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Optimization of Airside Vehicle Movement Management to Minimize Runway Incursion Risk at Sentani International Airport

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Abstract: The safety of vehicle movements within the airside area is a critical component of aviation safety, as ineffective management may increase the risk of runway incursions. This study aims to analyze the existing management of airside vehicle movements, identify the factors influencing runway incursion risk, and develop optimization strategies for airside vehicle movement management at Sentani International Airport. The study employed a qualitative approach using a case study design. Data were collected through in-depth interviews, field observations, and document analysis, and were analyzed using the interactive model of Miles, Huberman, and Saldana. Data credibility was ensured through triangulation and member checking. The findings indicate that airside vehicle movement management has been implemented through operational procedures, surveillance systems, personnel authorization mechanisms, and safety reporting practices. However, the findings indicate that the effectiveness of airside vehicle movement management may be influenced by several interrelated factors, including human performance, situational awareness, visual guidance effectiveness, operational complexity, and operational workload. These findings highlight the importance of strengthening existing safety controls through an integrated and proactive approach. Based on these findings, this study proposes a conceptual model for optimizing airside vehicle movement management by integrating five strategic components: Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture. The proposed model contributes to strengthening the implementation of the Safety Management System (SMS) and provides practical recommendations for airport operators to enhance operational safety and minimize the risk of runway incursions.

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INTRODUCTION

Aviation safety is a fundamental indicator of air transportation performance and requires the comprehensive implementation of a Safety Management System (SMS) across all airport operational activities. The increasing complexity of flight operations is driven not only by the growth in air traffic volume but also by the increasing interaction among aircraft, operational personnel, and support vehicles within airport airside areas. Consequently, effective airside vehicle movement management has become an important component of airport safety, as deviations from established operational procedures may create movement conflicts that potentially affect flight operations. One of the significant safety threats recognized by the International Civil Aviation Organization (ICAO) is a runway incursion, defined as the incorrect presence of an aircraft, vehicle, person, or other object on the protected area designated for the landing and take-off of aircraft (ICAO, 2022).

The complexity of airport ground operations requires safety management approaches that address the interaction of human, technical, infrastructural, and organizational factors. According to

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the Federal Aviation Administration (FAA, 2023), runway incursions are associated not only with technical conditions but also with human factors, communication, operational environments, surveillance effectiveness, and coordination among operational units. Recent studies similarly indicate that runway incursion risk results from interactions among multiple contributing factors rather than from isolated operational errors (Omosebi et al., 2023; Yan et al., 2024; Koc & Cınar, 2025). These findings indicate that airside vehicle movement management should be positioned as an integral component of airport safety management rather than merely as a supporting operational activity. Accordingly, preventive strategies need to consider operational procedures, human performance, surveillance, infrastructure, and organizational safety management in an integrated manner.

Sentani International Airport was selected as the research setting because of its strategic operational role and the complexity of interactions occurring within its airside environment. As an important air transportation gateway serving Papua and supporting regional connectivity, the airport accommodates aircraft movements as well as various supporting activities involving operational personnel and ground vehicles. Based on the 2025 Air Traffic Statistics, the airport recorded 40,808 aircraft movements during the year. This operational intensity provides a relevant context for examining airside vehicle movement management because increasing aircraft activity is accompanied by more frequent interactions among aircraft, Ground Support Equipment (GSE), maintenance vehicles, airport operational vehicles, and other support vehicles operating within airside areas. Previous research has indicated that higher traffic intensity can increase operational complexity and the potential for runway incursions and vehicle-aircraft conflicts (Omosebi et al., 2023). Therefore, Sentani International Airport provides a relevant case for examining how multiple safety dimensions can be integrated into airside vehicle movement management within a regional airport context.

The selection of Sentani International Airport is also relevant from a regional airport perspective. Airports outside major metropolitan aviation hubs may face operational characteristics that differ from those of large international hub airports, particularly in managing increasing operational activity while maintaining effective coordination, surveillance, infrastructure, and safety management mechanisms. In this context, examining airside vehicle movement management at Sentani International Airport provides empirical insight into how an integrated safety management approach can be applied within a regional airport environment. The study therefore does not merely examine the existence of individual safety controls but focuses on the interaction among the factors that influence the effectiveness of airside vehicle movement management.

Within the Safety Management System (SMS) framework, aviation safety is achieved through a systematic and continuous process of hazard identification, risk assessment, and risk mitigation (ICAO, 2018). This approach emphasizes that safety is an organizational responsibility rather than merely an individual obligation. Consequently, effective risk management depends not only on procedural compliance but also on personnel competency, situational awareness, infrastructure effectiveness, surveillance capability, technological support, and organizational safety culture. Previous studies have identified situational awareness, communication, and human performance as important contributors to runway incursion risk (Endsley, 1995; Yan et al., 2024). Other studies have examined the role of digital surveillance technologies in improving monitoring of airside operational activities (Zhang et al., 2022), while Reason (1997) demonstrated that safety occurrences may emerge through interactions among multiple latent organizational conditions rather than from isolated human errors. Furthermore, recent research has highlighted the potential of digital surveillance, real-time vehicle monitoring, and data-driven safety reporting to support hazard identification and operational decision-making in airport movement areas (Cheng et al., 2024).

