Vol. 7, No. 1, 2026, pp. 115-123
DOI: https://doi.org/10.29210/07essr717700

Contents lists available at Journal IICET

Education and Social Sciences Review
ISSN 2720-8915 (Print), ISSN 2720-8923 (Electronic)

Journal homepage: https://jurnal.iicet.org/index.php/essr

Assessing emergency response plan competency gains through interactive scenario-based simulation in airport safety management

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Article Info

Article history:

Received Aug 4th, 2026
Revised Aug 20th, 2026
Accepted Aug 20th, 2026

Keywords:

Emergency response plan
Scenario-based simulation
Aviation safety management
Interactive learning
Airport fire fighting

ABSTRACT

Effective Airport Emergency Plan (ERP) implementation requires personnel to translate documented procedures into appropriate decisions and coordinated actions during dynamic emergencies. However, empirical evidence regarding the effectiveness of scenario-based simulation for developing airport ERP competencies remains limited. This study examines the effectiveness of ESCAPE (Electronic Scenario-based Airport Emergency Exercise) as a scenario-based simulation approach for supporting ERP competency development. An R&D approach using the ADDIE model was employed. ESCAPE was validated by two subject-matter experts and two media experts selected through purposive sampling. Implementation involved 20 airport personnel selected through total sampling; no random assignment or control group was used. Product validity was assessed using expert questionnaires, while learning outcomes were evaluated using a one-group pre-test–post-test design. Data were analysed using validity percentages, Cronbach's alpha, ICC, N-Gain, and a paired-samples *t*-test. Material and media validation achieved 89.50% and 87.78%, respectively, with good internal consistency and inter-rater agreement. Mean ERP competency scores increased from 70.75 to 88.13, yielding an N-Gain of 0.59 (medium category). The improvement was statistically significant, $t(19) = 15.13$, $p < 0.001$, with a 95% confidence interval of 14.97–19.78 and a very large effect size (Cohen's $d = 3.38$). These findings indicate that scenario-based simulation through ESCAPE is associated with substantial improvement in ERP competency. Its main contribution is integrating ERP procedures with contextualized emergency scenarios, decision-making, resource positioning, and performance feedback, thereby providing a structured environment for connecting procedural knowledge with emergency-response application. Further controlled comparative studies are required to determine whether ESCAPE provides advantages over conventional ERP training approaches.

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Introduction

Air transport is widely recognized as a highly safe mode of transportation; nevertheless, aviation operations remain exposed to low-probability, high-consequence events that can result in substantial human, operational,

and organizational consequences. Aviation safety therefore depends not only on preventing accidents but also on the capacity of aviation organizations and personnel to respond effectively to abnormal or emergency conditions. The International Civil Aviation Organization (ICAO) promotes a systemic approach to aviation safety through State Safety Programs (SSP), Safety Management Systems (SMS), and emergency preparedness, which are complementary components of risk management. The objective of reducing aviation fatalities to the lowest practicable level, including ICAO's long-term aspiration toward zero fatalities, consequently requires both proactive risk control and effective management of residual risk when preventive barriers fail (Malakis & Kontogiannis, 2023).

The theoretical relationship between emergency preparedness and aviation safety can be understood through the concept of safety barriers and organizational resilience. In the Swiss Cheese Model, accidents occur when multiple defensive layers are simultaneously penetrated by active and latent conditions (Underwood & Waterson, 2014). From this perspective, an Airport Emergency Plan (AEP) serves as an organizational layer of defense that becomes particularly important following an accident or major incident. However, the existence of an emergency plan alone does not guarantee effective risk containment. Its effectiveness depends on whether personnel can interpret the situation, make appropriate decisions, communicate information, coordinate resources, and implement prescribed procedures under dynamic and time-critical conditions. Similarly, the resilience perspective emphasizes an organization's capacity to anticipate, monitor, respond to, and learn from changing operational conditions (Yu et al., 2018). These perspectives indicate that emergency preparedness should be understood not merely as regulatory compliance but as a capability that depends on the interaction between procedures, organizational arrangements, and human competence (Patriarca et al., 2020); Petridou et al., 2023).

