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A Conceptual Model of Aircraft Rescue and Fire Fighting (ARFF) Training Effectiveness for Enhancing National Aviation Safety

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ABSTRACT

Indonesia's persistent record of aviation incidents underscores the urgent need for a more effective and contextually adaptive framework for Aircraft Rescue and Fire Fighting (ARFF) training. Although current practices formally align with international standards, significant challenges remain due to implementation gaps and the absence of an integrated national framework for evaluation and modernization. This study employs a Systematic Literature Review (SLR) approach, synthesizing empirical and conceptual evidence from 32 key publications and regulatory documents to develop the Conceptual Model of ARFF Training Effectiveness (I–P–O–O Model). The thematic synthesis reveals four essential pillars that support effective ARFF training: (1) competency-based training and assessment, (2) immersive technologies such as virtual and augmented reality, (3) non-technical skills and psychological resilience, and (4) continuous evaluation and improvement. The I–P–O–O Model conceptualizes ARFF training as a dynamic, cyclical system encompassing four interrelated stages Input, Process, Output, and Outcome each contributing to measurable improvements in operational competence, preparedness, and safety culture. As Indonesia's first systematic framework for ARFF training effectiveness, the model bridges global best practices with local operational contexts, offering a strategic foundation to strengthen aviation safety and organizational resilience.

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INTRODUCTION

The Indonesian aviation sector constitutes a strategically significant industry that operates in a complex, high-stakes environment. Maintaining uncompromising safety standards is therefore not only a regulatory requirement but also a critical imperative for sustaining public confidence and operational reliability. This urgency is particularly evident when viewed against Indonesia's safety record, which remains one of the most challenging in the Asian region. Historically, the nation's commercial aircraft accident rate has averaged nine incidents per year, compared with only three to four in neighboring Asian countries [1]. Within this context, Aircraft Rescue and Fire Fighting (ARFF) units assume a pivotal role as the first line of defense in managing aviation emergencies and mitigating loss of life and infrastructure.

Although Indonesia has formally adopted international frameworks such as ICAO Doc 9137, the translation of these high-level standards into consistent operational readiness remains a persistent challenge. The country's overall safety oversight has shown measurable progress demonstrated by an ICAO Universal Safety Oversight Audit Program (USOAP) compliance score of 81.15% in 2017 [2] yet such figures do not necessarily reflect uniform performance at the operational level. Field evidence continues to reveal disparities in workforce capacity and competency. For example, a study conducted at one Indonesian international airport found that "junior personnel numbered only four from the standard of seven, and basic personnel only three from the standard of eight" [3]. These findings highlight the enduring gap between regulatory compliance and practical implementation. Compounding this issue are the rapid technological advancements in aviation such as the integration of composite materials and alternative fuels that require ARFF personnel to continuously update their technical and tactical competencies [4].

Such dynamics underscore the need for a transformative approach to ARFF training in Indonesia. Although advanced tools such as Fire Dynamics Simulators (FDS) [5] and sophisticated evacuation modelling systems [6] have introduced data-driven paradigms into emergency response training, a significant research gap persists in the Indonesian context. Despite alignment with ICAO standards, there remains no comprehensive conceptual framework to systematically assess and enhance the effectiveness of ARFF training at the national level. Existing studies tend to focus on discrete components such as Virtual Reality-based simulations [7] without integrating technical, non-technical, and evaluative dimensions within a unified structure. This fragmentation risks rendering Indonesia's ARFF training programs inconsistent, weakly evaluated, and slow to adapt to evolving operational demands.

To address this gap, the present study proposes the development of a holistic and contextually adaptive conceptual model for assessing and improving ARFF training effectiveness in Indonesia. The model is designed to serve as a strategic reference for aviation regulators, airport authorities, and training institutions in formulating, executing, and evaluating ARFF programs that are both internationally compliant and locally responsive. In doing so, it aims to strengthen Indonesia's overall aviation safety architecture and ensure the long-term sustainability and resilience of its emergency response system.

METHODS

This study employs a qualitative methodology through a Systematic Literature Review (SLR) design to identify, evaluate, and synthesize both empirical and conceptual evidence concerning the effectiveness of Aircraft Rescue and Fire Fighting (ARFF) training [8]. The adoption of the SLR approach is grounded in its capacity to generate a comprehensive, transparent, and replicable synthesis of existing knowledge, thereby providing a robust empirical foundation for developing an evidence-based conceptual model tailored to the Indonesian aviation context.