Previous studies have provided important contributions by examining different dimensions of runway incursion and airport safety. Yan et al. (2024), for example, emphasize the importance of human factors and situational awareness in understanding runway incursion risk. Cheng et al. (2024) focus on the role of surveillance technology and digital monitoring in supporting airport safety

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management. Omosebi et al. (2023) examine operational factors associated with runway incursion and highlight the complexity of interactions within airport movement areas. Meanwhile, Apiratanarungsi and Dowpiset (2024) emphasize the importance of organizational safety culture in supporting aviation safety performance. These studies demonstrate that human performance, technology, operational risk, and organizational culture are all important dimensions of runway incursion prevention.

However, the existing studies predominantly examine these dimensions from separate perspectives. Research focusing on human factors does not necessarily integrate infrastructure and technology considerations, while studies emphasizing surveillance technology primarily address monitoring capabilities rather than the broader organizational and human context. Similarly, studies on operational risk and safety culture provide important insights into specific aspects of aviation safety but do not fully integrate these aspects into a framework specifically oriented toward airside vehicle movement management. Thus, the limitation in the existing literature is not the absence of research on runway incursion, but the limited integration of multiple safety dimensions into a unified framework for managing airside vehicle movements.

This gap becomes particularly relevant in regional airport environments, where the interaction between aircraft operations, ground vehicles, personnel, infrastructure, surveillance, and organizational safety mechanisms requires a comprehensive management perspective. The existing literature provides a strong foundation for understanding individual risk contributors, but further research is needed to explain how these dimensions can be integrated as complementary layers of safety control within the Safety Management System. Such integration is important because runway incursion risk may emerge through the interaction of multiple conditions rather than through a single human, technical, or organizational factor.

To address this gap, this study proposes an integrated conceptual model for optimizing airside vehicle movement management through five strategic dimensions: **Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture**, within the Safety Management System framework. The novelty of this study lies in integrating these five dimensions into a unified framework specifically oriented toward airside vehicle movement management at a regional airport. Rather than treating individual safety factors independently, the proposed framework connects human, infrastructural, technological, operational, and organizational dimensions as complementary layers of safety control.

Accordingly, this study aims to analyze the existing management of airside vehicle movements, identify the factors influencing runway incursion risk, and formulate an integrated framework for strengthening airside vehicle movement safety. Theoretically, the study contributes to the application of Safety Management System principles by integrating multiple safety dimensions within an airside vehicle management perspective. Practically, the proposed framework provides a basis for strengthening existing safety controls, supporting risk-informed decision-making, and improving the coordination of airside vehicle operations in regional airport environments.

RESEARCH METHOD

This study employed a qualitative approach using a case study design to obtain an in-depth understanding of airside vehicle movement management in minimizing runway incursion risk at Sentani International Airport. A qualitative case study was considered appropriate because runway incursion is a complex operational phenomenon influenced by interactions among human factors, organizational management, airport infrastructure, operational procedures, surveillance systems, and environmental conditions. This approach enables researchers to investigate operational phenomena comprehensively within their natural settings while exploring participants' experiences and perspectives in depth (Sugiyono, 2023; Yin, 2018).

The research was conducted at Sentani International Airport, Jayapura Regency, Papua Province, Indonesia. As the primary airport serving eastern Indonesia, Sentani International Airport experiences

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relatively high levels of aircraft operations and airside vehicle movements. The study focused on operational vehicle activities within designated airside operational areas where interactions between vehicles, personnel, and aircraft movements may occur. The analysis emphasized vehicle movement management, operational coordination, surveillance practices, and safety risk management without disclosing specific operational locations or security-sensitive information.

Research participants were selected using purposive sampling, targeting individuals with direct experience, knowledge, and involvement in airside vehicle management. The participants included Apron Movement Control (AMC) personnel responsible for supervising operational vehicle movements, Ground Support Equipment (GSE) operators, operational vehicle drivers, and other personnel involved in airside operations. A total of 4 participants participated in the study, and data collection was continued until data saturation was achieved, indicated by the absence of new themes or significant information emerging from subsequent interviews (Patton, 2015). The participants were selected based on their direct operational experience and relevance to the research objectives.

Data were collected using three complementary techniques: semi-structured interviews, non-participant observations, and document analysis. Semi-structured interviews were conducted to obtain information regarding the implementation of operational procedures, vehicle surveillance practices, factors influencing runway incursion risk, and strategies for improving operational safety. Each interview lasted approximately 20–40 minutes and was conducted according to the availability of the participants and the research requirements. Non-participant observations were carried out to examine actual vehicle movement activities, AMC surveillance practices, visual guidance facilities, and characteristics of the operational environment. Document analysis was conducted to corroborate evidence obtained from interviews and field observations using relevant operational, safety, and regulatory documentation. The integration of multiple sources of evidence strengthened the credibility and consistency of the research findings (Yin, 2018).

The validity of the qualitative data was ensured through credibility, transferability, dependability, and confirmability using triangulation, member checking, and prolonged engagement, as recommended in qualitative research procedures (Sugiyono, 2023). Credibility was enhanced through source triangulation, method triangulation, and member checking. Transferability was supported by providing detailed descriptions of the research context and operational environment. Dependability was maintained through a systematic research procedure, while confirmability was ensured by documenting analytical decisions throughout the research process. Data credibility was strengthened through source triangulation, method triangulation, and member checking to ensure the consistency and accuracy of the research findings (Sugiyono, 2023).

