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Developing a Crisis Management Training Model for Reducing Air Traffic Control Challenges in Iran

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ABSTRACT

Purpose: This study aimed to develop and validate a crisis management training model designed to reduce the challenges affecting air traffic control operations.

Methods and Materials: This applied study employed an exploratory sequential mixed-methods design consisting of qualitative and quantitative phases. In the qualitative phase, an emergent grounded theory approach was used. Nineteen experts in air traffic control, crisis management, and educational management were selected through purposive sampling and interviewed using semi-structured interviews. In the quantitative phase, a descriptive-survey design was adopted. The statistical population comprised 430 air traffic control personnel working at Mehrabad Airport Control Tower, Tehran Approach Control, and the Area Control Center. Using Cochran's formula and stratified random sampling, 203 participants were selected. Qualitative data were analyzed in MAXQDA, while quantitative data were examined through structural equation modeling using SPSS and AMOS. Data were collected using a researcher-developed questionnaire whose face, content, and construct validity and internal consistency reliability were confirmed.

Findings: The qualitative analysis generated a model comprising five dimensions, 19 components, and 93 indicators. Structural equation modeling supported the proposed measurement and structural model and confirmed the significant contribution of the five principal dimensions to crisis management training. These dimensions were operational preparedness and capability; crisis management and rapid response; leadership, structure, and resources; knowledge and continuous learning; and emerging technologies. The model demonstrated that simulation-based training, safety management, navigational resilience, cybersecurity, communication, climatic preparedness, risk prioritization, command structure, occupational health, human resources, legal and strategic frameworks, training sustainability, meteorological information, and intelligent data analysis were significant components of an integrated crisis management training system.

Conclusion: The validated model provides a comprehensive and operational framework for strengthening crisis preparedness, improving rapid-response capacity, and reducing air traffic control challenges in Iran.

Keywords: *Air Traffic Control; Crisis Management; Crisis Management Training; Aviation Safety; Operational Preparedness*

1. Introduction

The aviation industry operates as a highly interconnected, technology-intensive, and safety-critical system in which operational continuity depends on the coordinated performance of airports, airlines, air navigation service providers, air traffic controllers, meteorological units, emergency-response agencies, and regulatory authorities. Although aviation is widely recognized as one of the safest modes of transportation, its operational environment remains exposed to crises arising from technical failures, adverse weather, airspace congestion, human error, security threats, infrastructure disruption, cyberattacks, aircraft emergencies, and large-scale natural or geopolitical events. The consequences of such crises may extend beyond immediate flight disruption and include loss of life, damage to infrastructure, interruption of national and international transportation networks, economic losses, reputational harm, and declining public confidence. Therefore, crisis management in aviation should not be viewed as a reactive activity limited to emergency response; rather, it constitutes an integrated managerial process encompassing risk identification, preparedness, prevention, rapid decision-making, coordinated response, recovery, organizational learning, and resilience development (Abdallah et al., 2025; Cook et al., 2024; Taylor, 2026).

Crisis management generally refers to the systematic set of policies, structures, procedures, and actions through which organizations anticipate potentially disruptive events, reduce their adverse consequences, respond effectively, and restore normal operations. Contemporary approaches emphasize that crisis-management effectiveness depends on preparedness before a disruptive event, coordinated action during the event, and systematic learning after the event. From this perspective, crisis management requires clear command structures, defined responsibilities, reliable communication channels, operational flexibility, resource mobilization, risk assessment, and continuous training. In complex transportation and logistics systems, crisis-management models must also address interorganizational dependence because the failure of one operational unit may rapidly affect other parts of the network. Theoretical and practical models developed for transportation and logistics accordingly emphasize risk mapping, continuity planning, scenario development, stakeholder coordination, and adaptive decision-making as essential foundations of crisis resilience (Jarašūnienė & Gelžinis, 2025; Safari et al., 2025).

