach because it involves not only a visible change in authority but also more subtle aspects of unpredictability. In other words, two authorities will carry out the same measure somewhat differently due to organizational culture and training ([Kirschenbaum & Rapaport, 2017](#)), and so on. However, as one reviewer has noted, assigning multiple authorities to the same duties could lead to confusion and conflict, which would hinder security efficiency and effectiveness. Additionally, it is important for the implementation to find a balance between overt and covert applications and maintain an appropriate deployment frequency. Overly frequent deployment may lead to habituation with a negative impact on deterrence, while infrequent use may reduce the measure's effectiveness. Balancing overt and covert applications is crucial as excessive covert measures can decrease their deterrent effect by making security seem absent, while too many overt measures can affect passenger perceptions negatively. It should also be acknowledged that evaluating the deterrent effect of covert measures (e.g., switching of workplaces; see Table 3) is challenging because they are not visible to the target group. Nonetheless, there are mitigating factors for insider threats discussed in subsequent sections. Finding 4: Implementing measures that focus on airport and security personnel's unpredictability can help reduce the risk of an insider threat. The study revealed that various security measures already incorporate unpredictability through changes in work stations and schedules, especially in smaller airports where shifts are more predictable than in larger ones. This suggests that changing employees' workplace could be a viable approach. These unpredictability measures seem to impact both malicious and non-malicious insiders. Additionally, incorporating these measures supports a system of non-transparency ([Haldimann, 2018](#)). Consequently, it becomes harder to accumulate knowledge because the absence of consistent patterns in operations and processes leads to variation. Moreover, unpredictability can hinder predictive abilities (e.g., when planning an attack) if the opponent is aware of the variation and deterred as a result. However, research indicates that unpredictability also plays a role in enhancing security awareness among airport employees and potentially has a positive impact on security culture: A security culture where everyone is alert and attentive towards potential threats tends to be more sensitive to blind spots. Therefore, the concept of unpredictability should be considered in programs aimed at preventing insider threats ([Wallace & Loffi, 2014](#)).

We discovered three distinct viewpoints on integrating unpredictability measures into current security concepts: traditional security measures could be diversified (1), added with unpredictability measures (2),

or replaced by such measures (3). While a simple variation of a regular measure does not require any additional human resources, these are required for additional security measures. Both viewpoints, however, suggest the possibility of enhanced security through targeted implementation. Economically speaking, the third viewpoint shows promise as it could lead to reduced human resources, increased throughput, and a positive impact on passenger experience when a significant number of passengers are classified as low risk. However, this could also potentially reduce passengers' perception of security ([Stotz et al., 2020](#)) when communication is inadequate. Additionally, a decrease in the number of controls could pose a security risk, which is why this approach has not been implemented so far. Our research indicates that most unpredictability measures are seen as alternative or supplementary to existing security measures at present. Unpredictability is currently not being used instead of regular security measures, but this strategy may become important in the future. Identifying and distinguishing high-risk groups more accurately from low-risk groups could make risk-based screening more effective (for further details on risk-based screening, see ... e.g., Ref. ([Wong & Brooks, 2015](#))), unpredictability can be intriguing when conducting random checks on low-risk passengers to maintain a level of deterrence (also known as the TSA's PreCheck program); ([Stewart & Mueller, 2016](#)). However, it is clear that an assessment is needed to generate additional recommendations for implementation.

4.2. Limitations and further research

One limitation of the current study is the relatively small number of experts involved. Despite making efforts to engage as many experts as possible, it was challenging to achieve the desired level of confidential exchange. This may be due in part to the sensitive nature of the topic itself, which is still considered a security concern. Our use of institutional networks to address this issue may have influenced our sample's perspectives on the topic.

Another factor contributing to the low participation rate among experts could be that most airports do not prioritize unpredictability measures at present, with expert contributions primarily focused on minimal compliance. Additionally, concerning insider threats, interviews revealed that while most experts are aware of these threats, they perceive them as inconvenient due to their impact on employer-employee trust relationships."

Given a sample of airports consisting of one large and four small airports, it was not possible to systematically explore whether the significance of unpredictability varies based on airport size. For instance, some may contend that security patterns in small airports are more predictable at times, making efforts to enhance unpredictability more crucial for these locations. Conversely, others may argue that the risk of insider threats is lower at small airports due to fewer security officers who are better acquainted with each other compared to those at large airports, suggesting that measures targeting insider threats' unpredictability might be less critical for small airports. It would be valuable and interesting to further our research by methodically investigating which unpredictable measures hold what level of importance for both small and large-scale operations.

Our objective was to understand the usage and purpose of unpredictability measures, prioritizing in-depth information over a comprehensive list. Due to time constraints during interviews with experts, we initially gathered all applied measures before delving into detailed discussions on some. The researcher's role involved navigating through the collected measures, influencing the final list. Regular team meetings were held for reflection and approach refinement, balancing novel information acquisition with expert input. For future research in this area, scheduling ample time for contacting interviewees and building trust is advised. Additionally, our study revealed a lack of systematic evaluation of unpredictability

measures concerning various aspects such as security effectiveness and passenger experience. Subsequent research could investigate the deterrent effect of these measures to enhance their assessment regarding key performance indicators like security effectiveness.

5. CONCLUSION

Further Research on Unpredictability Measures in Airport Security, Expanding on the previous research, there is a need for a systematic evaluation of unpredictability measures concerning various aspects such as security effectiveness and passenger experience. The current study highlighted the potential benefits of incorporating unpredictability measures into airport security systems, but it also revealed several limitations that need to be addressed in further research.

One key area for further investigation is the significance of unpredictability measures in relation to airport size. It would be valuable to systematically explore whether the effectiveness and importance of unpredictability vary based on the scale of airport operations. This could involve comparing the security patterns and insider threat risks in small and large airports to determine the optimal unpredictability measures for each setting. Understanding the specific needs of different airport sizes will help in tailoring security strategies accordingly.

Additionally, future research should delve into the deterrent effect of unpredictability measures to enhance their assessment regarding key performance indicators like security effectiveness. It is important to evaluate how these measures impact the awareness and responsiveness of airport employees, as well as how they influence the overall security culture within the airport environment. This could involve conducting surveys and interviews to gauge the perception and experience of airport personnel and passengers regarding the implementation of unpredictability measures.

Furthermore, there is a need for continued exploration of the economic implications of integrating unpredictability measures into security concepts. Research could focus on assessing the cost-effectiveness of these measures and their potential impact on passenger experience. Understanding the balance between security and passenger convenience is crucial for developing sustainable and effective security strategies. In conclusion, while the current study provided valuable insights into the role of unpredictability measures in mitigating insider threats in airport security, it is evident that further research is warranted to address the identified limitations and to deepen our understanding of the implications and effectiveness of these measures. This ongoing research will contribute to the ongoing evolution and enhancement of airport security protocols.

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