Data were analyzed using the interactive model proposed by Miles, Huberman, and Saldana (2014), which consists of three interconnected stages: data condensation, data display, and conclusion drawing and verification. During the data condensation stage, interview transcripts, observation notes, and documentary evidence were transcribed, coded, and categorized into major themes related to airside vehicle movement management, factors contributing to runway incursions, and risk mitigation strategies. The data display stage involved organizing the findings into thematic narratives, analytical matrices, and synthesized relationships among themes to facilitate interpretation. Finally, conclusions were continuously verified throughout the analytical process to ensure consistency in interpreting the existing conditions of airside vehicle movement management, the factors influencing runway incursion risk, and the proposed optimization strategies aligned with the principles of the Safety Management System (SMS).

The analytical framework adopted in this study was based on the Safety Management System (SMS) developed by the International Civil Aviation Organization (ICAO, 2018). The analysis focused on three essential safety management processes: hazard identification, risk assessment, and risk mitigation. Empirical findings were subsequently synthesized into an integrated conceptual model consisting of five strategic components, namely Human-Centered Safety Management, Infrastructure

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Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture. The model was developed through thematic synthesis by integrating empirical evidence with established aviation safety theories and previous studies.

RESULTS AND DISCUSSION

Sentani International Airport is the primary airport in Papua Province and serves as the main air transportation hub in eastern Indonesia. In addition to accommodating scheduled passenger flights, the airport supports logistics distribution, cargo operations, pioneer flights, and various operational activities that contribute to regional development in Papua. The high intensity of these operations makes Sentani International Airport one of the busiest airports in eastern Indonesia. Consequently, airside operations are characterized by a high level of complexity due to the interaction among aircraft, operational personnel, and various airport support vehicles.

According to the 2025 Air Traffic Statistics, Sentani International Airport recorded 40,808 aircraft movements, consisting of 20,223 arrivals, 20,269 departures, and 316 local movements. This high volume of aircraft operations indicates that airport activities are conducted continuously throughout the year and require effective coordination among Air Traffic Control (ATC), Apron Movement Control (AMC), Ground Support Equipment (GSE) operators, and all personnel operating within the airside area.

Table 1. Aircraft Movements at Sentani International Airport in 2025

Month	Arrivals	Departures	Local	Total
Januari	1.896	1.900	17	3.813
February	1.571	1.574	20	3.165
March	1.484	1.486	45	3.015
April	1.359	1.365	21	2.745
May	1.457	1.450	19	2.926
June	1.464	1.478	41	2.983
July	1.831	1.841	21	3.693
August	1.796	1.802	26	3.624
September	1.649	1.653	21	3.323
October	1.831	1.832	17	3.680
November	1.787	1.789	30	3.606
December	2.098	2.099	38	4.235
Total	**20.223**	**20.269**	**316**	**40.808**

Source: Sentani International Airport Air Traffic Statistics, 2025.

As presented in Table 1, aircraft movements remained relatively stable throughout the year, with a noticeable increase between July and December. The highest traffic volume was recorded in December, with 4,235 aircraft movements, while the lowest occurred in April, with 2,745 movements. These fluctuations reflect variations in air transportation demand associated with seasonal travel, economic activities, and governmental operations in Papua. The increasing number of aircraft movements directly contributes to a higher frequency of operational vehicles entering the airside area, thereby increasing the potential for interactions between vehicles and aircraft.

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The high operational intensity within the airside environment requires an effective airside vehicle management system capable of consistently ensuring operational safety. Operational vehicles—including Ground Support Equipment (GSE), maintenance vehicles, airport engineering vehicles, baggage handling vehicles, and other support vehicles—must operate in accordance with established procedures to avoid interference with aircraft movements. In this context, Apron Movement Control (AMC) plays a crucial role in regulating, supervising, and controlling all vehicle activities within the operational area to ensure that every movement is conducted safely, efficiently, and in compliance with aviation safety regulations.

Based on these operational characteristics, Sentani International Airport presents considerable challenges in managing airside vehicle movements. Such complexity arises not only from the high volume of air traffic but also from the frequent interactions among operational vehicles, personnel, and aircraft within a constrained operational environment. Therefore, airside vehicle management should not merely focus on maintaining operational efficiency but should also constitute an integral component of the Safety Management System (SMS) to minimize the risk of runway incursions and enhance overall airport operational safety. The increasing intensity of aircraft movements also indicates a proportional increase in the frequency of interactions between aircraft and operational vehicles operating within the movement area. Previous studies have demonstrated that higher traffic density substantially increases the complexity of airport surface operations, thereby elevating the probability of runway incursions if surveillance and coordination systems are not strengthened (Omosebi et al., 2023; Koc & Cınar, 2025). Therefore, the operational characteristics of Sentani International Airport provide a relevant context for evaluating the effectiveness of airside vehicle movement management.

Existing Airside Vehicle Movement Management

The findings indicate that airside vehicle movement management at Sentani International Airport has been implemented through the application of operational procedures, personnel and vehicle authorization systems, supervision by Apron Movement Control (AMC), and the use of Closed-Circuit Television (CCTV) as a surveillance tool. These measures constitute an integral part of the airport's Safety Management System (SMS), which is intended to ensure that all operational vehicle activities are conducted safely, systematically, and without interfering with aircraft movements. Based on field observations and an examination of operational documents, vehicle movement management has been implemented in accordance with the Quality Procedures and Work Instructions (PMIK), which establish standardized procedures governing vehicle operations within the airside area.