The importance of these principles is particularly evident in air traffic control, where controllers must continuously organize aircraft movements, maintain safe separation, manage traffic flows, communicate with flight crews, coordinate with adjacent sectors, and respond to rapidly changing operational conditions. Air traffic control is characterized by real-time decision-making, limited tolerance for error, substantial cognitive demands, and a continuous requirement for situational awareness. A seemingly minor failure in communication, surveillance, navigation, data processing, or human judgment can propagate through the air traffic network and create significant operational risk. Accordingly, the capacity of air traffic control organizations to manage crises depends not only on the availability of technical systems but also on the preparedness of personnel to interpret incomplete information, prioritize competing demands, coordinate under pressure, and maintain safe operations under abnormal conditions. Crisis-management training must therefore be designed around the actual operational characteristics of air traffic control rather than being limited to general or theoretical emergency-management content (Abdallah et al., 2025; Taylor, 2026).

The increasing complexity of air traffic has further intensified the need for specialized crisis-management training. Air traffic complexity is a multidimensional concept influenced by traffic density, aircraft convergence, speed and altitude variation, crossing routes, sector configuration, weather deviations, communication demands, and the dynamic interaction of multiple aircraft. As complexity increases, controllers must process larger volumes of information, anticipate potential conflicts, and implement timely interventions while maintaining an accurate mental representation of the airspace. Research on the evolution of air traffic complexity demonstrates that traditional measures based only on traffic volume are insufficient, because operational difficulty is also shaped by interaction patterns, uncertainty, and the spatial and temporal structure of traffic (Pérez Moreno et al., 2024). Consequently, crisis-management preparation should train controllers to recognize not merely high traffic volume but also complex combinations of technical, environmental, and operational conditions that may rapidly increase risk.

Controller workload is closely associated with air traffic complexity and represents a major determinant of performance and safety. Excessive workload may reduce attention, impair decision quality, delay responses, increase communication errors, and undermine the controller's

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ability to maintain situational awareness. Conversely, inadequate workload may also produce reduced vigilance and slower detection of emerging hazards. The relationship between workload and safety is therefore nonlinear and context dependent. Studies mapping the research field of air traffic controller workload have highlighted the importance of cognitive demands, traffic characteristics, automation, human–machine interaction, fatigue, stress, and organizational conditions in shaping controller performance (Zamarreño Suárez et al., 2024). A comprehensive crisis-management training model must accordingly include mechanisms for managing cognitive pressure, distributing workload, strengthening teamwork, maintaining attention during long shifts, controlling stress, and making decisions under time constraints.

Air traffic flow management is another critical area in which crises may emerge or intensify. The primary purpose of air traffic flow management is to balance airspace and airport demand with available capacity while maintaining safety and operational efficiency. However, weather disturbances, runway closures, technical failures, aircraft incidents, staffing shortages, or sudden demand fluctuations can disrupt this balance and generate cascading delays across the network. Recent reviews of air traffic flow management emphasize the growing use of optimization, collaborative decision-making, predictive models, and data-driven tools to improve capacity allocation and reduce congestion (Chen et al., 2024). Research on operational efficiency has similarly demonstrated that reducing network scale and complexity may contribute to more efficient traffic management and more manageable operational structures (Zhao et al., 2024). These developments indicate that crisis-management training should prepare personnel to understand network effects, anticipate congestion, prioritize critical flights, manage alternative routing, and coordinate capacity decisions across interconnected control units.

Scheduling disruptions constitute a further challenge because flight delays and stopovers can create complex interactions among aircraft rotations, airport capacity, crew availability, and traffic-management decisions. Mathematical and multi-operator approaches to flight-loop scheduling show that effective disruption management requires the simultaneous consideration of delays, intermediate stops, operational constraints, and the interests of multiple operators (Ding et al., 2025). Although air traffic controllers are not solely responsible for airline scheduling, they operate within the consequences of disrupted schedules and must manage altered traffic demand, irregular flight patterns, emergency priorities, and congestion. Training programs should therefore expose controllers to realistic scenarios in which technical failures, adverse weather, route restrictions, and delayed departures interact and produce rapidly changing traffic conditions.