This distinction is particularly important in aviation because preventive safety systems cannot eliminate residual operational risk. Emergency response capability represents an additional layer of protection when preventive controls are unsuccessful (Nugraha et al., 2025). In this study, emergency response capability is operationally defined as the ability of airport personnel to apply ERP procedures, interpret emergency information, make appropriate decisions, communicate and coordinate with relevant stakeholders, and allocate available resources during an emergency scenario (Salas et al., 2006). Similarly, ERP competency refers to the measurable knowledge and performance-related ability required to execute these emergency response functions appropriately within a defined scenario. These definitions shift the focus from whether an airport has an emergency plan to whether its personnel can implement it effectively.

In Indonesia, airports are required to establish an Airport Emergency Plan (AEP) to provide an organized framework for coordinating personnel, agencies, facilities, and resources during aviation emergencies. Implementation of an AEP requires personnel from different operational functions and stakeholder organizations to understand communication procedures, command and coordination structures, resource allocation, decision-making processes, and crisis-management responsibilities (Hendra et al., 2023). Consequently, airport emergency preparedness cannot be assessed solely by examining the existence of written plans or regulatory compliance. The practical effectiveness of an emergency plan ultimately depends on whether personnel have the competence to translate documented procedures into coordinated actions during an emergency (Flauto et al., 2024).

Existing research on airport emergency planning has predominantly examined emergency-plan frameworks, regulatory requirements, organizational coordination, and preparedness arrangements (Dermawan et al., 2023). These studies provide important foundations for understanding how airports should organize their emergency response systems. However, comparatively less attention has been given to the personnel competency dimension of ERP implementation, particularly to how emergency response competencies can be developed, practiced, and objectively assessed through simulation-based interventions (Kwon et al., 2020). This creates an important conceptual distinction between plan availability and plan execution capability. Although an airport may have a formally established AEP, personnel may still need opportunities to develop and demonstrate the competencies required to implement that plan under dynamic emergency conditions.

Conventional emergency-response training approaches, including lectures, procedural briefings, and tabletop exercises, remain valuable for knowledge acquisition and procedural familiarization, but may provide fewer opportunities for learners to repeatedly practice time-critical decision-making, coordinated response, and performance feedback within dynamic emergency scenarios. Full-scale emergency exercises can provide greater realism but require substantial resources, coordination, time, and operational disruption (Cavdur et al., 2020). These constraints create a need for complementary training approaches that can provide controlled, repeatable, and scenario-driven practice without reproducing the full cost and risk of an actual emergency exercise (Gue et al., 2023; Heath & Kassutto, 2024).

Scenario-Based Simulation (SBS) offers a potential solution by placing participants in contextualized situations where they must interpret information, identify hazards, make decisions, coordinate actions, and respond to changing conditions (Song et al., 2023). From an experiential learning perspective, effective learning occurs through active engagement with situations, decision-making, feedback, and reflection (Liu, Becerik-Gerber, et al., 2023; Liu, Zhu, et al., 2023). Research in higher education also indicates that games and simulations can support cognitive, behavioral, and affective learning outcomes when appropriately designed (Vlachopoulos & Makri, 2017). In aviation and other safety-critical domains has demonstrated the potential of simulation-based learning to support decision-making, communication, coordination, and problem-solving. Nevertheless, the application of interactive scenario-based simulation specifically to airport ERP competency development remains insufficiently examined (Ross & Gilbey, 2023; Kim & You, 2023).

The research gap is therefore not simply the absence of another digital learning product. Rather, three interrelated gaps remain. First, research on AEP has largely focused on what airports and organizations should prepare, while providing comparatively limited empirical evidence on how personnel can develop and demonstrate the competencies required to execute those plans (Janev et al., 2012). Second, existing aviation simulation research has frequently focused on flight operations, cockpit decision-making, or general safety training. In contrast, fewer studies have integrated airport emergency procedures, multi-stakeholder coordination, resource allocation, and time-critical decision-making into a single interactive scenario-based learning environment (Supri et al., 2020). Third, empirical evidence regarding the effectiveness and user acceptance of such a simulation among operational airport personnel in the Indonesian regulatory context remains limited. Addressing these gaps requires an intervention that connects the procedural requirements of ERP with measurable changes in personnel competency (Cahyadi et al., 2022).

To address this gap, this study examines ESCAPE (Electronic Scenario-based Airport Emergency Exercise), an interactive scenario-based simulation designed to support Emergency Response Plan training in airport safety management. The primary outcome of the intervention is ERP competency gain, operationalized as the change in participants' competency scores between the pre-test administered before the intervention and the post-test administered after participation in ESCAPE-based training. The study also examines user acceptance, defined as participants' perceived usability, appropriateness, and acceptability of ESCAPE as a training medium.

