Analysis of the Use of X-Ray Technology in Supporting Aviation Security Systems at Juanda Airport

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ABSTRACT

This study aims to analyze the use of X-Ray technology in supporting the Aviation Security system at Juanda Airport and to examine its implications for aviation vocational education. A descriptive qualitative approach was employed through semi-structured interviews, non-participant observation, and documentation review involving Aviation Security personnel and experts. The data were analyzed using thematic analysis and validated through source triangulation, technique triangulation, and member checking. The findings show that X-Ray technology functions as both a primary screening tool and a decision-support system for identifying suspicious and prohibited items in cabin baggage, checked baggage, and cargo. However, the effectiveness of X-Ray screening depends on the interaction between machine capability, operator competence, procedural compliance, and operational support. Operator competence is influenced by image interpretation skills, knowledge of prohibited items, Junior AVSEC licensing, refresher training, recurrent training, and adherence to standard operating procedures. The study also found that workload, fatigue, limited licensed personnel, concentration, equipment maintenance, and calibration may affect screening consistency and increase the risk of human error. From an educational perspective, real X-Ray screening practices can be transformed into contextual, case-based, and practice-based learning materials for aviation vocational education. These materials can strengthen cadets' competencies in X-Ray operation, image interpretation, prohibited item identification, suspicious baggage handling, secondary inspection, human factors, equipment reliability, and AI-assisted screening awareness. This study contributes to Aviation Security practice and vocational learning by positioning X-Ray screening as a human-technology-procedure system.

I. Introduction

Aviation security is a critical component of airport operations because it is designed to protect passengers, baggage, cargo, aircraft, and airport facilities from potential threats and unlawful interference (Singh & Dhiraj, 2026). The increasing volume of passengers and baggage in air transportation requires airport security systems that are able to maintain high threat-detection capability while supporting operational efficiency and passenger flow (Nounou & Shaban, 2025). Airport baggage operations are closely related to security performance, passenger experience, technological readiness, and coordination between airport authorities and airlines (Nounou & Shaban, 2025). In this context, security screening at airport checkpoints becomes an important process because it directly determines whether passengers and their belongings can enter secure areas and board aircraft safely (Stotz et al., 2022). Security checkpoint procedures also need to consider passenger experience because space design, procedural clarity, and the quality of interactions can influence passenger stress and checkpoint experience (Gotti et al., 2026). Passenger flow and checkpoint capacity are important because the number of available security checkpoints can affect waiting time, queue length, and passenger density in airport terminals (Inturri et al., 2026).

X-Ray technology remains one of the most widely used technologies in aviation security screening because it enables non-intrusive inspection of luggage and cargo (Singh & Dhiraj, 2026). X-Ray screening supports airport security officers in identifying prohibited items, contraband, explosives, weapons, and other dangerous objects that may be hidden inside passengers' baggage (Hättenschwiler et al., 2018). The use of X-Ray imaging is important in airport operations because screening systems must process a large number of bags under strict regulatory requirements and limited infrastructure (Singh & Dhiraj, 2026).

The effectiveness of X-Ray screening is not determined only by the machine, but also by the ability of security officers to interpret images accurately and make correct decisions under operational pressure (Huegli et al., 2020). X-Ray baggage screening is a visual inspection task that requires search, decision-making, and problem-solving when image interpretation is not immediately clear (Swann et al., 2024). Human factors are essential in X-Ray baggage screening because operators must visually inspect complex images, identify possible threats, and decide whether further inspection is required (Latscha et al., 2024). Real-world visual search involves complex scenes, multiple possible targets, and cognitive processes

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beyond simple perception, which makes operator attention and cognitive ability important in security screening tasks (Wagner et al., 2024). Operator expertise, experience, trust in automation, and human–machine interaction influence the quality of screening performance in airport security operations (Huegli et al., 2020)