Interviews with AMC personnel revealed that vehicle surveillance is conducted through a combination of routine field patrols and CCTV monitoring. Field inspections are performed periodically to ensure operators comply with established operational procedures, while CCTV is utilized to monitor vehicle activities in areas that cannot be directly observed by AMC personnel. This integrated approach enables broader surveillance coverage and supports the early identification of operational deviations. These findings indicate that Sentani International Airport has implemented a combination of direct surveillance and technology-assisted surveillance, consistent with the operational surveillance principles recommended in ICAO Annex 14.

The findings indicate that CCTV-based surveillance provides important support for monitoring airside vehicle activities. At the same time, opportunities remain to further enhance surveillance effectiveness through technology-assisted monitoring and proactive risk identification. Such enhancement may support earlier recognition of potential operational conflicts and strengthen situational awareness among personnel responsible for airside monitoring. Consequently, surveillance effectiveness remains highly dependent on operators' vigilance and response time (Cheng et al., 2024).

Nevertheless, the findings indicate that conventional surveillance approaches may still present limitations in identifying potential hazards before they develop into safety occurrences. The

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effectiveness of surveillance depends not only on the availability of monitoring personnel and equipment but also on the capability to maintain continuous situational awareness and provide timely responses to emerging operational risks. These conditions highlight the importance of strengthening surveillance approaches through more proactive and risk-based mechanisms (Omosebi et al., 2023; Yan et al., 2024).

The findings suggest that surveillance based primarily on periodic inspections may benefit from complementary approaches that support continuous monitoring and timely hazard identification. Within the context of modern aviation safety, surveillance should function not only as a compliance monitoring mechanism but also as a proactive hazard identification tool that enables organizations to implement timely risk mitigation measures. Therefore, strengthening surveillance through a risk-based approach may improve the ability to prioritize operational areas according to their relative safety risks.

In addition to the surveillance system, the findings indicate that operational vehicle control is supported by regulatory requirements that mandate all personnel and vehicles entering the airside area to satisfy administrative and competency requirements. All operators are required to possess valid licenses or certifications appropriate to their assigned duties and demonstrate adequate knowledge of applicable operational procedures. These findings indicate that Sentani International Airport has established an administrative control system consistent with the fundamental principles of operational safety by ensuring that only qualified and authorized personnel are permitted to conduct activities within the movement area.

Interview results further revealed that most operators possess a strong awareness of operational safety and consistently regard safety as the highest priority in performing their duties. This finding suggests that procedural compliance has been well established at the individual level. However, the existence of operational procedures and competent personnel alone has not been sufficient to eliminate the potential for runway incursions. This indicates that operational safety is influenced not only by individual compliance with established procedures but also by the effectiveness of the organizational system in managing the various operational risks encountered during daily airport activities.

From the perspective of Reason's Swiss Cheese Model (Reason, 1997), operational procedures, personnel licensing, and surveillance systems represent multiple layers of defense within the organizational safety system. However, each defensive layer contains inherent latent conditions that may interact under specific circumstances, creating opportunities for safety occurrences. Accordingly, the effectiveness of airside vehicle movement management should not be evaluated solely by the existence of operational procedures but also by the organization's capability to identify and manage systemic weaknesses before they develop into more significant operational risks.

Overall, the findings demonstrate that Sentani International Airport has established a solid foundation for airside vehicle movement management through the implementation of operational procedures, authorization systems, AMC surveillance, and technological surveillance support. Nevertheless, further improvements are required to enhance the effectiveness of the existing system, particularly in the areas of risk-based surveillance, real-time operational monitoring, and the adoption of a more proactive safety management approach consistent with the principles of the Safety Management System (SMS). These findings provide the basis for identifying the factors influencing runway incursion risk, which are discussed in the following section.

Factors Contributing to Runway Incursion Risk

The analysis of interview data, field observations, and document reviews indicates that the risk of runway incursions at Sentani International Airport is not attributable to a single factor but rather results from the interaction of multiple interrelated factors. Through thematic analysis, this study identified five principal themes influencing runway incursion risk: (1) human factors, (2) visual facility conditions, (3) operational environment characteristics, (4) operational pressure, and (5) organizational

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factors. These findings are broadly consistent with previous systematic research identifying human, technical, environmental, airport-related, and organizational factors as important contributors to runway incursions (Wang et al., 2018). These findings suggest that mitigating runway incursion risk requires a systemic approach that considers the interdependence of various components within the airport safety system.

Human Factors

The findings indicate that human performance and situational awareness are important factors in managing runway incursion risk. The dynamic nature of airside operations may influence operators' ability to continuously perceive, interpret, and anticipate changes in the operational environment, particularly when multiple activities occur simultaneously. These conditions suggest that situational awareness should be considered within a broader operational and organizational context rather than being attributed solely to individual performance.

These findings are consistent with Endsley's (1995) Situational Awareness Theory, which emphasizes the importance of perceiving environmental conditions, understanding their significance, and anticipating their future development. Accordingly, improving operational safety requires not only competency development but also organizational measures that support effective communication, workload management, recurrent training, safety briefings, and operational coordination.

The present findings are consistent with those of Yan et al. (2024), who identified inadequate situational awareness as one of the primary contributors to runway incursions. Similarly, Chang et al. (2012) argued that operational errors rarely occur in isolation but instead result from interactions among human, environmental, and organizational factors. Therefore, improving operational safety requires more than strict procedural compliance; it also necessitates continuous competency development through recurrent training, safety briefings, and operational simulations designed to enhance situational awareness. Human performance in airport operations is highly influenced by workload, time pressure, environmental complexity, and communication quality. Therefore, improving situational awareness should not rely solely on recurrent training but also require organizational interventions aimed at reducing operational distractions and improving coordination among operational units (Yan et al., 2024; Koc & Cınar, 2025).