The contribution of this study extends beyond documenting regulatory requirements or describing the availability of airport emergency plans. It provides an empirical connection between ERP requirements, scenario-based experiential learning, and measurable personnel competency development. By shifting the analytical focus from emergency-plan availability to personnel capability to implement emergency procedures, the study contributes to research on aviation safety management, emergency preparedness, and simulation-based training. The findings also provide a foundation for subsequent controlled studies comparing scenario-based simulation with conventional training approaches, as well as for future development incorporating adaptive learning, artificial intelligence, and virtual reality technologies.

Method

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Ramdhani et al., 2025). The ADDIE model was selected because it provides a systematic, iterative framework for developing educational products and enables continuous improvement through expert feedback and user evaluation (Abdullah et al., 2021). The study aimed to develop and evaluate the feasibility, user acceptance, and effectiveness of the Electronic Scenario-based Airport Emergency Exercise (ESCAPE) as a scenario-based simulation tool for Emergency Response Plan (ERP) training in airport safety management.

Product validation was conducted by two subject-matter experts and two media experts, selected through purposive sampling for their professional expertise and experience. The subject-matter experts possessed academic and professional backgrounds in aviation safety management, airport emergency planning, and Aircraft Rescue and Fire Fighting (ARFF). They had at least 5 years of relevant experience. The media experts had expertise in educational technology and digital learning media development, and at least 5 years of professional experience. The experts evaluated the content accuracy, instructional quality, relevance to ERP competencies, system functionality, interface design, usability, and visual presentation of the ESCAPE application.

The implementation phase involved 20 airport personnel selected through total sampling, representing the entire accessible population available during the study period. Participants were personnel involved in airport operations, safety management, emergency response, or ARFF-related functions and had previously received

basic emergency response training. Individuals who did not complete all stages of the implementation and assessment process were excluded from the study.

Three research instruments were used. The first was a content and media validation questionnaire completed by the expert validators to assess the feasibility of the developed product (Ramdhani et al., 2025). The second was a user acceptance questionnaire designed to evaluate participants' perceptions regarding usability, usefulness, learning support, ease of use, and overall satisfaction with ESCAPE. The third instrument was an ERP competency test administered before and after the intervention to measure participants' understanding of emergency procedures, communication protocols, stakeholder coordination, resource allocation, and emergency decision-making. All instruments were developed in accordance with Airport Emergency Plan requirements, aviation safety management principles, and scenario-based learning concepts. Content validity was established through expert review before implementation (Suryan et al., 2023).

User acceptance data were analyzed by calculating the percentage of responses. Learning effectiveness was evaluated using a one-group pretest–posttest design, in which participants completed an ERP competency test before and after using ESCAPE. Improvement in competency scores was measured using the Normalized Gain (N-Gain) index (Nissen et al., 2018). To determine whether the observed improvement in competency scores was statistically significant, a paired-samples t-test was conducted at the 0.05 significance level. The ESCAPE application was considered effective when expert validation results reached at least the feasible category, user acceptance was positive, and competency scores showed meaningful improvement following the intervention.

Results and Discussions

The product resulting from this research is the electronic scenario-based Airport Emergency Exercise (ESCAPE), a scenario-based simulation learning tool designed to support instruction on Emergency Response Plans (ERP) within aviation vocational education. The ADDIE model, consisting of the stages Analysis, Design, Development, Implementation, and Evaluation, was employed to guide the development process. The ADDIE model is widely used to develop learning materials because it helps ensure that the results are valid, practical, and effective through continuous validation and evaluation.

During the design phase, the system architecture, storyboard, emergency scenarios, and learning flow are developed.

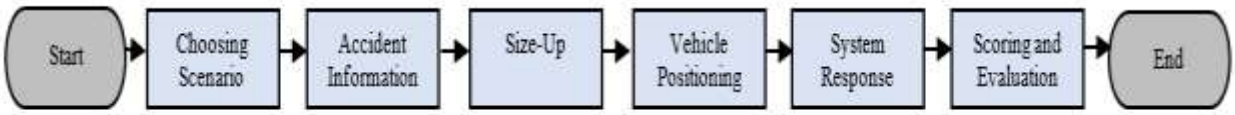

Figure 1 <Application Flowchart>

The simulation begins with selecting an emergency scenario, followed by displaying accident information to establish situational context. A size-up process is then conducted to assess emergency conditions and determine an appropriate response strategy (Di Donato & Atkins, 2017). Based on this assessment, the positioning of emergency vehicles is selected, and the system then generates a response accordingly. Upon completion of the simulation, the application evaluates performance using a scoring system and provides feedback on the effectiveness of the response before concluding.