The resilience of the aviation industry depends on its ability to absorb disturbances, adapt operational processes, and recover without compromising safety. Reviews of aviation crises have shown that organizational responses vary according to the nature, duration, and scale of the crisis, but effective responses commonly involve flexible planning, rapid communication, resource reallocation, stakeholder coordination, and learning from previous events (Cook et al., 2024). Resilience in air traffic control similarly involves maintaining essential services when primary systems are degraded, restoring normal operations after system failure, using backup communication and navigation resources, and preserving decision quality under uncertainty. Therefore, training should include manual-operation procedures, degraded-mode operations, system recovery, contingency routing, infrastructure redundancy, and post-crisis evaluation. These capabilities are especially important because excessive dependence on automated systems may leave personnel insufficiently prepared to operate when digital or navigational technologies become unavailable.

Technology has transformed both the operational environment of aviation and the methods available for crisis management. Advanced surveillance, digital communication, automated decision-support systems, artificial intelligence, big-data analytics, and predictive modeling can improve traffic monitoring, anomaly detection, risk forecasting, weather integration, and resource allocation. Artificial intelligence may support real-time analysis of complex data and enable earlier identification of emerging hazards; however, its effective implementation requires personnel who understand system capabilities, limitations, data quality, and the risks of automation bias. The adoption of artificial intelligence in aviation crisis management therefore creates an urgent need for reskilling and upskilling, particularly in data interpretation, digital decision-making, human–AI collaboration, and cyber awareness (Gupta & Bethapudi, 2026). Training models that fail to incorporate emerging technologies may become rapidly outdated and may not prepare controllers for the technological conditions under which future crises will occur.

Cybersecurity is especially significant because modern air traffic control depends on interconnected digital systems,

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data networks, surveillance technologies, and communication infrastructure. Cyber intrusion, data manipulation, denial-of-service attacks, unauthorized access, and system disruption may compromise situational awareness or reduce the availability of critical operational information. Consequently, digital resilience should be incorporated into crisis-management training alongside conventional technical and operational emergencies. Controllers and managers must be able to recognize unusual system behavior, implement cybersecurity protocols, shift to backup systems, protect sensitive information, and coordinate with technical and security units. Artificial intelligence and intelligent analytics can strengthen cyber-threat detection, but they also introduce new dependencies and vulnerabilities, making human competence and procedural readiness indispensable (Gupta & Bethapudi, 2026; Taylor, 2026).

Communication is a central element of crisis response because timely and accurate information exchange directly affects coordination, decision-making, public confidence, and operational safety. Within air traffic control, standardized phraseology, message clarity, communication redundancy, and coordination among controllers, pilots, meteorological services, airport emergency units, firefighting services, and national crisis organizations are essential. Communication failures may delay response, create conflicting actions, or amplify uncertainty. Beyond operational communication, public and media communication also influence the social consequences of aviation crises. Research on media models for air accident crisis management has emphasized the need for structured communication mechanisms capable of delivering accurate information, controlling rumors, supporting public trust, and coordinating institutional messages (Saremi et al., 2023). Social media platforms have become particularly influential because information, eyewitness reports, speculation, and misinformation can circulate rapidly during crises. Their use may facilitate public warning and stakeholder engagement, but it also requires systematic monitoring, message verification, and communication planning (Selvakumar & Babu, 2023).

Educational interventions are fundamental to converting crisis-management policies into operational capability. Crisis-related training should not be restricted to transferring information; it should develop practical competence, judgment, emotional regulation, communication ability, teamwork, and adaptive behavior. Educational guidance for crisis intervention highlights the importance of structured preparation, recognition of warning signs, appropriate intervention strategies, and support for individuals operating under psychologically demanding circumstances (Jazayeri, 2023). In aviation, this implies that crisis-management education should integrate theoretical instruction with simulations, case analysis, group exercises, scenario-based decision-making, and performance feedback. High-fidelity simulations are particularly valuable because they allow personnel to experience rare but high-risk situations without exposing actual operations to danger. They can also reveal weaknesses in procedures, communication, command structures, and team coordination before those weaknesses contribute to a real incident.