Recent developments in airport screening technology show that conventional X-Ray systems have evolved into dual-view, multi-view, computed tomography, three-dimensional imaging, and AI-assisted threat-detection systems (Singh & Dhiraj, 2026). The Airport 4.0 transition also indicates that future airport security checkpoints may develop toward smart security systems, centralized image processing, biometric walk-through screening, and digital technologies that reduce the need for passengers to remove items during screening (Marmier et al., 2023). Image enhancement features such as slice views, material filtering, and zoom may support threat detection, but these features must be introduced carefully because not all enhancements provide additional value for screeners (Muhl-Richardson et al., 2025). Computed tomography can improve threat detection because it allows screeners to view objects from multiple angles and reduce problems caused by object overlap or occlusion in baggage images (Parker et al., 2022). Three-dimensional imaging allows screeners to rotate baggage images and view cross-sectional slices, and recent evidence indicates that 3D imaging can improve detection performance when image quality is adequate (Latscha et al., 2025). Automated explosive detection systems can assist screeners by indicating areas in X-Ray images that may contain explosive materials, although human operators remain responsible for interpreting and responding to screening results (Hättenschwiler et al., 2018). The use of automation in airport security screening can improve detection performance, but its effectiveness depends on automation reliability, false alarm rates, and operator compliance with system alerts (Huegli et al., 2020). In automated baggage screening, false alarm cues may influence operator trust, response time, and compliance with system recommendations, so operators need appropriate training to understand the strengths and limitations of automated support systems (Chavaillaz et al., 2020). Artificial intelligence has become an important direction in X-Ray screening research because AI-assisted systems can support automated and semi-automated threat analysis in passenger checkpoint screening, checked baggage screening, and cargo screening (Singh & Dhiraj, 2026).

Despite the benefits of technology, X-Ray screening still faces operational challenges related to workload, time pressure, staffing, and operator fatigue (Buser et al., 2023). Time on task and task load can influence the performance of X-Ray baggage screeners, especially when high workload causes officers to speed up image inspection and potentially reduce hit rate over time (Buser et al., 2023). Work environment, noise, social stressors, task load, and time on task also influence baggage screening performance because screeners must maintain accuracy while working in demanding airport conditions (Latscha et al., 2024). The performance of airport security screeners can also be evaluated through threat image projection data, which provides a way to measure whether screeners are able to detect prohibited items in X-Ray images (Buser et al., 2025). These studies show that X-Ray screening is a human–technology system in which machine capability, operator competence, workload management, and performance evaluation must work together to support aviation security (Latscha et al., 2024).

Although previous studies have discussed X-Ray technology, automation, human factors, workload, and threat-detection performance in aviation security, limited attention has been given to how X-Ray screening is implemented in the operational context of Indonesian airports and how these practices can be translated into learning materials for aviation vocational education. Most existing studies focus on technological performance or human–machine interaction, while fewer studies connect real screening practices, operator competence, regulatory compliance, and field challenges with the development of Aviation Security learning competencies. This gap is important because aviation vocational education needs contextual learning resources that reflect real airport security practices, especially in preparing cadets or prospective Aviation Security personnel to understand screening procedures, image interpretation, prohibited item identification, human factors, and technology-supported decision-making.

Therefore, this study aims to analyze the use of X-Ray technology in supporting Aviation Security systems at Juanda Airport by focusing on technology use, operational procedures, operator competence, training and licensing, operational challenges, and educational implications for aviation vocational learning. By examining X-Ray screening practices in a real airport context, this study is expected to contribute not only to the improvement of airport security practices, but also to the development of contextual and practice-based learning materials for Aviation Security education.

II. Method

This study employed a descriptive qualitative approach to analyze the use of X-Ray technology in supporting Aviation Security systems at Juanda Airport and to examine how operational practices can inform aviation vocational learning. A qualitative design was selected because this study focused on understanding screening procedures, operator experience, human factors, and technology use in a real airport security context rather than measuring statistical relationships. Qualitative research is appropriate when a study aims to explore participants' experiences, meanings, and practices in a natural setting. This approach is also relevant in aviation security research because it allows researchers to examine operational practices, human factors, and expert perspectives in real security environments (Zeballos et al., 2023).

A. Research Design

This study employed a descriptive qualitative design, selected to capture the complexity of airport security screening practices in a naturalistic manner. The design was considered appropriate because it allows for a rich, detailed portrayal of how X-Ray technology is utilized in operational contexts, how AVSEC personnel interpret scan images, how suspicious items are identified and managed, and what organizational or technical challenges influence the overall effectiveness of screening procedures. By focusing on everyday practices and real-world scenarios, descriptive qualitative research provides a comprehensive summary of events without attempting to construct abstract theories. Instead, it emphasizes thick description, documenting processes, interactions, and decision-making in terms that are accessible and grounded in practice. This approach ensures that the study not only highlights the technical aspects of X-Ray screening but also illuminates the human factors, situational judgments, and operational constraints that shape security outcomes in aviation environments.