The review process was conducted systematically across four main stages. First, research questions were formulated to explore the essential components of an effective ARFF training framework and its contextual integration within Indonesia's operational environment. Second, an extensive literature search was carried out across major academic databases namely Scopus, Web of Science, ScienceDirect, and Google Scholar using a combination of relevant keywords such as *"Aircraft Rescue and Fire Fighting," "competency-based training," "virtual reality in training," "emergency response,"* and *"non-technical skills,"* supplemented by regulatory and technical documentation. Third, inclusion and exclusion criteria were applied to ensure the quality and relevance of the selected studies. From an initial corpus of 1,280 records, duplicate entries were removed, yielding 850 unique studies. Title and abstract screening was then conducted to select peer-reviewed publications published between 2015 and 2025 that focused on training within emergency service contexts, while non-academic and unrelated works were excluded. Finally, data extraction and analysis were performed using a manual thematic synthesis technique to ensure analytical depth and contextual accuracy.

Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, the selection process produced 60 full-text articles, of which 32 met all inclusion criteria and were subjected to in-depth qualitative analysis. The manual coding process involved three iterative steps: (a) line-by-line coding of relevant data and findings, (b) organization of the resulting codes into descriptive themes such as *"use of virtual reality in training"* and *"importance of competency-based training approaches"* and (c) development of higher-order analytical themes, including *"integration of technology into competency-based curricula."*

Through this structured and systematic analytical process, the study successfully constructed a coherent, comprehensive, and empirically grounded conceptual model for evaluating and enhancing ARFF training effectiveness in Indonesia. This model not only consolidates existing global best practices but also provides contextual insights relevant to the operational realities of Indonesia's aviation safety framework.

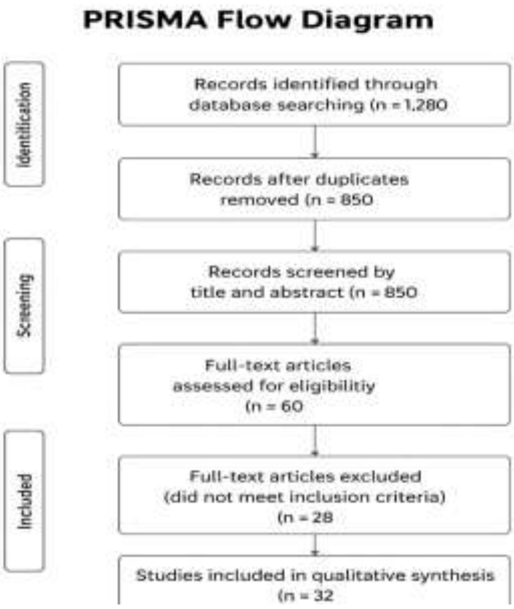

Figure 1. PRISMA Flow Diagram of the Article Selection Process

Literature Review and Hypothesis Development

Transformation of ARFF Training Paradigms: From Conventional Models to CBTA

Historically, training practices within high-risk operational sectors such as Aircraft Rescue and Fire Fighting (ARFF) have predominantly adhered to conventional instructional models that emphasize compliance with prescribed training durations and standardized modules, rather than ensuring demonstrable attainment of individual competencies. Over the past two decades, however, this paradigm has undergone a substantive transformation toward the Competency-Based Training and Assessment (CBTA) framework. This shift represents more than a methodological modification; it signifies a deeper epistemological reorientation that places verifiable operational competence at the core of the learning and assessment process [9].

Under the CBTA paradigm, the central question of training effectiveness is no longer defined by "how long an individual has been trained," but by "what the individual is demonstrably capable of performing" within an operationally realistic environment. Accordingly, the model prioritizes observable and measurable outcomes, including proficiency in executing aircraft rescue procedures, accuracy in deploying firefighting agents, and effectiveness in inter-unit communication and coordination [10]. This outcome-driven orientation aligns training objectives with the dynamic demands of real-world aviation emergencies, emphasizing competence over compliance.