The effectiveness of crisis-management training also depends on continuity and sustainability. One-time training programs may generate temporary knowledge but are unlikely to produce durable operational readiness unless they are supported by periodic refresher courses, updated scenarios, performance evaluation, and organizational learning. Aviation risks evolve as technologies, traffic patterns, regulations, and security threats change. Accordingly, training content should be revised in response to new incidents, emerging airspace users, artificial intelligence applications, cybersecurity risks, and changes in international standards. Modular training can provide focused instruction on specific competencies, while recurrent simulation can help maintain skills that may otherwise deteriorate because serious aviation emergencies occur infrequently. The objective is not merely to teach procedures but to institutionalize preparedness as a continuous organizational process (Gupta & Bethapudi, 2026; Taylor, 2026).

National and local conditions should also inform crisis-management models. Traffic crisis research in Iran has emphasized the importance of integrated planning, institutional coordination, intelligent systems, and the prioritization of crisis-management components. Research concerning traffic crises during natural disasters has shown that the effectiveness of response depends on the prioritization of managerial dimensions and operational components, particularly when infrastructure disruption and emergency demand occur simultaneously (Hosseinian et al., 2023). Similarly, studies of smart urban management have highlighted the need to use intelligent technologies, integrated data, and coordinated decision-making to address traffic-related crises in Tehran (Adibi Saadi-Nejad & Seif, 2023). Although urban traffic and air traffic differ substantially, both involve complex flows, limited capacity, interdependent infrastructure, and the need for real-time control. These findings support the broader argument that crisis-management models should combine technological intelligence with clear organizational structures and trained human resources.

In the Iranian aviation context, air accident crisis management has been examined from policy, system-dynamics, media, and organizational perspectives. System-dynamics analysis has indicated that accident prevention and flight-safety improvement require attention to interacting causal factors rather than isolated corrective measures (Moradi et al., 2024). Such an approach is important because aviation crises often emerge through combinations of latent organizational weaknesses, technical limitations, environmental pressures, and human factors. Media-based research has likewise demonstrated that crisis outcomes are influenced not only by operational response but also by the organization of information and communication during and after air accidents (Saremi et al., 2023). These studies provide valuable insights; however, a specific educational model focused on the competencies required by air traffic control personnel remains necessary.

International studies further demonstrate that aviation crisis management must be adapted to institutional and national circumstances. The examination of crisis management in Kuwait's aviation industry, for example, reinforces the importance of preparedness, organizational coordination, leadership, and rapid response in protecting aviation operations (Abdallah et al., 2025). More broadly, airport and airline crisis-management frameworks emphasize integrated planning across operational, organizational, technological, and communication domains (Taylor, 2026). Nevertheless, models developed for airlines, airports, logistics organizations, or other national systems cannot be transferred uncritically to Iranian air traffic control. Differences in infrastructure, organizational arrangements, available technologies, training systems, airspace characteristics, regulatory structures, and interagency relationships require a context-specific model.

An effective model for Iran should therefore integrate several complementary domains. Operational preparedness should encompass simulation, safety management, infrastructure capability, navigational resilience, management of emerging airspace interference, and cybersecurity. Rapid-response capacity should include crisis communication, weather-related decision-making, emergency prioritization, and risk forecasting. Leadership and organizational resources should address command structures, occupational health, crew resource management, legal responsibilities, and strategic coordination. Continuous learning should be supported through practical training methodologies, refresher programs, scenario updates, and skill-retention assessment. Finally, emerging technologies should be incorporated through integrated meteorological information, big-data analysis, intelligent algorithms, and predictive analytics. Bringing these domains together can overcome the fragmentation that often separates technical, human, managerial, and educational aspects of crisis preparedness.