The study did not aim to develop a new theory as in grounded theory, nor to quantify the frequency of textual categories as in content analysis. Instead, the study aimed to identify and interpret recurring operational themes from interviews, observations, and documentation. Therefore, thematic analysis was considered suitable because it enables researchers to identify, analyze, and report patterns or themes within qualitative data (Braun & Clarke, 2006). In this study, thematic analysis was used to organize field data into meaningful themes related to technology use, operator competence, procedural compliance, operational challenges, and educational implications.

Figure 1 illustrates the qualitative research procedure used in this study. The process began with a literature review to identify previous studies related to X-Ray technology, Aviation Security, human factors, and aviation vocational education. The next stage was problem identification, followed by the preparation of interview guidelines, observation guidelines, and documentation checklists. Data were then collected through semi-structured interviews, non-participant observation, and documentation review. The collected data were reduced, coded, and categorized thematically to identify recurring patterns related to X-Ray technology use, operator competence, procedural compliance, operational challenges, and educational implications. To strengthen data trustworthiness, the findings were compared across interviews, field observations, and supporting documents, and were confirmed through member checking. The final stage involved presenting the findings and mapping relevant X-Ray screening practices into possible Aviation Security learning competencies.

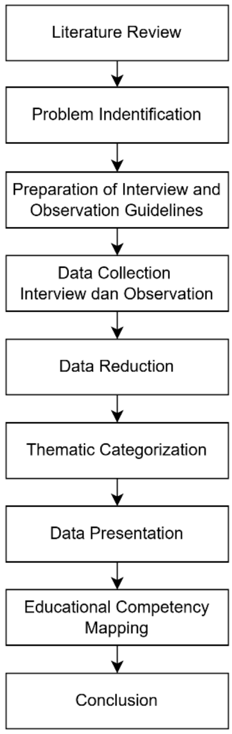

Fig. 1. Qualitative Research Procedure and Educational Competency Mapping

B. Research Context and Participants

The research was conducted in the context of Aviation Security operations at Juanda Airport, Surabaya, Indonesia, particularly in relation to the use of X-Ray screening technology at Security Check Points. The research sites included the domestic departure Security Check Point, the X-Ray operator station, the international departure Security Check Point, and the Aviation Security unit. These areas were selected because they represent key locations where X-Ray screening, image interpretation, secondary inspection, equipment monitoring, and operational decision-making take place.

Participants in this study were selected through purposive sampling, a technique widely employed in qualitative research to ensure the inclusion of information-rich informants who can provide deep insights into the phenomenon under investigation (Patton, 2015). This approach was deemed appropriate because the research required individuals with direct knowledge and hands-on experience in airport security operations, particularly those involving X-Ray screening. The selected participants were expected to contribute nuanced perspectives on how AVSEC personnel interpret scan images, manage suspicious items, oversee procedural compliance, and address challenges related to equipment reliability and regulatory enforcement. By deliberately targeting participants with specialized expertise, purposive sampling enhanced the credibility and relevance of the

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data, ensuring that the findings reflect the practical realities of aviation security rather than generalized assumptions. This method also allowed the study to capture context-specific insights that are critical for understanding both the technical and human dimensions of screening effectiveness.

The inclusion criteria were:

- Active involvement in Aviation Security operations or supervision
- Experience in operating, supervising, inspecting, or managing X-Ray screening activities
- Willingness to provide information through interviews and/or member checking

Participants who did not have direct relevance to X-Ray screening activities were excluded from the study.

The study engaged six informants, carefully selected to represent both operational and supervisory perspectives within airport security. Of these, four were operational AVSEC personnel, who contributed data through in-depth interviews and direct field observations. Their insights provided a grounded understanding of day-to-day screening practices and the challenges encountered in interpreting X-Ray images. In addition, two key informants participated in the member-checking process, serving a critical role in validating and confirming the accuracy of the interpretations drawn from the data. Based on field notes and member-checking documentation, the informants comprised a diverse profile of roles central to aviation security operations: a senior X-Ray operator, a checkpoint supervisor, a security officer, a security manager, the Airport Security Screening Chief, and an Aviation Security Inspector. This composition ensured that the study captured perspectives across multiple levels of responsibility, from frontline operations to managerial oversight and regulatory compliance. Such diversity strengthened the credibility and trustworthiness of the findings by integrating both practitioner and supervisory viewpoints. The detailed profile of the informants is presented in Table 1, which outlines their roles and contributions to the study.