The global endorsement of CBTA by leading aviation authorities such as the European Union Aviation Safety Agency (EASA), the Civil Aviation Authority of Singapore (CAAS), and the Japan Civil Aviation Bureau (JCAB) further attests to its recognized international validity and operational relevance [11]. Empirical evidence from large-scale airport studies in the United States demonstrates that CBTA implementation has significantly improved ARFF performance indicators, particularly in reducing emergency response times and minimizing operational errors during simulation exercises [12]. Such outcomes reinforce the direct correlation between mastery of core competencies encompassing technical proficiency, situational awareness, and decision-making capability and overall operational effectiveness [13].

Conceptually, the success of CBTA implementation is contingent upon the clarity of its competency framework and the precision of its assessment mechanisms to ensure both validity and reliability. Without explicit performance indicators, the foundational principle of CBTA risks being diluted. Therefore, ARFF training under a CBTA framework must be anchored in a comprehensive competency matrix that integrates technical, tactical, communicative, and psychological dimensions, as delineated in ICAO Doc 9137. Analytical instruments such as the Curriculum Analytics Tool (CAT) provide valuable mechanisms for training institutions to map, verify, and evaluate the alignment and completeness of competency elements across various instructional levels [14].

In this context, the paradigm shift toward CBTA serves as the conceptual cornerstone of the present study. Competency attainment is positioned not merely as an outcome but as the central organizing principle that informs curriculum design, instructional delivery, and performance assessment within the ARFF training ecosystem.

The Role of Immersive Technologies and Simulation in ARFF Training Modernization

In alignment with the global transition toward Competency-Based Training and Assessment (CBTA), the integration of immersive digital technologies has redefined the methodological landscape of Aircraft Rescue and Fire Fighting (ARFF) training. While CBTA establishes the framework of *what* competencies must be achieved, immersive technologies determine *how* these competencies can be developed most effectively. The incorporation of high-fidelity simulation both physical and virtual has become a cornerstone of modern ARFF training, enabling personnel to gain operational proficiency in handling complex emergency situations without direct exposure to physical hazards.

Full-scale aircraft fire simulations remain the recognized “gold standard” in ARFF training due to their ability to authentically replicate real-world emergency conditions. These simulations facilitate the evaluation of critical performance dimensions such as team coordination, command decision-making, and the tactical effectiveness of firefighting strategies [5]. Modern ARFF training facilities are increasingly equipped with modular aircraft mock-ups capable of reproducing diverse fire, explosion, and evacuation scenarios, allowing trainers to systematically assess both technical and behavioral competencies under controlled yet realistic conditions [15].

Despite their operational advantages, constructing and maintaining full-scale simulation facilities demands significant financial and logistical investment. In response, the adoption of Extended Reality (XR) a collective term encompassing Virtual Reality (VR) and Augmented Reality (AR) has emerged as an innovative and cost-efficient complement to traditional physical training. XR environments offer immersive, interactive, and repeatable learning experiences that enhance cognitive understanding, situational awareness, and knowledge retention [16]. Through VR-based simulations, trainees can repeatedly practice complex rescue procedures, refine motor coordination, and build psychological readiness, all within safe and controllable settings that eliminate the risk of physical injury [17].

Nonetheless, several limitations constrain the full transferability of VR-based training to real-life contexts. A primary concern is the absence of comprehensive multisensory feedback such as heat, pressure, or fatigue sensations which reduces perceptual realism and physiological engagement [18].

Empirical evidence from comparative studies indicates that stress perception and cognitive load differ markedly between virtual simulations and actual field operations [19]. To mitigate this limitation, recent research has explored the integration of multisensory feedback systems and haptic technologies designed to enhance immersion and physiological realism. Moreover, the effectiveness of immersive training systems relies heavily on the application of user-centered design (UCD) principles to ensure scenario relevance, intuitive interaction, and the minimization of simulator-induced discomfort or motion sickness [20].

In practice, VR and AR are not envisioned as replacements for physical training but rather as complementary tools that reinforce and extend traditional training paradigms. The most promising approach emerging from current research advocates a blended learning framework that integrates full-scale physical simulations with intensive XR-based modules. Such a hybrid model allows ARFF trainees to experience both the cognitive and physical dimensions of emergency response, thereby fostering the comprehensive development of technical, procedural, and psychological competencies essential for high-stakes aviation environments.