The content validity of the ESCAPE learning media was evaluated by two subject-matter experts and two media experts. The evaluation used a five-point Likert scale, with scores ranging from 1 (very poor) to 5 (very good). The validation results were analyzed using the percentage of the maximum possible score, Cronbach's alpha, and the intraclass correlation coefficient (ICC).

Table 1 <Results of Material and Media Validation>

Validation Aspect	No. of Items	Obtained Score	Maximum Score	Validity (%)	Mean Score	Cronbach's α	ICC (2,1)	Interpretation
Material	20	179	200	89.50	4.48	0.826	0.711	Highly valid; good agreement
Media	18	158	180	87.78	4.39	0.868	0.776	Highly valid; good agreement

The material validation obtained a total score of 179 out of a maximum possible score of 200, corresponding to a validity percentage of 89.50% and a mean score of 4.48. The Cronbach's alpha coefficient was 0.826, indicating good internal consistency. The ICC (2,1) value was 0.711, demonstrating good inter-rater agreement between the two material validators.

Similarly, the media validation produced a total score of 158 out of 180, corresponding to a validity percentage of 87.78%, with a mean score of 4.39. The Cronbach's alpha coefficient of 0.868 indicated good internal consistency, while the ICC (2,1) value of 0.776 indicated good agreement between the two media validators.

Overall, both the material and media components of ESCAPE achieved validity percentages above 85%, indicating that the developed learning media was highly valid and suitable for further implementation and effectiveness testing. The ICC results also demonstrated good agreement between the validators, supporting the consistency of the expert evaluation.

Figure 2 <Login and Scenario Page>

The ESCAPE login page serves as the application's initial interface, providing user access to the simulation system. It displays the application's identity and an illustration of an aviation emergency representing the Emergency Response Plan (ERP) material. Users can start the simulation using the "Play" button or exit the application via the "Exit" button. Upon selecting "Play," three playable scenarios appear: Scenario 1 simulates handling a landing gear fire, Scenario 2 covers handling a fuel spill fire, and Scenario 3 deals with handling a cabin fire.

Figure 3 <Simulation and Assessment Page>

The simulation screen presents an aviation emergency scenario that the user must manage. At this stage, the user makes decisions regarding the emergency response, the positioning of ARFF (Aircraft Rescue and Fire Fighting) vehicles, and firefighting actions based on the simulated conditions. Meanwhile, the assessment screen displays the results of the user's performance evaluation following the simulation. The system scores various aspects—such as response time, positioning, and fire-rescue operations—enabling the user to gauge their competence and identify areas for improvement.

Group testing was conducted with 20 participants, and the results are presented in the diagram on Figure 4. Based on Figure 4 the high acceptance scores across all dimensions indicate that ESCAPE successfully integrates usability, interactivity, and instructional functionality within a single learning environment. The highest score obtained in the interactivity dimension (92.8%) suggests that scenario-based decision-making activities can actively engage participants during ERP training. This finding is consistent with previous studies reporting that simulation-based learning environments improve learner engagement and decision-making performance in safety-critical domains (Campos et al., 2020). Similarly, the high score for perceived usefulness (91.9%) supports the argument that scenario-based simulations can bridge the gap between theoretical ERP knowledge and

operational emergency-response practice. To measure how effective the media is, we compare the scores from before and after the test.