Table 1. Participant Profile

Code	Position / Role	Unit / Work Context	Expertise Relevance	Role in Data Collection
AVSEC-01	Senior X-Ray Operator	Security Check Point	Direct experience in operating X-Ray screening equipment and identifying prohibited items	Interview and field observation
AVSEC-02	Checkpoint Supervisor	X-Ray Operator Station	Experience in supervising X-Ray operators and monitoring image interpretation procedures	Interview and field observation
AVSEC-03	Security Officer	International Departure SCP	Experience in secondary inspection and verification of suspicious baggage	Interview and field observation
AVSEC-04	Security Manager	Aviation Security Unit	Experience in managing workload, equipment reliability, and operational challenges	Interview and field observation
MC-01	Airport Security Screening Chief	Airport Security Division	Expertise in X-Ray screening management, licensing, training, and AVSEC operations	Member checking
MC-02	Aviation Security Inspector, Associate Expert	Airport Authority Office Region III	Expertise in aviation security regulation, SOP compliance, equipment standards, and inspection	Member checking

Before the interviews and member checking process, the informants were informed about the purpose of the study, the use of data for academic publication, and the confidentiality of research information. Participation was voluntary, and the researcher used informant codes in the presentation of interview findings to protect participant identity. This ethical procedure is consistent with qualitative research principles that emphasize informed consent, confidentiality, and respect for participants.

C. Data Collection Technique

Data were collected through semi-structured interviews, non-participant observation, and documentation review. Semi-structured interviews were conducted to explore the role of X-Ray machines, screening procedures, scan interpretation, officer competence, training and licensing, operational effectiveness, field challenges, equipment maintenance, and future technological development. Semi-structured interviews are suitable for qualitative inquiry because they provide flexibility for researchers to explore participants' experiences while maintaining focus on the research questions (Kallio et al., 2016).

Non-participant observation was conducted to understand the real operational context of X-Ray screening. Observation is useful in qualitative research because it allows researchers to understand behavior, interaction, and practices within their natural setting. In this study, the researcher observed the screening process without interfering with the work of AVSEC personnel. The observation focused on the flow of baggage screening, operator attention, interpretation of X-Ray images, communication between operators and secondary inspection officers, handling of suspicious items, passenger flow, workload, and equipment reliability.

Structured field notes were employed during the observation process to systematically record the date, time, location, descriptive notes, interview excerpts, analytical reflections, and emerging codes. This format ensured that the observational data remained organized and traceable for subsequent analysis. The field notes document four observation sessions conducted on 1, 2, 6, and 7 April 2026, across several critical sites, including the domestic departure Security Check Point (SCP), the X-Ray Operator Station, the international departure SCP, and the Aviation Security Unit. Observations in these varied settings provided a comprehensive view of operational practices, enabling the researcher to capture both routine procedures and situational challenges encountered in the screening process.

Table 2. Observation Schedule

Day	Date	Time	Location	Focus of Observation
1	1 April 2026	08.00–12.00 WIB	Domestic Departure Security Check Point	Initial observation of X-Ray screening operations, passenger flow, baggage screening process, and operator coordination
2	2 April 2026	09.00–13.00 WIB	X-Ray Operator Station	Image interpretation process, color indicators, object density, operator attention, and use of image adjustment features
3	6 April 2026	08.00–12.00 WIB	International Departure Security Check Point	Secondary screening procedures, suspicious baggage verification, passenger clarification, and procedural compliance
4	7 April 2026	10.00–14.00 WIB	Aviation Security Unit	Equipment reliability, maintenance and calibration, workload management, fatigue, and operational challenges

In total, the observation was conducted for approximately 16 hours across four operational areas related to X-Ray screening and Aviation Security management.

Documentation review was conducted to support the interview and observation data. Documentation in qualitative research can be used to complement interview and observation data and to provide contextual evidence for interpretation (Bowen, 2009). The reviewed documents included field notes, interview documentation, member-checking forms, and regulatory or procedural information related to X-Ray screening, operator licensing, recurrent training, equipment standards, and Aviation Security procedures. Documentation was used to strengthen data triangulation and to support the mapping of operational findings into aviation vocational learning needs.