Visual Facility Conditions

The findings indicate that the condition and adequacy of visual guidance facilities remain important considerations in supporting safe vehicle navigation. Continuous maintenance of pavement markings, signs, lighting, and other visual guidance elements is particularly important under conditions involving reduced visibility or increased operational complexity. From a Safety Management System perspective, visual guidance facilities can be considered an important layer of defense that supports situational awareness and reduces the likelihood of navigation-related errors.

Accordingly, regular inspection and maintenance of visual guidance facilities should form part of systematic safety risk mitigation. Rather than being considered solely as routine maintenance activities, infrastructure inspections can be integrated into hazard identification processes to ensure that potential environmental contributors to operational risk are identified and addressed proactively.

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Figure 1. Vehicle Operator's Visual Perspective of the Airside Movement Area

These findings are consistent with those reported by Pangestuti (2025), who demonstrated that the quality of pavement markings, signage, and visual facilities significantly affects the effectiveness of operational vehicle navigation at airports. Moreover, ICAO Annex 14, Volume I, identifies pavement markings and airfield lighting systems as essential visual aids supporting the safe movement of aircraft and vehicles within airport operational areas. Consequently, regular inspection and maintenance of visual facilities should be incorporated into airport safety risk mitigation strategies. From the perspective of safety risk management, deteriorated visual facilities represent latent organizational hazards that may remain unnoticed until combined with human errors or operational pressure. Consequently, regular infrastructure inspections should be integrated into airport hazard identification programs rather than conducted solely as routine maintenance activities.

Operational Environment Characteristics

In addition to human factors and visual facilities, this study found that the physical characteristics of the operational environment also contribute to runway incursion risk. Interview findings indicate that certain airside operational areas may present spatial and maneuvering constraints for vehicle operators. Such conditions require careful vehicle maneuvering, effective communication, and adequate situational awareness, particularly when multiple operational activities occur simultaneously. These conditions require operators to perform vehicle maneuvers with a higher level of precision than in less constrained operational areas.

From a systems ergonomics perspective, limited maneuvering space increases operators' mental workload because they must process multiple sources of information within a relatively short period. As operational complexity increases, so does the likelihood of decision-making errors. This finding is consistent with previous studies indicating that operational complexity, human factors, and airport surface conditions collectively contribute to runway incursion risk by increasing cognitive demands and reducing situational awareness among operational personnel (Endsley, 1995; Omosebi et al., 2023; Yan et al., 2024).

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Operational Pressure

Operational records indicate that the airport experienced a relatively high level of aircraft activity during the study period. Such operational intensity may increase workload and coordination demands among personnel and operational units. Within the Safety Management System framework, these conditions should be considered in assessing operational pressure and maintaining effective risk controls.

Within the Safety Management System (SMS) framework, increasing workload may generate operational pressure, defined as work-related demands that encourage personnel to complete tasks rapidly, thereby increasing the likelihood of procedural deviations. Although interview participants consistently emphasized that safety remains their highest operational priority, the increasing intensity of airport operations should be recognized as an important factor in operational risk management.

These findings reinforce the principles presented in ICAO Doc 9859, which identifies operational pressure as an organizational factor capable of influencing decision-making quality and increasing the likelihood of unsafe acts when not adequately managed through an effective risk management system.

Organizational Factors

The findings indicate that existing organizational mechanisms provide an important foundation for safety management, while opportunities remain to further strengthen proactive hazard identification, particularly in operational areas characterized by greater complexity and interaction. This highlights the importance of continuously developing risk-based surveillance and organizational learning mechanisms within the Safety Management System.

According to Reason's Swiss Cheese Model (Reason, 1997), safety occurrences may emerge through interactions among multiple defensive layers and contributing conditions. Accordingly, runway incursion risk should not be interpreted solely from the perspective of individual performance, but rather as a systemic issue involving human, organizational, environmental, infrastructural, and technological factors. This perspective reinforces the importance of comprehensive system-level safety improvements.

Organizational resilience depends not only on written operational procedures but also on the organization's capability to continuously learn from safety occurrences and near-miss events. Therefore, safety reporting systems should function as organizational learning mechanisms supporting continuous safety improvement rather than merely serving administrative reporting purposes (ICAO, 2018; Apiratanarungsi & Dowpiset, 2024).

Synthesis of Findings

Overall, the findings demonstrate that runway incursion risk at Sentani International Airport results from the interaction of human factors, visual facility conditions, operational environment characteristics, operational pressure, and organizational factors. These five factors are highly interdependent and cannot be effectively addressed in isolation within the airport safety management process.

The findings further suggest that risk mitigation strategies focusing on a single aspect—such as personnel competency development or procedural enforcement alone—are insufficient to effectively reduce runway incursion risk. Instead, an integrated approach consistent with the principles of the Safety Management System (SMS) is required. Such an approach should combine human resource competency development, safety infrastructure enhancement, technology utilization, risk-based surveillance, and the strengthening of organizational safety culture. This synthesis provides the conceptual foundation for developing the optimization strategies for airside vehicle movement management presented in the following section.

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Optimization Strategies for Airside Vehicle Movement Management to Minimize Runway Incursion Risk

Based on the thematic analysis, this study demonstrates that the risk of runway incursions at Sentani International Airport results from the interaction among human factors, infrastructure conditions, operational environment characteristics, operational pressure, and organizational systems. These findings indicate that runway incursion risk cannot be effectively mitigated through isolated interventions but instead requires an integrated strategy consistent with the principles of the Safety Management System (SMS). Accordingly, this study proposes a conceptual model for optimizing airside vehicle movement management, integrating five key components: Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture.

