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DEVELOPMENT OF A SAFETY RISK MODEL FOR OFFSHORE HELICOPTER OPERATIONS IN CRITICAL PHASES THROUGH A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Background: *Offshore helicopter operations are essential for the oil and gas industry, particularly for transporting personnel and supplies to offshore platforms. However, the critical phases of flight—approach, landing, and take-off—contribute to over 60% of helicopter-related aviation accidents worldwide. In Indonesia, these risks are amplified by extreme weather conditions, poor helideck infrastructure, pilot fatigue, and inconsistent regulatory enforcement. An effective, context-specific risk management model is therefore urgently needed.*
Method: *This study applies a Systematic Literature Review (SLR) approach to examine current research on risk management in offshore helicopter operations. A total of 38 relevant articles were selected from databases including Scopus, Web of Science, and Google Scholar. Thematic synthesis was used to extract insights related to risk factors, mitigation strategies, and modeling approaches.*
Result: *The review identified four major risk factors: adverse weather, helideck design flaws, human error, and pilot fatigue. Effective mitigation strategies include simulation-based pilot training, predictive technologies, UAV-based inspections, and compliance with international safety standards. Despite these advancements, challenges such as limited infrastructure, lack of standardization, and enforcement gaps remain, particularly in Indonesia. Modeling in this context refers to the use of analytical frameworks such as STPA, Bayesian Networks, SWARA-CoCoSo, and FMEA-BWM to represent, simulate, and prioritize safety risks.*
Conclusion: *This study proposes a predictive, data-driven risk model that combines international best practices with Indonesia's operational realities. The model aims to improve offshore aviation safety by enabling proactive decision-making, supporting policy development, and strengthening flight safety standards across critical phases.*

Keywords: *Offshore helicopter operations, aviation safety, critical phases of flight, risk management model, systematic literature review, predictive modeling, Indonesia, helideck safety, pilot training, weather-related risks.*

INTRODUCTION

Offshore helicopter operations play a vital role in supporting oil and gas industry activities, particularly in the transportation of personnel and logistics to offshore platforms. However, the critical phases of flight—such as approach, landing, and take-off—account for more than 60% of aviation accident incidents (Zhang et al., 2023). Countries like Norway and the United Kingdom have developed risk management models based on predictive technology and real-time data to reduce the risk of accidents. In Norway, the use of predictive analytics has succeeded in reducing risk by up to 40% (Hauge et al., 2021).

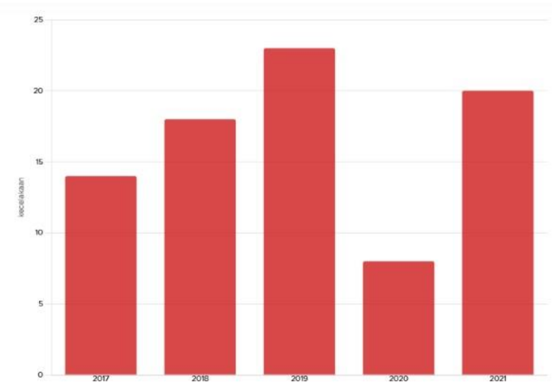

Figure 1. Airtraffic accidents in 2017 - 2022
https://data.goodstats.id/statistic/jumlah-kecelakaan-pesawat-sepanjang-periode-2017-2021-M07OR

Furthermore, in the European Union, the European Union Aviation Safety Agency

(EASA) has issued a series of stringent regulations governing helicopter safety. These include mandatory safety audits, the use of technology-based simulation for pilot training, and risk analysis at each stage of operations (EASA, 2022). In the United Kingdom, the British Helicopter Association (BHA) has also introduced a collaborative approach between helicopter operators and safety authorities to ensure that every helicopter mission—especially those involving offshore operations—is conducted with maximum safety standards (BHA, 2021).

Between 2017 and 2021, a total of 83 aircraft accidents occurred worldwide. According to data from the Aviation Safety Network, the highest number of incidents occurred in 2019, with 23 recorded accidents. These accidents resulted in 289 fatalities. The number of aircraft accidents over the five-year period fluctuated. A significant decrease was seen in 2020, with only 8 incidents, although the number of fatalities excluding ground casualties still reached 137. Looking at fatalities per year, the lowest number occurred in 2017, with 14 accidents resulting in only 59 deaths. In contrast, 2018 saw the highest number of fatalities, reaching 561.

In Indonesia, the Minister of Transportation Regulation PM 83 of 2017 has established operational standards for critical phases, but its implementation still faces technical and administrative challenges. According to the National Transportation Safety Committee (KNKT) report, from 2019 to 2023 there were 118 recorded aviation incidents, consisting of accidents and serious incidents, many of which occurred during critical phases of flight.