D. Research Instrument

The main instrument in this study was the researcher, supported by interview guidelines, observation guidelines, structured field notes, and documentation checklists. In qualitative research, the researcher serves as the primary instrument because data collection and interpretation depend on the researcher's ability to interact with participants, observe the setting, and interpret meaning from the data.

The interview guideline was developed based on the main focus of the study, including X-Ray technology use, scan interpretation, prohibited item identification, suspicious baggage handling, operator competence, training and licensing, screening effectiveness, operational challenges, equipment maintenance, and future technology development. The observation guideline focused on the actual use of X-Ray machines at Security Check Points, the role of operators, the flow of baggage inspection, interaction between operators and secondary inspection officers, and the handling of suspicious items. The structured field notes were used to ensure that observation data were recorded systematically by including observation notes, interview excerpts, analytical reflections, and emerging codes.

E. Data Analysis Technique

The data were analyzed using thematic analysis. Thematic analysis was selected because the study aimed to identify recurring patterns across interview, observation, and documentation data. Thematic analysis is a flexible method for identifying, analyzing, and reporting patterns within qualitative data (Braun & Clarke, 2006). It is appropriate for studies that aim to organize qualitative findings into themes without being tied to a specific theoretical tradition (Nowell et al., 2017).

The analysis was conducted in several stages. First, the researcher reviewed interview notes, field notes, and documentation results to become familiar with the data. Second, relevant data were coded based on recurring issues such as X-Ray as the main screening tool, operator competence, image interpretation, suspicious item handling, licensing, workload, fatigue, equipment maintenance, and AI-assisted screening. Third, similar codes were grouped into broader themes. Fourth, the themes were reviewed by comparing interview findings, observation records, and documentation data. Fifth, the findings were presented narratively and connected with previous studies on X-Ray screening, Aviation Security, human factors, and aviation vocational education.

The initial coding process produced several emerging codes, including screening efficiency, threat detection capability, human–machine interaction, operator competence, image interpretation accuracy, training effectiveness, decision support system, risk verification, procedural compliance, workload management, system reliability, and human factors. These codes were then organized into broader analytical themes used in the Results and Discussion section.

F. Data Trustworthiness

The trustworthiness of the data was ensured through source triangulation, technique triangulation, structured field notes, and member checking. In qualitative research, trustworthiness can be strengthened through credibility, transferability, dependability, and confirmability. Triangulation and member checking are commonly used to improve credibility by comparing data sources and confirming interpretations with participants (Nowell et al., 2017).

Source triangulation was conducted by comparing information from different informants, including operators, supervisors, security officers, managers, and aviation security experts. Technique triangulation was conducted by comparing data obtained from interviews, observation, and documentation. Interview findings were checked against field observations and supporting documents. For example, statements about operator competence, secondary inspection, workload, and equipment maintenance were compared with field notes from the Security Check Point, X-Ray Operator Station, and Aviation Security Unit.

Member checking was conducted after the initial analysis to confirm whether the researcher's summary and interpretation were consistent with the informants' intended meaning. Member checking is used in qualitative research to validate whether the researcher's interpretation accurately reflects participants' views. The process involved at least two key informants. The first member checking was conducted with Amarmuslim, Airport Security Screening Chief, on 7 April 2026. His confirmation emphasized the role of X-Ray as a main screening tool, the importance of Junior AVSEC licensing, refresher training, recurrent training, operator competence, workload management, equipment maintenance, and technology modernization. The second member checking was conducted with Deden Heryana, Aviation Security Inspector, Associate Expert, from the Airport Authority Office Region III on 8 April 2026. His confirmation emphasized regulatory compliance, SOP implementation, operator competence, equipment condition, classification of safe, suspicious, and dangerous items, human factors, fatigue, and future use of AI-assisted screening.

The member-checking process showed that the summarized findings were generally consistent with the information provided by the informants. The process also strengthened several interpretations, particularly the need to emphasize regulatory compliance, quality control, operator licensing, recurrent training, fatigue management, equipment maintenance, and the development of AI-assisted X-Ray screening. Therefore, member checking did not substantially change the main themes, but it refined the interpretation and strengthened the connection between operational findings and aviation vocational learning implications.