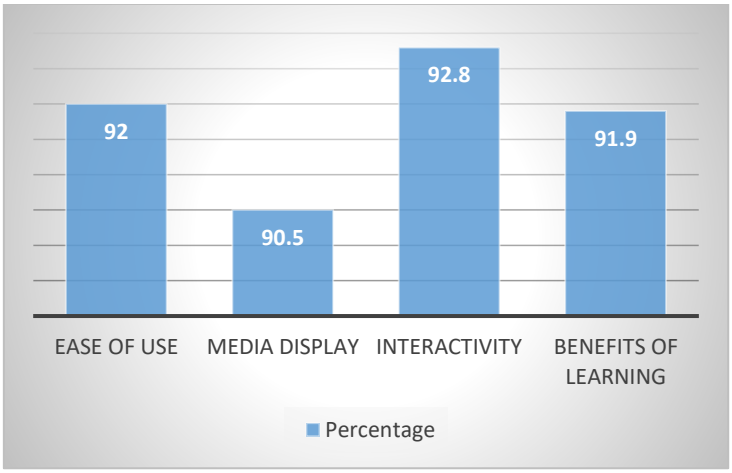

Figure 4 <Results of Group Testing>

Table 2 <Pre-test and Post-Test Scores>

Indicator	**Value**
Number of participants	20
Mean pre-test score	70.75
Mean post-test score	88.13
Mean increase	17.38
N-Gain	0.59
N-Gain Category	Medium
t-value	15.13
p-value	< 0.001
Cohen's d	3.38
95% CI	14.97 – 19.78

The effectiveness of ESCAPE was evaluated using a one-group pre-test–post-test design involving 20 airport personnel. The results demonstrated a substantial improvement in ERP competency following participation in the simulation-based training. The mean pre-test score increased from 70.75 to 88.13 in the post-test, resulting in a mean gain of 17.38 points. The calculated N-Gain score was 0.59, which falls within the medium category, indicating a meaningful improvement in participants' competency levels.

To determine whether the observed improvement was statistically significant, a paired-samples t-test was conducted. The analysis revealed a statistically significant difference between pre-test and post-test scores, $t(19) = 15.13$, $p < 0.001$. The mean difference was 17.38 points, with a 95% confidence interval of 14.97 to 19.78. These findings indicate that the improvement in ERP competency was unlikely to have occurred by chance.

The practical significance of the intervention was assessed using Cohen's *d*. The analysis produced an effect size of $d = 3.38$, indicating a very large effect according to Cohen's classification. This result suggests that ESCAPE had a substantial impact on participants' understanding of emergency response procedures, decision-making processes, communication protocols, and resource allocation strategies in airport emergency scenarios.

The findings support the premise that scenario-based simulation can facilitate experiential learning by enabling participants to apply ERP procedures in realistic, dynamic emergencies. Through repeated exposure to operational scenarios, participants were able to connect theoretical knowledge with practical decision-making, thereby enhancing their emergency-response competency (Amalia et al., 2022; Zhang et al., 2024). These results are consistent with previous studies demonstrating the effectiveness of simulation-based learning in improving performance, situational awareness, and decision-making in safety-critical environments (Aghaei et al., 2023).

Several limitations should be considered when interpreting the findings of this study. First, the expert validation process involved only two subject-matter experts and two media experts. Although the inter-rater agreement indicated a high level of consistency, a larger number of validators could provide broader perspectives and strengthen the evaluation's robustness. Second, the implementation phase involved only 20 airport personnel from a limited operational context, which may restrict the generalisability of the findings to other

airport environments. Third, the effectiveness evaluation employed a one-group pretest–posttest design without a control group, limiting the ability to attribute competency gains exclusively to the intervention. Future studies should involve larger, more diverse samples and adopt quasi-experimental or experimental designs to further examine the effectiveness of ESCAPE compared with conventional training approaches.

Conclusions

ESCAPE (Electronic Scenario-based Airport Emergency Exercise) was developed as a scenario-based simulation tool for Emergency Response Plan (ERP) education. Expert validation indicated high validity for both material (89.50%; Cronbach's $\alpha = 0.826$; ICC = 0.711) and media (87.78%; Cronbach's $\alpha = 0.868$; ICC = 0.776), supporting the consistency and appropriateness of the developed learning tool. Among 20 airport personnel, the mean ERP competency score increased from 70.75 to 88.13, with an N-Gain of 0.59 (medium category). The improvement was statistically significant, $t(19) = 15.13$, $p < 0.001$, with a very large effect size (Cohen's $d = 3.38$). These findings indicate that ESCAPE is associated with improved ERP competency, although the absence of a control group limits causal interpretation.

The principal contribution of ESCAPE is its integration of ERP procedures with scenario-based experiential learning, requiring learners to interpret emergencies, make response decisions, position resources, and receive performance feedback in a controlled and repeatable environment. Thus, ESCAPE provides a practical simulation-based approach for bridging procedural ERP knowledge and its application in airport emergencies. Further studies should use larger samples and controlled comparative designs to establish its effectiveness relative to conventional ERP training.

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