Psychological Dimensions and Non-Technical Skills (NTS): The Hidden Foundations of ARFF Effectiveness

Mastery of technical competencies through Competency-Based Training and Assessment (CBTA) and advanced technological simulations alone does not guarantee optimal performance in Aircraft Rescue and Fire Fighting (ARFF) operations. The true effectiveness of ARFF personnel equally relies on their psychological resilience and Non-Technical Skills (NTS), which collectively shape the human capacity to function under extreme stress. Crisis situations impose intense cognitive and emotional demands that can significantly disrupt judgment and decision-making, even among technically proficient individuals [21].

Accordingly, the development of an integrated ARFF training curriculum must move beyond procedural instruction to encompass psychological preparedness as a core dimension. Training models that focus exclusively on technical proficiency risk producing personnel who are operationally competent but psychologically vulnerable when confronted with real emergencies.

Insights from operational and cognitive psychology underscore the centrality of NTS in high-risk environments. The THINCS model encompassing Teamwork, Humility, Interpersonal Communication, Nondirective Leadership, Concentration, and Situational Awareness emphasizes that effective interpersonal communication and coordinated teamwork form the backbone of successful incident command [22]. The capacity to communicate calmly and precisely under pressure promotes shared situational awareness, enabling teams to construct a collective and coherent understanding of rapidly evolving operational conditions an indispensable prerequisite for maintaining safety and control.

Furthermore, core NTS elements such as decision-making under pressure, adaptive leadership, and emotional regulation have been shown to strongly correlate with mission success and reduced error rates in emergency response contexts [23]. Among various interventions, stress inoculation training has emerged as one of the most effective strategies for cultivating psychological resilience. This method systematically exposes trainees to escalating levels of controlled stress, allowing them to develop adaptive coping mechanisms that mirror real-world crisis dynamics [24].

Conceptually, the integration of NTS should not be confined to a standalone training module but embedded holistically across all simulation exercises and operational scenarios. Instructors must be equipped not only to assess technical competence but also to evaluate behavioral markers of resilience, communication, and teamwork. Such an integrative pedagogical approach ensures that ARFF personnel are not merely trained to perform tasks but are psychologically conditioned to sustain performance under the most demanding circumstances.

Continuous Evaluation and Performance-Based Certification

The integration of CBTA, technological tools, and non-technical skills within ARFF training frameworks necessitates the establishment of a robust validation mechanism to ensure instructional effectiveness. Contemporary training paradigms advocate a paradigm shift from summative or terminal evaluation approaches toward formative and continuous assessment systems. Within the ARFF context, competency verification should not be regarded as a singular event but rather as a sustained and iterative process.

The Federal Aviation Administration underscores the criticality of recurrent training and annual competency assessments, supported by empirical evidence indicating that infrequently practiced operational skills tend to deteriorate over time. Accordingly, integrated assessment models that combine written examinations, performance-based simulations, and behavioral evaluations are recommended to generate a more comprehensive profile of personnel capability [25]. The adoption of continuous evaluation mechanisms allows instructors to identify emerging competency gaps at an early stage and to implement targeted learning interventions accordingly. Evidence from the *Effectiveness of Prehospital Paramedic Training in Critical Care (EPPTC)* study demonstrates that continuous assessment systems significantly enhance both technical and non-technical skill retention, with positive effects persisting for up to one year post-training [26].

In the ARFF domain, the systematic implementation of After Action Reviews (AARs) following each training session has proven to be an effective organizational learning tool. Rather than serving as a fault-finding mechanism, AARs facilitate reflective analysis of performance to identify both strengths and improvement areas. A meta-analysis conducted by Keiser and Arthur (2021) revealed that structured AAR implementation exerts a substantial positive influence on training outcomes (effect size = 0.79). Ultimately, certification systems within ARFF organizations should transition from seniority-based credentialing models toward performance-based certification frameworks subjected to periodic validation. This approach ensures that all active ARFF personnel not only fulfill administrative and regulatory standards but also consistently demonstrate sustained competence, operational readiness, and alignment with evolving industry requirements [15].