III. Results and Discussion

The thematic analysis resulted in four major themes: (1) X-Ray technology as a screening and decision-support system, (2) operator competence, licensing, and procedural compliance, (3) operational challenges, human factors, and equipment reliability, and (4) educational implications for aviation vocational learning. These themes were developed from interview data, field observations, documentation review, and member checking. The findings indicate that X-Ray screening at Juanda Airport is not merely a technological process, but a human–technology–procedure system that depends on machine capability, operator competence, regulatory compliance, workload management, and continuous training.

Table 3. Main Themes of X-Ray Screening Practices and Educational Implications

Main Theme	Key Findings	Educational Implications
X-Ray technology as a screening and decision-support system	X-Ray is used as a primary screening tool for cabin baggage, checked baggage, and cargo. It supports faster inspection and helps officers identify suspicious or prohibited items.	Cadets need to understand X-Ray technology as both a screening tool and a decision-support system.
Operator competence, licensing, and procedural compliance	Screening effectiveness depends on image interpretation skills, knowledge of prohibited items, Junior AVSEC licensing, refresher training, recurrent training, and compliance with SOP.	Learning activities should include image interpretation, prohibited item identification, licensing-related knowledge, and procedural decision-making.
Operational challenges, human factors, and equipment reliability	Fatigue, workload, limited licensed personnel, concentration, equipment maintenance, and calibration affect screening consistency.	Aviation Security learning should include human factors, fatigue management, equipment reliability, and operational risk management.
Educational implications for aviation vocational learning	Real X-Ray screening practices can be converted into contextual, case-based, and practice-based learning materials.	Aviation vocational education should integrate real airport screening scenarios into AVSEC learning competencies.

A. X-Ray Technology as a Screening and Decision-Support System

The findings show that X-Ray technology functions as a primary layer of Aviation Security screening at Juanda Airport. Field observation at the domestic departure Security Check Point showed that all cabin baggage passed through X-Ray screening before passengers entered the departure waiting area. During the observation period, approximately 250–300 passengers passed through the checkpoint, with passenger flow increasing significantly between 08.30 and 10.00 WIB. This condition shows that X-Ray technology is essential not only for threat detection, but also for maintaining passenger flow and screening efficiency during busy operational periods.

1) This finding was supported by one informant who stated:

"X-Ray machines are our main tool for detecting prohibited items. Without them, visual inspection alone would not be sufficient to identify hidden objects inside baggage." (AVSEC-01, Senior X-Ray Operator, translated from Indonesian)

The quote indicates that X-Ray screening is perceived by operators as an essential technology in detecting objects that cannot be easily identified through manual inspection (Singh & Dhiraj, 2026). This finding is consistent with previous studies explaining that X-Ray imaging remains a major technology in aviation security because it enables non-intrusive inspection of luggage and cargo and assists screeners in identifying prohibited items and potential threats (Hättenschwiler et al., 2018).

However, the local context of Juanda Airport adds an important point to previous literature. In this study, X-Ray technology was not used as an independent decision-maker, but as a decision-support tool that still required human interpretation and procedural verification. During observation at the international departure Security Check Point, secondary inspection was conducted when image clarity was insufficient or when object characteristics indicated possible prohibited items.

2) One informant explained:

"Not every suspicious image indicates a dangerous item. Secondary inspection helps us verify the actual content before making a decision." (AVSEC-03, Security Officer, translated from Indonesian)

This finding shows that X-Ray screening works through a layered decision-making process. The machine provides visual information, but the final security decision depends on operator judgment, secondary inspection, and procedural compliance. This extends previous studies that mainly discuss X-Ray technology in terms of detection performance and automation. In the operational context of Juanda Airport, screening effectiveness is shaped by the interaction between technology, operator interpretation, passenger flow, and verification procedures. Therefore, X-Ray technology should be understood not only as a detection device, but also as part of a broader decision-support system in Aviation Security operations.

B. *Operator Competence, Licensing, and Procedural Compliance*

The second theme shows that operator competence is a central factor in determining the effectiveness of X-Ray screening. The observation at the X-Ray Operator Station showed that operators identified objects based on color representation, material density, and image characteristics. Different materials appeared in different colors, helping operators distinguish organic materials, metals, and mixed substances. Some baggage images required magnification and adjustment to improve object identification. This indicates that X-Ray screening requires visual literacy, technical skill, and repeated practice.