Airlines such as PT. P and PT. T face significant challenges during these phases, ranging from extreme weather conditions, non-standard helideck designs, pilot fatigue, to limitations in monitoring technology. Data-driven approaches and simulation-based training have become crucial for enhancing safety.

With the development of a more structured and collaborative risk management model, it is expected that a safer and more reliable offshore aviation system can be established in Indonesia.

PT. P faces significant challenges in offshore flight operations due to geographical conditions and extreme weather in remote areas such as Natuna and the Java Sea. Severe weather conditions such as strong winds, tropical storms, and low visibility are major causes of flight disruptions, with 40% of incidents linked to extreme weather (Peterson et al., 2023).

These challenges are further exacerbated by the suboptimal integration of real-time weather modeling technologies in operations, leading pilots to often make decisions based on inaccurate information.

Safety issues also arise from the condition of helidecks on several offshore platforms that do not meet international standards. Slippery surfaces, limited size, and poor lighting increase the risks during landing and take-off. The incident involving a PT. P helicopter skidding on a wet helideck in East Kalimantan in 2020 serves as a clear example of the need for improved helideck design and maintenance (Wood et al., 2023).

PT. T, which operates with a higher flight volume, faces risks related to pilot fatigue and human error during critical phases of flight. Around 30% of incidents involving PT. T are attributed to human error (Hauge et al., 2021), highlighting the importance of simulation-based training.

Although PT. T has implemented technologies such as weather radar and helicopter monitoring systems, the application remains uneven, particularly in remote locations (Chen et al., 2023).

Both airlines also encounter obstacles in implementing safety regulations, such as Regulation PM 83 of 2017, due to administrative and technical barriers. The necessary solutions include data-driven analytical approaches for risk evaluation, more intensive crew training, and strong collaboration between operators, regulators, and technology providers.

With strategic investment in technology and training, PT. P and PT. T have the potential to become pioneers of offshore aviation safety in Indonesia.

METHODS

A Systematic Literature Review (SLR) is a comprehensive, structured, and methodical approach used to identify, evaluate, and synthesize the findings of existing research studies that are relevant to a clearly defined research question or topic. The main objective of an SLR is to minimize bias in the review process by following a transparent and replicable methodology. Unlike traditional or narrative literature reviews that tend to be more subjective and selective, SLRs are designed to be objective, rigorous, and focused on producing reliable and evidence-based conclusions. The process typically begins with the formulation of a specific and focused research question, often guided by frameworks such as PICO (Population, Intervention, Comparison, Outcome) or SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type), depending on the field of study.

After the research question is established, a review protocol is developed. This protocol includes important details such as the purpose of the review, the inclusion and exclusion criteria for selecting studies, the databases to be searched (e.g., Scopus, Web of Science, PubMed, Google Scholar), the keywords or search terms to be used, and the methods for screening and assessing the quality of the studies. A thorough and systematic search is then conducted to gather all relevant literature, including peer-reviewed journal articles, conference papers, reports, and sometimes grey literature such as theses and government documents. Each study retrieved is screened in stages, starting from the title and abstract, followed by a full-text review to determine its eligibility based on the established criteria.

Once the relevant studies are selected, they undergo a quality assessment using standardized tools or checklists (such as PRISMA or CASP) to ensure that the data synthesized is based on high-quality evidence. The next step is data extraction, where key information from each study—such as authorship, publication year, research design, sample characteristics, methods, and main findings—is systematically collected. The extracted data is then synthesized either qualitatively (e.g., through thematic analysis or narrative synthesis) or quantitatively (e.g., through meta-analysis, if applicable), depending on the type and consistency of the data.

Finally, the findings of the SLR are reported in a structured format, often following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. These reports typically include a flow diagram that outlines the study selection process, summary tables of included studies, and a comprehensive discussion of results, implications, limitations, and directions for future research. The systematic nature of this method ensures that the conclusions drawn are based on a complete and unbiased review of the existing literature. SLRs are widely used in fields such as medicine, psychology, education, business, and social sciences to inform practice, guide policy decisions, and identify research gaps for future studies.

RESULTS AND DISCUSSION

The offshore helicopter industry plays a crucial role in supporting oil and gas activities, particularly in remote and offshore locations. The critical phases of flight—

approach, landing, and take-off—are identified as the most hazardous, contributing to over 60% of aviation-related incidents (Zhang et al., 2023). Countries such as Norway and the United Kingdom have taken proactive measures using predictive models and real-time data to mitigate risks. In contrast, Indonesia faces persistent operational, environmental, and regulatory challenges including adverse weather conditions, limited infrastructure standards, and inconsistent enforcement of aviation regulations.