Proposed Conceptual Framework

A comprehensive synthesis of the four thematic dimensions Competency-Based Training and Assessment (CBTA), Immersive Technology, Non-Technical Skills (NTS), and Continuous Evaluation reveals that these constructs are not discrete or independent entities. Rather, they represent interdependent and mutually reinforcing components that collectively form an integrated cycle of training effectiveness. Within this framework, CBTA serves as the foundational dimension, defining the expected performance standards and learning outcomes. Immersive Technology functions as the enabling instrument, providing innovative and contextually realistic training modalities that enhance engagement and skill acquisition. Non-Technical Skills constitute the complementary competencies that enable personnel to perform effectively under operational pressure, encompassing aspects such as communication, decision-making, teamwork, and situational awareness. Continuous Evaluation, in turn, operates as the verification and validation mechanism that ensures sustained competence and operational readiness over time.

Drawing upon this conceptual synthesis, a holistic framework for ARFF training effectiveness has been developed, as depicted in Figure 2 (presented in the subsequent chapter). The framework visually delineates the logical interrelationships, dynamic feedback loops, and process flows among the four core dimensions, thereby serving as the structural foundation for the proposed integrated model. This model aims to capture the complexity of ARFF training processes while promoting systematic improvement, accountability, and continuous professional development.

RESULT AND DISCUSSION

Research Findings: Conceptual Model of ARFF Training Effectiveness

Drawing upon an extensive synthesis of existing literature and a comprehensive conceptual analysis, this study introduces a Conceptual Model of Aircraft Rescue and Fire Fighting (ARFF) Training Effectiveness specifically tailored to the Indonesian context. The proposed model is holistic, systemic, and adaptive, capturing the causal interrelationships among components that shape the ARFF training continuum from planning and implementation to the long-term enhancement of the national aviation safety system. Fundamentally, the model comprises four interrelated stages Input, Process, Output, and Outcome that interact dynamically to establish a sustainable training ecosystem oriented toward strengthening operational performance and safety standards.

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Stage 1 – Training Input: The Foundational Stage of Success

The input stage forms the cornerstone of the entire training process. The initial component entails the establishment of national competency standards aligned with *ICAO Doc 9137*, yet sufficiently adaptive to accommodate Indonesia's geographical diversity, varied airport typologies, and distinctive aviation risk profiles. These standards are envisioned as a living framework, subject to continuous review and refinement in response to evolving operational demands [27].

Equally essential is a rigorous participant selection mechanism based on both psychological attributes and individual capabilities. The selection process should extend beyond traditional physical fitness assessments to include psychological evaluations that measure stress resilience, decision-making speed, and cognitive adaptability under pressure [28].

Furthermore, the quality of training infrastructure and instructional personnel constitutes a critical determinant of overall training effectiveness. Long-term investment in modern training facilities including advanced live-fire training grounds and immersive VR/AR simulation laboratories should be recognized as a strategic commitment to operational excellence [29]. Instructors, in turn, must demonstrate verified technical competence, substantial field experience, and interprofessional facilitation skills to ensure pedagogical integrity and instructional credibility [30].

Stage 2 – Training Process: Mechanism of Competence Formation

The process stage constitutes the central mechanism of the model, in which the input components are systematically transformed into structured learning experiences. The curriculum is designed to implement a Competency-Based Training and Assessment (CBTA) framework grounded in the principles of backward design, ensuring alignment between learning objectives, instructional strategies, and assessment outcomes. To facilitate the mastery of complex professional tasks, the Four-Component Instructional Design (4C/ID) model is recommended as an organizing framework [31]. The learning process should ideally adopt a blended learning approach, integrating physical training environments with digital simulations. The incorporation of Virtual Reality (VR) and Augmented Reality (AR) technologies enhances procedural learning fidelity, while full-scale live fire exercises serve as the culminating phase for evaluating the integration of both technical and non-technical competencies [32].

Furthermore, the process emphasizes cross-functional exercises that promote the reinforcement of Non-Technical Skills (NTS) such as communication, teamwork, coordination, leadership, and psychological resilience (Carpenter et al., 2017; Ketelaars et al., 2024). This stage concludes with formative assessments and reflective feedback mechanisms, primarily operationalized through After Action Review (AAR) sessions, which facilitate experiential learning and continuous improvement [34].