1) One informant emphasized:

"The effectiveness of X-Ray technology greatly depends on operator competence. The machine provides the image, but interpretation depends on the operator's experience and training." (AVSEC-02, Checkpoint Supervisor, translated from Indonesian)

This quote directly supports the finding that the effectiveness of X-Ray screening is not determined solely by the machine. It depends on the ability of operators to interpret images accurately and make appropriate decisions (Huegli et al., 2020). Human–machine interaction, operator compliance, visual inspection, attention, and decision-making under operational pressure are important factors that influence airport security screening performance (Latscha et al., 2024).

The findings also show that operator competence is closely related to licensing and continuous training. Member-checking data confirmed that X-Ray operators are required to have a Junior AVSEC license, participate in annual refresher training, and complete recurrent training every two years. Operators are also expected to master image analysis, prohibited item identification, and technical operation of the machine. This means that competence in X-Ray screening is not a one-time qualification, but a continuous professional requirement.

This study adds to previous research by showing how competence is regulated and operationalized in the Indonesian airport context. While previous studies emphasize operator expertise and human–machine performance, this study highlights the importance of regulatory compliance, licensing, refresher training, and recurrent training as part of screening effectiveness. In other words, the reliability of X-Ray screening at Juanda Airport depends on three interconnected elements: the availability of appropriate technology, the competence of licensed operators, and strict adherence to Aviation Security procedures.

Procedural compliance is also important in handling suspicious or dangerous objects. Member-checking data from the Aviation Security Inspector confirmed that screening results must be classified systematically into safe, suspicious, or dangerous categories. If the item indicates a serious threat such as an Improvised Explosive Device component, the operator must report it to the supervisor without directly intervening. This shows that

X-Ray screening requires risk-based decision-making and discipline in following SOP.

Therefore, operator competence in this study should be understood as a combination of technical ability, regulatory knowledge, procedural discipline, and professional judgment. This finding is important for Aviation Security education because students should not only learn the function of X-Ray machines, but also how operators interpret images, classify risks, follow procedures, and make decisions in real airport security situations.

C. Operational Challenges, Human Factors, and Equipment Reliability

The third theme relates to operational challenges that may influence the quality and consistency of X-Ray screening. The findings show that screening performance is affected by workload, fatigue, concentration, limited licensed personnel, equipment condition, maintenance, and calibration. Observation at the Aviation Security Unit showed that X-Ray systems undergo routine maintenance and calibration according to airport security requirements. However, operational personnel also reported that increased passenger volume during peak hours may increase workload and operator fatigue, which can affect image interpretation performance.

1) One informant stated:

"The technology itself can be reliable, but workload management is equally important because operators must remain concentrated during the screening process." (AVSEC-04, Security Manager, translated from Indonesian)

This statement shows that reliable technology does not automatically guarantee reliable screening outcomes. The operator must remain focused throughout the screening process (Buser et al., 2023). Time on task, workload, work schedules, and circadian rhythm may influence X-Ray baggage screening performance and cognitive performance in airport security operations (Riz à Porta et al., 2024).

The local finding from Juanda Airport adds another layer to the discussion. Operational challenges are not only related to individual fatigue, but also to staffing, licensing, and equipment readiness. Member-checking data from the Airport Security Screening Chief indicated that several challenges still exist, including limited licensed personnel, high operator workload, and equipment conditions that may become less optimal when maintenance is insufficient. These factors may reduce screening effectiveness and increase the risk of human error.

Member-checking data from the Aviation Security Inspector further emphasized that human factors include experience, eye health, concentration, psychological condition, fatigue, repetitive work, long working duration, and professional objectivity. This finding extends previous literature by showing that human factors in X-Ray screening are not only cognitive or technical issues, but also organizational and ethical issues. In the Indonesian airport context, maintaining screening quality requires not only training and technology, but also supervision of working hours, task rotation, health checks, professionalism, integrity, and quality assurance.

Equipment reliability is also a key issue. X-Ray machines need regular maintenance, calibration, and replacement according to their service life. If equipment condition declines, image quality may also decline, which may affect operator interpretation. Airport screening technology must support detection accuracy and operational efficiency; however, this study adds that in real operational settings, technology performance depends not only on system design but also on maintenance practices, staff allocation, and operational management (Singh & Dhiraj, 2026).

Based on these findings, this study proposes that X-Ray screening effectiveness can be understood through a human–technology–procedure framework. In this framework, screening quality is produced through the interaction of four elements: machine capability, operator competence, procedural compliance, and operational support. If one element is weak, such as insufficient licensed personnel, operator fatigue, or poor equipment maintenance, screening effectiveness may decline even when the X-Ray machine itself is technologically advanced.