After narrowing down based on relevance, language, and publication year, 749 sources were shortlisted. Following further screening, 38 key articles were selected and synthesized thematically to extract insights on safety risks, mitigation strategies, and risk modeling in offshore helicopter operations.

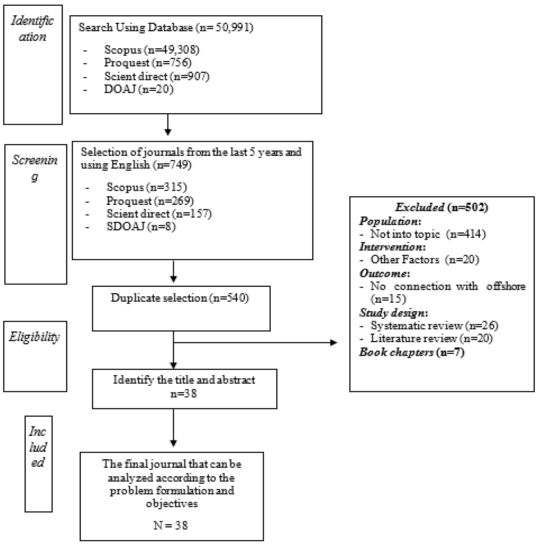

Figure 2. The stages of the Systematic Literature Review (SLR) process

This study utilized a Systematic Literature Review (SLR) approach, analyzing 50,991 records from Scopus, ProQuest, ScienceDirect, and DOAJ.

Among the prominent risks identified, environmental factors such as wind, fog, and storms dominate (Jin et al., 2020; Wang et al., 2022), alongside infrastructure limitations like inadequate helideck design and lighting (Wood et al., 2023). Human error, often caused by fatigue and limited situational awareness, remains a critical contributor to incidents (Hauge et al., 2021). Wang and Yan (2020) emphasize the integration of human factor variability into risk modeling frameworks to better understand operational hazards in sociotechnical systems.

In terms of modeling techniques, multiple studies highlight the application of System-Theoretic Process Analysis (STPA) for capturing system-software interactions (Svensson et al., 2022), and Bayesian Networks for dynamic, probabilistic modeling, particularly under conditions of uncertainty (Yang et al., 2021). The integration of fuzzy logic methods like SWARA-CoCoSo (Yousefi et al., 2021) and hybrid models such as FMEA with the Best-Worst Method (Karami et al., 2020) offer structured tools to prioritize risk factors where quantitative data may be limited or uncertain.

Key mitigation strategies discussed across the literature include simulation-based pilot training to reduce human error and improve decision-making under pressure (Ali et al., 2020; Østergaard et al., 2021), the use of UAVs for helideck and structural inspections (Mokhtari et al., 2022), and predictive maintenance systems employing AI for early fault detection and maintenance optimization (Chen et al., 2021). Health and Safety Management Systems (HSMS) are also promoted, particularly when they integrate organizational learning and stakeholder collaboration (Ghasemi et al., 2021).

Broader technological trends such as the use of drones (Beiranvand et al., 2021), artificial intelligence for operational decision support (Al-Hamed et al., 2022), and model-based safety analysis in LNG systems (Rahimi et al., 2022) suggest a move toward increasingly intelligent, autonomous safety infrastructures. Additionally, studies on resilience in emergency management (Johansen et al., 2021) and cybersecurity in maritime systems (Liu et al., 2020) reveal cross-sector relevance that may inform offshore helicopter safety protocols.

This review provides a comprehensive understanding of how multiple risk factors converge in offshore aviation and how they can be addressed through strategic, evidence-based safety modeling. For Indonesia, adopting these global best practices—while considering local environmental, infrastructural, and regulatory conditions—is imperative. This includes establishing a nationally integrated safety framework involving predictive models, simulation training, regulatory enforcement, and stakeholder collaboration.

In conclusion, enhancing offshore helicopter safety requires a multidimensional approach that incorporates advanced risk modeling, human factors, and adaptive technologies. The review offers both theoretical and practical insights to guide the development of a robust safety risk model tailored to Indonesia's offshore operations. Future directions should explore the integration of AI-based forecasting tools, adaptive training systems, and real-time risk monitoring technologies to proactively manage the complexities of offshore aviation.

Key references include Zhang et al. (2023) on helicopter accident trends, Hauge et al. (2021) on predictive analytics, Wood et al. (2023) on infrastructure risk, STPA by Svensson et al. (2022), Bayesian networks by Yang et al. (2021), fuzzy risk prioritization by Yousefi et al. (2021) and Karami et al. (2020), UAV applications by Mokhtari et al. (2022), HSMS by Ghasemi et al. (2021), and human-AI interaction by Johansen et al. (2021).