Stage 3 – Training Output: Measurable Short-Term Results

The output stage captures the immediate learning outcomes emerging from the training process at both individual and collective levels. Performance success at this stage is determined through empirically measurable indicators that reflect observable changes in competence and behavior. First, the improvement of technical and tactical competencies is evaluated through performance-based assessments, ensuring that learners demonstrate operational proficiency under realistic conditions [35]. Second, the enhancement of stress management capacity and non-technical skills is assessed using behavioral observation tools, particularly Behavioral Marker Systems developed under the THINCS (Teamwork, Human Factors, Interaction, Non-Technical, Cognitive, and Stress) framework [33][36]. Third, the emergence of stronger team cohesion and coordination is examined through direct observation during full-scale operational exercises, reflecting the degree of collective competence and situational adaptability.

Stage 4 – Long-Term Outcomes: Systemic Impact on Aviation Safety

The final stage concerns the sustained, system-level outcomes that extend beyond the training environment into the broader national aviation safety framework. The systematic implementation of this model is anticipated to enhance national emergency preparedness, supported by consistent training standards and regular safety audit mechanisms. In measurable terms, the long-term impact can be observed through Key Performance Indicators (KPIs) such as reduced incident response times, improved hazard mitigation efficiency, and greater inter-agency coordination across airport emergency systems. At the organizational level, the model fosters the development of a robust safety culture and institutionalizes a continuous improvement cycle, thereby transforming the Airport Rescue and Firefighting (ARFF) system into a dynamic learning ecosystem that continually adapts to evolving operational demands [37]. Comprehensive details of each stage including their key components, conceptual underpinnings, and core performance indicators are synthesized and presented in Table 1.

Table 1. Conceptual Model of ARFF Training Effectiveness in Indonesia (I–P–O–O Model)

Stage	Key Components	Academic Description	Key Indicators
1. Input	National Competency Standards	Development of national standards based on ICAO Doc 9137 guidelines, adapted to Indonesia's geographical context and aviation risk profile. This document serves as the primary reference in defining the required knowledge, skills, and attitudes (KSA) across all ARFF career levels.	National standard document, update frequency, alignment with ICAO standards.
	Participant Selection Based on Psychological Profile	Recruitment includes psychological assessment to ensure candidates possess stress resilience, rapid decision making ability, and strong teamwork orientation.	Psychological assessment results, selection pass rate, instructor satisfaction with participant readiness.
	High-Quality Facilities and Instructors	Availability of modern training facilities (live-fire training grounds, VR/AR laboratories) and internationally certified instructors with relevant field experience.	Facility adequacy, instructor–participant ratio, number of certified instructors.
2. Process	Integrated CBTA Curriculum	Curriculum designed using a competency-based framework with a backward design and 4C/ID approach, ensuring each module aligns with national competency outcomes.	Curriculum alignment with standards, 4C/ID effectiveness, curriculum validation results.
	Blended Learning (Physical and Virtual Simulation)	Combination of VR/AR exercises for repetitive procedural training and full-scale live-fire simulations to integrate technical and non-technical skills.	Total hours of virtual/physical training, final validation test results.
	Cross-Functional and Non-Technical Training	Collaboration with medical, security, and airport operations units to strengthen coordination, communication, and psychological resilience.	Improved teamwork scores, results of resilience and stress inoculation evaluations.
	Feedback Mechanism (AAR)	Implementation of structured After Action Reviews (AAR) using data and video analysis to support reflective learning and continuous improvement.	AAR frequency, participant engagement rate, number of improvement recommendations.
3. Output	Technical and Tactical Competence	Enhancement of ARFF personnel's operational and tactical performance evaluated through performance-based assessment.	Response time, procedural accuracy, technical assessment scores.
	Non-Technical Skills and Stress Management	Significant improvement in communication, decision-making, and emotional regulation under emergency conditions following training.	Behavioral Marker Systems (THINCS) scores, observed behavioral performance.
	Team Cohesion and Coordination	Improved team communication and adaptability during emergency simulations, reflecting higher inter-member synergy.	Team coordination observation scores, full-scale exercise results.
4. Outcome	National Preparedness	Broad implementation of the model enhances national ARFF readiness through regular safety audits and periodic emergency drills.	Regulator audit results, frequency of full-scale emergency exercises.

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Stage	Key Components	Academic Description	Key Indicators
	Improved Operational Safety	Tangible outcomes include reduced response times and enhanced effectiveness of emergency incident mitigation at airports.	Average response time, number of incidents successfully managed..
	Safety Culture and Continuous Improvement	Establishment of a reflective safety culture and collective accountability within the ARFF system, promoting continuous learning and organizational improvement.	National AAR frequency, safety culture survey results, annual improvement cycle.