The proposed optimization strategy reflects a systems-thinking perspective in which runway incursion prevention is achieved through the interaction of organizational, technological, infrastructural, and human dimensions rather than through isolated corrective measures. Similar observations have been reported by Omosebi et al. (2023), who emphasized that runway incursions commonly result from multiple interacting operational factors. Likewise, Yan et al. (2024) concluded that effective mitigation strategies should simultaneously address human performance, organizational processes, and operational environments.

The conceptual model was developed through a synthesis of empirical findings, aviation safety theories, and previous research. Rather than functioning independently, these five components interact to establish a comprehensive and preventive risk management system designed to enhance the effectiveness of airside vehicle operations while reducing the likelihood of runway incursions.

Human-Centered Safety Management

The findings indicate that human performance and situational awareness represent important dimensions in managing runway incursion risk. The dynamic nature of airside operations may influence operators' ability to continuously perceive, interpret, and anticipate changes in the operational environment, particularly when multiple activities occur simultaneously. These conditions suggest that human performance should be considered within a broader operational and organizational context rather than being attributed solely to individual performance.

From the perspective of modern aviation safety, humans are no longer viewed as the primary cause of accidents but rather as integral components of a safety system that requires continuous development and support. Therefore, optimization efforts should prioritize strengthening personnel competency through recurrent training, Runway Safety Awareness programs, scenario-based operational simulations, and the implementation of Fatigue Risk Management (FRM). These initiatives are intended to improve operators' ability to recognize, interpret, and anticipate changes in the operational environment, thereby enabling appropriate decision-making in high-risk situations.

These findings are consistent with the systematic review conducted by Yan et al. (2024), which identified inadequate situational awareness, communication breakdowns, and workload-related factors as the dominant contributors to runway incursions worldwide. However, unlike previous studies that primarily focused on pilot performance, the present study demonstrates that similar human performance issues also affect airside vehicle operators, indicating that human-centered safety interventions should encompass all operational personnel involved in airport surface movements.

This strategy is consistent with the principles of Human-Centered Safety Management, which emphasizes human capability development as the cornerstone of aviation safety risk management. It also supports Endsley's (1995) Situational Awareness Theory, which argues that improving operators' abilities to perceive, comprehend, and project operational situations can significantly reduce the likelihood of human error. Furthermore, the findings suggest that competency improvement should be regarded as a continuous organizational investment rather than a periodic regulatory requirement.

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Continuous competency development enhances operational resilience by enabling personnel to recognize emerging hazards and adapt their decision-making processes under dynamically changing operational conditions.

Infrastructure Safety Enhancement

The findings indicate that the effectiveness of visual guidance infrastructure is an important element in supporting safe airside vehicle operations. Continuous attention to pavement markings, signs, lighting, and other visual guidance elements can contribute to improved situational awareness and safer vehicle navigation, particularly under changing operational and environmental conditions.

Based on these findings, the proposed Infrastructure Safety Enhancement strategy emphasizes continuous inspection, preventive maintenance, periodic evaluation, and improvement of visual guidance facilities according to operational risk priorities. These measures are intended to strengthen existing safety barriers and support the ability of vehicle operators to identify designated movement areas effectively.

Within the Safety Management System framework, infrastructure enhancement should therefore be considered as part of continuous safety improvement and risk mitigation rather than as a response to isolated infrastructure deficiencies.

Technology-Based Monitoring

The findings indicate that existing surveillance technologies provide valuable support for monitoring airside vehicle activities. Further integration of technology-assisted monitoring may enhance situational awareness, improve the availability of operational information, and support more timely identification of potential safety risks.

The proposed Technology-Based Monitoring strategy includes the potential integration of existing surveillance capabilities with vehicle tracking, digital safety reporting, and operational monitoring tools. This approach is supported by previous research conducted by Doig et al. (2012), which identified vehicle position information, operator alerting mechanisms, and automated detection capabilities as important technological elements for preventing runway incursions involving authorized ground vehicles. Such technologies can complement conventional surveillance by providing timely information and alerts to vehicle operators when approaching sensitive or restricted areas. Such integration may provide additional information for safety-related decision making while complementing existing operational procedures and human supervision.

The proposed approach is intended not to replace existing surveillance mechanisms or personnel functions, but rather to strengthen their effectiveness through improved access to timely and relevant operational information.

Risk-Based Airside Surveillance

The study indicates that operational risk is not uniformly distributed throughout the airside environment. Areas characterized by higher interaction intensity, restricted maneuvering conditions, or complex vehicle-aircraft movements may present relatively greater safety risks. These findings suggest that surveillance resources should be prioritized according to the level of operational risk identified through systematic hazard identification and risk assessment.

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This approach is consistent with the risk-based decision-making principles described in ICAO Doc 9859, which emphasize that organizational resources should be allocated to operational areas presenting the highest probability and severity of safety risks in order to maximize the effectiveness of risk mitigation efforts. This approach is also supported by Claros et al. (2017), who demonstrated

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that safety risk management for airport surface operations can be strengthened through quantitative assessment of runway incursion risk using operational and environmental variables. Their findings highlight the importance of identifying risk-related characteristics of the airfield to support the prioritization of safety interventions and allocation of risk mitigation resources.