Despite the growing literature on aviation resilience, air traffic complexity, controller workload, traffic-flow management, intelligent technologies, crisis communication, accident prevention, and traffic crisis management, limited research has developed and empirically validated a comprehensive crisis-management training model specifically directed toward reducing the operational challenges of air traffic control in Iran. Existing studies have generally focused on individual dimensions of the problem, whereas air traffic control crises require an integrated framework capable of linking operational readiness, rapid response, leadership, human resources, continuous learning, and emerging technologies. Addressing this gap may provide air navigation organizations, training centers, policymakers, and crisis managers with a structured basis for curriculum design, competency assessment, simulation planning, and organizational preparedness.

Accordingly, the present study aimed to develop a crisis management training model for reducing air traffic control challenges in Iran.

2. Methods and Materials

In terms of purpose, this study was applied research, and in terms of methodology, it employed an exploratory mixed-methods design conducted in two qualitative and quantitative phases. In the qualitative phase, an emergent grounded theory method was used, whereas the quantitative phase employed a descriptive-survey method. The statistical population of the qualitative phase consisted of specialists and experts in air traffic control, crisis management, and educational management. The sample size was not predetermined; instead, purposive sampling continued until theoretical saturation was achieved. Theoretical saturation was reached after conducting 19 interviews. In the quantitative phase, the statistical population comprised 430 air traffic control personnel in Iran, including 100 employees at Mehrabad Airport Control Tower, 100 employees at the Tehran Approach Control Unit, and 230 employees at the National Area Control Center. Based on Cochran's formula and using stratified random sampling, 203 individuals were selected as the study sample. Data were collected through library-based and field methods. In the qualitative phase, data were collected through semi-structured interviews. In the quantitative phase, the measurement instrument was a researcher-developed questionnaire constructed on the basis of the interview findings. The validity of the questionnaire was examined and confirmed through face, content, and construct validity. For face validity, the questionnaire was reviewed by a panel of experts. For content and construct validity, the average variance extracted (AVE) and composite reliability (CR) indices were calculated, and the results confirmed the adequacy of the questionnaire items. The reliability of the instrument was also assessed using Cronbach's alpha coefficient, and the findings indicated that the questionnaire had satisfactory reliability. The qualitative data were analyzed in accordance with the Strauss and Corbin approach through open, axial, and selective coding using MAXQDA. In the quantitative phase, the data were analyzed through structural equation modeling using SPSS and AMOS.

3. Findings and Results

Open coding is an interpretive process through which data are analytically examined. Open coding begins after the first interview. In the present study, the information and data obtained from semi-structured interviews with 19 experts—including specialists and experts in air traffic control in Iran, as well as scholars in crisis management and educational management—were carefully analyzed. MAXQDA 2020 qualitative data analysis software was used to analyze the interview data.

Table 1

Indicators Identified During the Open-Coding Stage

No.	Indicator
1	Extent of the use of high-fidelity simulators
2	Variety of crisis scenarios—traffic-related, technical, and meteorological—in training courses
3	Success rate in completing exercises under time pressure and cognitive workload
4	Extent of operational feedback provided after each simulation session
5	Alignment of training scenarios with the operational realities of the aviation domain
6	Speed of information transfer among different units, including air traffic control, firefighting, and emergency response services
7	Clarity and accuracy of voice and text messages during emergency situations
8	Availability of predetermined protocols for emergency communications
9	Extent of the use of backup communication systems when the primary system is unavailable
10	Coordination in the use of standard phraseology
11	Controllers' level of situational awareness regarding the surrounding environment
12	Incidence rate of operational errors resulting from incorrect decision-making
13	Accuracy in complying with standard safety protocols under abnormal conditions
14	Ability to rapidly identify warning signs of a crisis
15	Quality of the error-reporting process for organizational learning
16	Degree to which navigation and radar systems are up to date
17	Speed of system response to sudden changes in traffic conditions
18	Capacity to integrate different types of data, including radar, meteorological, and flight data
19	Resilience of digital infrastructure to power fluctuations or traffic loads
20	Availability of backup systems for critical equipment
21	Controllers' psychological resilience when confronting crises
22	Incidence rate of occupational burnout among specialized personnel
23	Ability to manage stress and regulate emotions during critical moments
24	Quality of psychological support and mental health programs for operational personnel
25	Level of concentration and performance accuracy during extended work shifts
26	Accuracy of meteorological data integration into decision-support systems
27	Speed of response to sudden changes in weather conditions, such as squalls or storms
28	Ability to manage alternative routes under adverse weather conditions
29	Accuracy of forecasting the effects of weather conditions on airport acceptance capacity
30	Coordination between the meteorological unit and the air traffic control unit
31	Clarity of the decision-making hierarchy during crises
32	Response speed of the chain of command
33	Clarity of each individual's roles and responsibilities during a crisis