The interrelationships among the components of this conceptual framework are comprehensively depicted in Figure 2. In accordance with the reviewers' recommendations, the diagram has been meticulously redesigned using professional diagramming software to ensure enhanced visual clarity, logical coherence, and overall presentation quality. The figure illustrates the systematic interactions among the four principal stages Input, Process, Output, and Outcome while simultaneously emphasizing the feedback loop that underpins the model's continuous improvement mechanism within the training cycle.

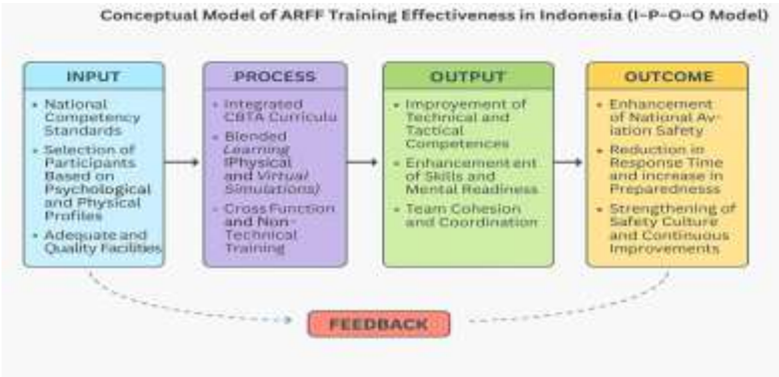

Figure 2. Conceptual Model of ARFF Training Effectiveness in Indonesia (I–P–O–O)

Conceptual Validation of the Model

To establish the validity and reliability of the proposed conceptual model, an initial validation phase has been systematically designed. Although the model was developed through a rigorous synthesis of relevant literature, additional validation is required to ensure its contextual applicability and operational feasibility within the Indonesian aviation framework.

The validation process will employ the expert judgment approach, in which the proposed Input–Process–Output–Outcome (I–P–O–O) model will be presented to a panel of domain experts, including aviation safety scholars, regulators from the Directorate General of Civil Aviation, senior Airport Rescue and Firefighting (ARFF) instructors, and airport operations managers from various regions across Indonesia.

These experts will critically evaluate the model in terms of its logical coherence, component completeness, contextual relevance, and practical feasibility. Their qualitative insights and evaluative feedback will serve as the basis for further refinement and adjustment of the model prior to its large-scale pilot implementation. This validation strategy ensures that the model is not only theoretically robust and methodologically sound but also empirically grounded and aligned with the operational realities of Indonesia's national aviation safety system.

Discussion

The distinction between the Results (model description) and Discussion (interpretation) sections is essential to maintain academic rigor and analytical clarity. This section provides a critical interpretation of the proposed Input–Process–Output–Outcome (I–P–O–O) model, examining its implications within the Indonesian aviation safety training context and situating it within the broader corpus of international research.

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Implications of the I–P–O–O Model in the Indonesian Context

The conceptual model proposed in this study (see Figure 2) offers a systemic and integrative framework that shifts the paradigm from fragmented training initiatives such as the isolated acquisition of virtual reality simulators toward the development of a comprehensive and interlinked training ecosystem. The model places substantial emphasis on the Input stage, particularly on the adaptation of national competency standards and the psychologically informed selection of participants, thereby addressing Indonesia's context-specific challenges.

Given Indonesia's archipelagic geography and the heterogeneity of airport risk profiles, a uniform approach grounded solely in International Civil Aviation Organization (ICAO) standards is insufficient. The model advocates for a context-sensitive adaptation, ensuring that training interventions are both locally relevant and operationally effective.

Within the Process stage, the integration of Virtual Reality (VR) and Augmented Reality (AR) technologies, alongside Competency-Based Training and Assessment (CBTA) methodologies, is conceptualized not as an end in itself but as an instrumental mechanism whose effectiveness is contingent upon the quality and preparedness of input factors. Furthermore, by embedding After Action Reviews (AAR) and Non-Technical Skills (NTS) into the training cycle, the model actively promotes a reflective and learning-oriented safety culture [34], thereby reducing the prevalence of reactive or blame-oriented organizational tendencies.