Strengthening Safety Culture

The final strategic component proposed in this study is Strengthening Safety Culture. The findings indicate that Sentani International Airport has established an effective safety reporting mechanism and standardized operational procedures. Nevertheless, a strong safety culture extends beyond procedural compliance and requires active participation by all personnel in hazard identification and organizational learning.

Safety culture can be strengthened through regular safety briefings, increased participation in safety reporting, implementation of Just Culture principles, and systematic use of near-miss investigations as organizational learning opportunities. These initiatives encourage an open reporting environment in which personnel can communicate safety concerns without fear of punitive consequences, enabling hazards to be identified and addressed at an early stage.

These findings are also consistent with Apiratanarungsi and Dowpiset (2024), who concluded that organizational safety culture significantly influences employees' willingness to report hazards and participate actively in continuous safety improvement initiatives. Therefore, strengthening safety culture should be viewed as a long-term organizational strategy rather than a short-term compliance program. These findings are also consistent with Musa and Isha (2021), who emphasized that a strong safety culture supported by active employee participation and continuous organizational learning significantly enhances safety performance in airport ground operations.

According to ICAO (2018), organizations with a mature safety culture tend to adopt more proactive approaches to risk management than organizations primarily focused on procedural compliance. Therefore, strengthening safety culture constitutes a fundamental element in achieving sustainable airside vehicle safety management. Moreover, establishing a positive reporting culture enables organizations to identify weak safety signals before they develop into major operational events. Consequently, safety reporting should function not only as a documentation process but also as an organizational learning mechanism supporting continuous improvement.

Synthesis of the Optimization Strategy

Based on the overall findings, the proposed optimization strategy for airside vehicle movement management extends beyond improving individual safety elements by integrating five complementary components within a unified Safety Management System framework. The integration of Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture establishes a comprehensive and mutually reinforcing risk management system.

The principal novelty of this study lies in the development of an integrated optimization framework specifically designed for regional airport operations. Unlike previous studies that primarily examined isolated operational factors, the proposed framework simultaneously integrates human competency development, infrastructure enhancement, digital surveillance technology, risk-based operational monitoring, and organizational safety culture into a unified Safety Management System. This integrated approach enables airport operators to implement proactive and sustainable runway incursion prevention strategies.

From a theoretical perspective, the model expands the practical implementation of the Safety Management System in the context of airside vehicle management by emphasizing proactive and continuous risk management. From a practical perspective, it provides airport operators with a systematic framework for developing safety policies, establishing surveillance priorities, and

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implementing operational safety improvement programs aimed at minimizing the risk of runway incursions.

Theoretical Synthesis

The findings of this study indicate that runway incursion risk at Sentani International Airport is not attributable to a single causal factor but rather results from the interaction of human factors, infrastructure conditions, operational environment characteristics, operational pressure, and organizational factors. These interrelated factors collectively form a dynamic risk system that continuously influences airport operational safety. This finding reinforces the fundamental principles of the Safety Management System (SMS), which conceptualizes safety as the outcome of an organization's capability to identify hazards, assess operational risks, and implement continuous risk mitigation measures.

Unlike most previous studies, which have examined the causes of runway incursions from isolated perspectives, this research integrates multiple causal factors into a comprehensive strategic framework for airside vehicle movement management. This integration resulted in five key strategic components: Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture. Rather than functioning as independent recommendations, these components constitute an integrated risk management system designed to complement one another in enhancing airport operational safety.

From a theoretical perspective, this study contributes to the advancement of Safety Management System implementation in the context of airside vehicle operations. Existing SMS applications have primarily emphasized hazard identification and general risk assessment processes. The present study demonstrates that runway incursion risk can be more effectively mitigated by integrating personnel competency development, improvements in safety infrastructure, advanced surveillance technologies, risk-based operational surveillance, and organizational safety culture into a unified safety management framework. Consequently, this research extends the practical application of SMS principles to the management of operational vehicles at regional airports.

From a practical perspective, the proposed conceptual model provides airport operators with a systematic framework for developing operational safety policies. Its implementation enables organizations to allocate resources more effectively according to operational risk levels, improve the effectiveness of airside vehicle surveillance, and strengthen coordination among operational units involved in airside activities. Furthermore, the findings may serve as valuable references for both airport authorities and regulatory agencies in designing proactive safety enhancement programs aimed at preventing runway incursions.

Overall, the theoretical synthesis demonstrates that effective airside vehicle movement management depends not only on compliance with operational procedures but also on an organization's ability to integrate human factors, infrastructure, technology, surveillance, and safety culture into a comprehensive risk management system. Therefore, the conceptual model proposed in this study offers an alternative framework for supporting the implementation of the Safety Management System at regional airports with operational characteristics comparable to those of Sentani International Airport.

CONCLUSION

The findings indicate that airside vehicle movement management at Sentani International Airport is supported by established operational procedures, personnel and vehicle authorization mechanisms, surveillance practices, and safety management processes. At the same time, the study identifies several factors that may influence runway incursion risk, including human performance, visual guidance conditions, operational complexity, workload, and organizational factors. Based on these findings, this study proposes an integrated conceptual framework consisting of five strategic

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components: Human-Centered Safety Management, Infrastructure Safety Enhancement, Technology-Based Monitoring, Risk-Based Airside Surveillance, and Strengthening Safety Culture. The framework emphasizes the interaction between human, technological, infrastructural, operational, and organizational dimensions within the Safety Management System to support continuous safety improvement and risk-informed decision-making.