CONCLUSION

The systematic review of 38 selected journal articles reveals that offshore helicopter operations are significantly influenced by a combination of extreme environmental conditions, inadequate infrastructure, human error, and limited integration of predictive technologies. The critical phases of flight—approach, landing, and take-off—are consistently identified as the most accident-prone, accounting for more than 60% of aviation-related incidents (Zhang et al., 2023).

Countries such as Norway and the United Kingdom have successfully implemented advanced, data-driven safety models including System-Theoretic Process Analysis (STPA), Bayesian Networks, and comprehensive simulation-based pilot training. Studies by Svensson et al. (2022) and Yang et al. (2021) highlight the utility of these modeling approaches in anticipating system failures under uncertainty. Complementary techniques such as fuzzy logic (SWARA-CoCoSo by Yousefi et al., 2021) and hybrid frameworks like FMEA-BWM (Karami et al., 2020) are proven effective in prioritizing risks where quantitative data is limited.

Mitigation strategies emphasized across the literature include simulation-based training (Ali et al., 2020; Østergaard et al., 2021), the use of UAVs for helideck and structural inspections (Mokhtari et al., 2022), and AI-based predictive maintenance (Chen et al., 2021). Moreover, the implementation of Health and Safety Management Systems (HSMS), particularly those emphasizing stakeholder collaboration and organizational learning, plays a pivotal role (Ghasemi et al., 2021).

Emerging technologies such as autonomous drones, AI-driven decision support, and model-based safety analysis are advancing the development of intelligent and autonomous safety systems. Cross-sectoral studies (Johansen et al., 2021; Liu et al., 2020) underline the relevance of organizational resilience and cybersecurity in offshore operations.

For Indonesia, the review recommends the adoption of a context-specific risk model that accounts for local environmental, infrastructural, and operational constraints. Strategic priorities should include standardized simulation training, enhanced helideck compliance, real-time environmental monitoring, and integrated regulatory frameworks supported by multi-stakeholder collaboration.

In summary, the future of offshore helicopter safety lies in a multidimensional, proactive approach that integrates advanced risk modeling, adaptive training, and smart technologies. This review offers both theoretical insights and practical recommendations to guide the development of a robust, predictive safety risk model tailored to Indonesia's offshore aviation sector.

Based on the analysis of the selected journals through the Systematic Literature Review (SLR), it is evident that helicopter accidents in offshore operations are most frequently associated with the approach and landing phases, with a lesser but still significant number occurring during take-off. These phases represent the most critical segments of flight due to their operational complexity and the heightened interaction between environmental, technical, and human factors.

The approach phase is particularly hazardous as helicopters must navigate challenging weather conditions such as fog, low visibility, strong crosswinds, and turbulence, especially when nearing offshore platforms that may be in motion due to sea conditions. Pilots are required to make precise calculations and rapid decisions, often with limited spatial awareness and visual cues, increasing the likelihood of misjudgments or navigation errors.

During the landing phase, risks escalate further due to the need for precision in aligning with small, often moving helidecks on offshore platforms. Mechanical issues, such as rotor or landing gear failures, and operational miscommunication between the pilot and deck crew can lead to hard landings or accidents. Additionally, sea-induced motion of the platform and unpredictable gusts of wind can destabilize the aircraft just seconds before touchdown.

While the take-off phase is generally more controlled, it still presents safety challenges. Engine failure during the initial lift-off, improper weight distribution, and sudden changes in wind direction can compromise stability. However, pilots usually have slightly more room for corrective action compared to the critical timing required during landing.

In summary, the approach and landing phases are statistically and operationally the most accident-prone stages in offshore helicopter operations. The primary causes of accidents across these phases include severe environmental conditions, equipment malfunctions, and human errors—particularly in perception, communication, and decision-making. These findings highlight the need for targeted safety improvements, especially in flight procedures, pilot training, and helideck design, to enhance operational resilience and reduce accident rates in offshore environments.

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The collaboration of these institutions has not only strengthened the empirical foundation of this research but also demonstrated a commendable commitment to advancing aviation safety and bridging academic research with industry needs. For all the support, information, and cooperation extended during this endeavor, the author remains deeply thankful.

CONFLICT OF INTEREST

The author declares that this systematic literature review was conducted independently and is free from any conflict of interest. No financial, professional, or personal affiliations influenced the selection, analysis, or interpretation of the reviewed studies. All sources were objectively evaluated based on scientific merit and relevance to the research objectives, ensuring the integrity and impartiality of the findings presented in this study.

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