The structured linkage between Output (measurable competencies) and Outcome (system-level impacts) provides actionable insights for both regulators and airport operators. This alignment enables a strategic evaluation of Return on Investment (ROI) not solely through certification achievements, but through quantifiable Key Performance Indicators (KPIs) such as reduced emergency response times, enhanced inter-agency coordination, and improved national preparedness levels.

Comparison with Global Models and Scientific Positioning

The proposed I–P–O–O model exhibits theoretical alignment with established global training evaluation frameworks, notably the Kirkpatrick Model, while introducing critical extensions suited to high-risk operational domains such as airport rescue and firefighting (ARFF). Unlike traditional frameworks that focus primarily on reaction and learning outcomes, this model explicitly integrates long-term systemic outcomes, consistent with advanced constructs embedded within ICAO's Safety Management Systems (SMS) framework.

The scientific contribution of this study lies in its synthesis, contextual adaptation, and theoretical extension. While prior research has extensively explored discrete elements such as Competency-Based Training and Assessment (CBTA) [9] and VR-based procedural training [17], most of these investigations were conducted in technologically advanced and resource-abundant contexts. The present study addresses this gap by translating and localizing global best practices into a feasible and sustainable model tailored to developing countries, particularly Indonesia.

For instance, while frameworks established by the Federal Aviation Administration (FAA) and the European Union Aviation Safety Agency (EASA) presuppose the availability of sophisticated technological infrastructure [29], the proposed I–P–O–O model integrates such advancements with contextual mechanisms, including psychological input selection [28] and localized competency standardization. Consequently, the model does not merely replicate Western best practices; rather, it reconstructs them into a systemic architecture calibrated to national risk profiles, operational capacities, and institutional realities.

This contextual and integrative orientation represents an original scholarly contribution to the global discourse on aviation safety management and emergency response training, expanding the applicability of contemporary training models beyond Western-centric frameworks and establishing a regionally grounded paradigm for the Global South aviation context.

CONCLUSIONS

This study has developed a comprehensive conceptual model aimed at enhancing the effectiveness and systemic integration of Aircraft Rescue and Fire Fighting (ARFF) training within the

Indonesian aviation context. The model, which comprises four interrelated components Input, Process, Output, and Outcome (I–P–O–O) was formulated to address the current absence of a nationally standardized and modernized training framework. Fundamentally, the model posits that effective training outcomes arise not from isolated or fragmented interventions, but from a cohesive and mutually reinforcing system that aligns inputs, processes, and performance evaluation mechanisms in a continuous improvement cycle.

The framework begins by consolidating foundational elements, including the formulation of measurable national competency standards and the selection of personnel based on psychological and performance-based criteria. It proceeds with the implementation of Competency-Based Training and Assessment (CBTA) methodologies that leverage advanced simulation technologies, while systematically cultivating non-technical skills (NTS) such as communication, teamwork, and resilience. Through this structured and iterative process, the model supports the development of highly competent, adaptive, and resilient ARFF personnel and teams, generating broader strategic benefits such as enhanced national emergency preparedness and the institutionalization of a sustainable safety culture across Indonesia's aviation sector. Conceptually, this framework reorients training objectives from the completion of instructional sequences toward the attainment and maintenance of enduring professional competence.

To ensure the applicability and institutional integration of the proposed model, it is recommended that the Directorate of Airports and the Ministry of Transportation adopt its underlying principles within the national ARFF training policy architecture. Such adoption may involve the harmonization of competency standards across airports, the implementation of simulation-based CBTA programs, and the establishment of comprehensive monitoring and evaluation mechanisms. Sustained coordination among regulatory authorities, training institutions, and industry stakeholders is essential to ensure quality assurance, policy coherence, and alignment with global aviation safety standards established by the International Civil Aviation Organization (ICAO).

Future research should focus on the empirical validation of this conceptual model through quantitative analysis or case-based field studies conducted within representative airport environments. Such investigations would enable the measurement of operational effectiveness, the testing of theoretical propositions, and the refinement of model components based on real-world implementation outcomes. Empirical validation will not only strengthen the model's academic credibility and methodological rigor but also contribute to evidence-based policymaking, thereby supporting long-term institutional capacity building and the sustainable advancement of ARFF training systems in Indonesia.

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