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34	Effectiveness of standard operating procedures in crisis management
35	Structural coordination between operational units and senior management
36	Ratio of practical training to theoretical instruction
37	Practical relevance of training content to current real-world challenges
38	Diversity of learning methods, including simulation, case studies, and group exercises
39	Rate of learning transfer from the classroom to the operational environment
40	Quality of the design and development of training scenarios
41	Speed of recovery to normal operations following technical failures in radar systems
42	Ability to operate manually or through systems with limited functionality
43	Accuracy of flight-position determination when automated systems are unavailable
44	Stability of voice and data communications during crisis conditions
45	Coverage of navigation signals during emergency situations
46	Accuracy of models used to forecast changes in traffic flow
47	Ability to identify latent risks before they develop into crises
48	Quality of statistical and data-driven analyses used to identify weaknesses
49	Speed of identifying hazardous patterns in flight or equipment behavior
50	Effectiveness of the designed risk-reduction programs
51	Speed of prioritizing flights experiencing technical failures
52	Ability to simultaneously manage multiple emergency situations in congested airspace
53	Accuracy in separating flights in crisis from the normal traffic flow
54	Effectiveness of conflict-management protocols during emergency situations
55	Coordination in allocating airspace to emergency flights
56	Quality of teamwork among different controllers
57	Accuracy of nonverbal communication and body language in team management
58	Level of mutual trust among members of the operational team
59	Ability to distribute workload during a crisis
60	Data response and updating time
61	Accuracy and reliability of received data
62	Level of system integration
63	Visual display capability and ease of comprehension
64	Integration of short-term forecasts
65	Extent of the use of big data in operational decision-making
66	Accuracy of intelligent algorithms in identifying traffic anomalies
67	Speed of processing large datasets to provide real-time reports
68	System capacity to provide predictive analytics
69	Quality of the integration of data received from different sources
70	Controllers' familiarity with laws and legal responsibilities during crises
71	Clarity of legal protocols for addressing ambiguous situations
72	Speed of aligning emergency decisions with international standards
73	Quality of documenting implemented actions for subsequent legal review
74	Resistance of air traffic control systems to cyber intrusions
75	Speed of detecting attacks or disruptions in the data network
76	Effectiveness of digital system recovery protocols
77	Security level of user access to sensitive systems
78	Extent of digital security training provided to operational personnel
79	Number of refresher training courses conducted annually
80	Modularity of training programs, including short and focused training modules
81	Extent of periodic updates to training content based on new incidents
82	Personnel participation rate in voluntary and mandatory training courses
83	Retention of acquired skills over time
84	Accuracy in separating commercial aircraft from unmanned aerial vehicles
85	Speed of detecting unauthorized aerial vehicles within controlled airspace
86	Ability to manage frequency and signal interference associated with emerging technologies
87	Alignment of control protocols with regulations governing unmanned aircraft operations
88	Effectiveness of automated systems for detecting small aerial vehicles
89	Alignment of internal protocols with the country's national crisis-management system
90	Ability to integrate the air traffic control unit with other national emergency-response organizations
91	Clarity of the unit's role in cross-border or regional crises
92	Quality of strategic planning for responding to large-scale crises
93	Coordination in the use of shared national resources during crises

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In axial coding, indicators are organized into subsets referred to as components. This coding procedure was introduced by Strauss and Corbin and is termed “axial” because coding is conducted around the axis of a category. At this stage, the extracted indicators were sorted and clustered according to the similarity among the codes or indicators. Consequently, 19 components were identified through axial coding.