From a practical perspective, the proposed framework may serve as a reference for airport operators in strengthening airside vehicle movement management, particularly through improved surveillance, operational coordination, personnel competency, infrastructure management, and organizational safety culture. However, this study has limitations. The research was conducted as a qualitative case study at a single airport, meaning that the findings reflect the operational and organizational characteristics of Sentani International Airport and cannot be directly generalized to all airports. In addition, the proposed framework was developed from interviews, observations, and document analysis and has not yet been empirically tested through implementation or quantitative measurement of its effectiveness in reducing runway incursion risk.

Future research should therefore examine the applicability of the proposed framework across multiple airports with different operational characteristics to assess its transferability and empirical validity. Further studies may employ mixed-methods or quantitative approaches to measure the relationship between the identified safety factors and runway incursion risk, as well as evaluate the effectiveness of technology-based monitoring, risk-based surveillance, and human-centered safety interventions using measurable safety performance indicators. Such research would provide empirical evidence for refining and validating the proposed framework as an operational model for airside vehicle movement management.

REFERENCES

Apiratanarungsi, P., & Dowpiset, K. (2024). Organizational and individual factors on safety culture in airside operations department at an international airport in Southeast Asia. *ABAC ODI Journal Vision. Action. Outcome*, *12*(1). https://doi.org/10.14456/abacodijournal.2024.26

Chang, Y. H., Yeh, C. H., & Wang, Y. C. (2012). Human risk factors associated with runway incursions. *Journal of Air Transport Management*, *24*, 25–30. https://doi.org/10.1016/j.jairtraman.2012.05.004

Cheng, Y., Liu, D., Vincenzi, D., & Metscher, D. (2024). Designing an interactive application to prevent runway incursion: A systems engineering approach. *Journal of Aviation Technology and Engineering*, *13*(2). https://doi.org/10.7771/2159-6670.1320

Claros, B., Sun, C., & Edara, P. (2017). Enhancing Safety Risk Management with Quantitative Measures. *Transportation Research Record*, *2603*(1). https://doi.org/10.3141/2603-01

Doig, W., Allen, W., & Gallagher, D. W. (2012). *Ground Vehicle Runway Incursion Prevention Alerting System Literature Review. Federal Aviation Administration, Airport Technology Research and Development Branch, DOT/FAA/TC-TN12/46.*

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors*, *37*(1), 32–64. https://doi.org/10.1518/001872095779049543

Fahmi, M. I. (2022). *Kajian penerapan Safety Management System terhadap runway incursion di Bandar Udara Soa Bajawa. Prosiding Seminar Nasional Inovasi Teknologi Penerbangan (SNITP).* https://doi.org/10.46491/snitp.v4i1.706

International Civil Aviation Organization. (2018). *Safety management manual (Doc 9859, 4th ed.).* ICAO.

International Civil Aviation Organization. (2022). *Annex 14 to the Convention on International Civil Aviation: Aerodromes (Vol. I, 9th ed.).* ICAO.

Koc, E., & Cınar, E. (2025). An examination of serious runway incursion incidents resulting from air traffic control services. *Journal of Aviation*, *9*(1), 59–70. https://doi.org/10.30518/jav.1552352

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Miles, M. B., Huberman, A. M., & Saldana, J. (2014). *Qualitative data analysis: A methods sourcebook (3rd ed.)*. Sage Publications. ISBN 978-1-4522-5787-7

Musa, M., & Isha, A. S. N. (2021). Holistic view of safety culture in aircraft ground handling: Integrating qualitative and quantitative methods with data triangulation. *Journal of Air Transport Management*, *92*, 102019. https://doi.org/10.1016/j.jairtraman.2021.102019

Omosebi, O., Azimi, M., Olowokere, D., Wanyan, Y., Zhao, Q., & Qi, Y. (2023). Investigating runway incursion incidents at United States airports. *Future Transportation*, *3*(4), 1209–1222. https://doi.org/10.3390/futuretransp3040066

Pangestuti, A. (2025). Identification of apron marking standardization on potentially posing safety risks in aircraft operation at airport. *Journal of Airport Engineering Technology*, *6*(1). https://doi.org/10.52989/jaet.v6i1.236

Patton, M. Q. (2015). *Qualitative research & evaluation methods (4th ed.)*. Sage Publications.

Reason, J. (1997). *Managing the risks of organizational accidents*. Ashgate Publishing.

Sugiyono. (2023). *Metode penelitian kualitatif: Untuk penelitian yang bersifat eksploratif, interpretif, interaktif, dan konstruktif (Cetakan ke-6)*. Alfabeta.

Wang, C., Hubbard, S., & Zakharov, W. (2018). Utilizing the systematic literature review in aviation: A case study for runway incursions. *The Collegiate Aviation Review International*, *36*(2). https://doi.org/10.22488/okstate.18.100489

Yan, Y., Boufous, S., & Molesworth, B. R. C. (2024). A systematic review of pilot-related runway incursions from a human factors perspective. *The International Journal of Aerospace Psychology*, *34*(1), 1–19. https://doi.org/10.1080/24721840.2023.2247441

Yin, R. K. (2018). *Case study research and applications: Design and methods (6th ed.)*. Sage Publications.

Zhang, X., Tian, Y., Pan, W., Chen, J., & Zou, X. (2022). A field study on safety performance of apron controllers based on digital tower. *International Journal of Environmental Research and Public Health*, *19*(23), Article 16077. https://doi.org/10.3390/ijerph19031623

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