D. Educational Implications for Aviation Vocational Learning

The fourth theme shows that X-Ray screening practices have strong relevance for aviation vocational education. The findings indicate that actual screening practices at Juanda Airport can be transformed into contextual and practice-based learning materials for Aviation Security education. These materials may include X-Ray machine operation, image interpretation, prohibited item identification, suspicious baggage handling, secondary inspection procedures, operator licensing, fatigue management, equipment maintenance, and AI-assisted screening.

This finding is important because aviation vocational education should prepare cadets for real operational environments where technology, procedures, and human judgment work together. The field data show that AVSEC personnel do not simply operate machines; they interpret images, classify risks, communicate with other officers, follow SOP, manage passenger flow, respond to suspicious items, and maintain concentration under workload pressure. Therefore, Aviation Security learning should not only focus on theoretical regulations, but also on practical scenarios that reflect real airport screening conditions. The educational implication of this study can be mapped into learning competencies as shown in Table 4.

This mapping provides a practical contribution to Aviation Security education. It shows how operational findings can be transformed into learning content and training activities. For example, the finding that operators rely on color indicators and material density can be developed into image interpretation exercises. The finding that suspicious baggage requires secondary inspection can be developed into scenario-based learning. The finding that fatigue and workload affect concentration can be developed into human factor and risk management learning materials.

Table 4. Mapping of X-Ray Screening Practices into Aviation Security Learning Competencies

X-Ray Screening Practice	Related AVSEC Competency	Possible Learning Activity
Operating X-Ray machines	Understanding screening equipment and its function	Simulation of X-Ray machine operation
Reading X-Ray images	Image interpretation skill	Practice identifying organic, inorganic, metal, and mixed objects
Identifying prohibited items	Threat identification	Case analysis using suspicious baggage scenarios
Handling suspicious baggage	Procedural decision-making	Scenario-based learning on secondary inspection
Reporting dangerous items	Risk communication and supervisor reporting	Role-play of suspicious item reporting procedures
Managing workload and fatigue	Human factor awareness	Discussion and reflection on fatigue, concentration, and task rotation
Maintaining equipment reliability	Awareness of maintenance and calibration	Case discussion on equipment failure and screening quality
Understanding AI-assisted screening	Digital and technological readiness	Introduction to AI, Automated Threat Recognition, and limitations of automation

This study also indicates that future Aviation Security learning should introduce students to AI-assisted screening and Automated Threat Recognition. Member-checking data confirmed that AI, machine learning, and automated threat recognition may support faster and more accurate object identification in the future. Airport X-Ray screening technology is developing toward AI-assisted threat analysis and human-centric system design; however, this study also emphasizes that AI should be introduced as a support system, not as a replacement for human responsibility (Singh & Dhiraj, 2026). Students need to understand both the potential and limitations of AI in Aviation Security screening.

Overall, the discussion shows that the contribution of this study is twofold. First, it contributes to Aviation Security practice by identifying how X-Ray screening effectiveness depends on technology, operator competence, SOP compliance, workload management, and equipment reliability. Second, it contributes to aviation vocational education by proposing that real airport screening practices can be transformed into contextual, case-based, and practice-based learning materials. In this way, X-Ray screening becomes not only an airport security operation, but also a learning resource for preparing competent Aviation Security personnel.

IV. Conclusion

This study concludes that X-Ray technology is a central component of Aviation Security screening at Juanda Airport because it supports the inspection of cabin baggage, checked baggage, and cargo more efficiently. However, X-Ray screening should not be viewed only as a technological process, but as a human–technology–procedure system. Its effectiveness depends on machine capability, operator competence, licensing, recurrent training, SOP compliance, workload management, and equipment reliability. The findings also show that fatigue, limited licensed personnel, concentration, maintenance, and calibration are important operational factors that may affect screening consistency. From an educational perspective, real X-Ray screening practices can be transformed into contextual and practice-based learning materials for aviation vocational education. These materials can strengthen Aviation Security learning competencies in image interpretation, prohibited item identification, suspicious baggage handling, secondary inspection, human factors, equipment reliability, and AI-assisted screening. Therefore, this study contributes to both Aviation Security practice and the development of vocational learning that reflects real airport security operations.

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