Table 2

Axial Coding

Component	Indicator	Interviewee Code
Operational Training and Simulation	Extent of the use of high-fidelity simulators	Interviews 4, 6, 2, and 1
	Variety of crisis scenarios—traffic-related, technical, and meteorological—in training courses	Interviews 5, 7, 3, and 2
	Success rate in completing exercises under time pressure and cognitive workload	Interviews 6, 8, 3, and 4
	Extent of operational feedback provided after each simulation session	Interviews 8, 9, 2, and 1
	Alignment of training scenarios with the operational realities of the aviation domain	Interviews 1, 2, 3, and 4
Crisis Communication Management	Speed of information transfer among different units, including air traffic control, firefighting, and emergency response services	Interviews 1, 2, 3, and 4
	Clarity and accuracy of voice and text messages during emergency situations	Interviews 5, 4, 3, and 6
	Availability of predetermined protocols for emergency communications	Interviews 2, 7, 2, and 9
	Extent of the use of backup communication systems when the primary system is unavailable	Interviews 3, 3, 6, and 8
	Coordination in the use of standard phraseology	Interviews 14, 12, 2, and 11
Safety and Human Error Management	Controllers’ level of situational awareness regarding the surrounding environment	Interviews 16, 13, 18, 19, 9, and 14
	Incidence rate of operational errors resulting from incorrect decision-making	Interviews 1, 8, 6, 5, 4, and 18
	Accuracy in complying with standard safety protocols under abnormal conditions	Interviews 1, 5, 6, 7, 8, and 17
	Ability to rapidly identify warning signs of a crisis	Interviews 16, 15, 14, 11, 4, and 12
	Quality of the error-reporting process for organizational learning	Interviews 12, 13, and 16
Infrastructure and Technology Management	Degree to which navigation and radar systems are up to date	Interviews 6, 7, and 9
	Speed of system response to sudden changes in traffic conditions	Interviews 2, 3, and 8
	Capacity to integrate different types of data, including radar, meteorological, and flight data	Interviews 16, 17, and 19
	Resilience of digital infrastructure to power fluctuations or traffic loads	Interviews 19, 12, and 22
	Availability of backup systems for critical equipment	Interviews 3, 5, and 9
Occupational Psychology and Health	Controllers’ psychological resilience when confronting crises	Interviews 12, 11, and 10
	Incidence rate of occupational burnout among specialized personnel	Interviews 13, 14, and 19
	Ability to manage stress and regulate emotions during critical moments	Interviews 12, 2, and 4
	Quality of psychological support and mental health programs for operational personnel	Interviews 3, 7, and 8
	Level of concentration and performance accuracy during extended work shifts	Interviews 4, 5, and 6
Environmental and Climatic Conditions Management	Accuracy of meteorological data integration into decision-support systems	Interviews 3, 5, and 6
	Speed of response to sudden changes in weather conditions, such as squalls or storms	Interviews 1, 2, 3, and 4
	Ability to manage alternative routes under adverse weather conditions	Interviews 5, 4, 3, and 6
	Accuracy of forecasting the effects of weather conditions on airport acceptance capacity	Interviews 2, 7, 2, and 9
	Coordination between the meteorological unit and the air traffic control unit	Interviews 3, 3, 6, and 8
Management and Command Structure	Clarity of the decision-making hierarchy during crises	Interviews 14, 12, 2, and 11
	Response speed of the chain of command	Interviews 16, 13, 18, 19, 9, and 14
	Clarity of each individual’s roles and responsibilities during a crisis	Interviews 1, 8, 6, 5, 4, and 18

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	Effectiveness of standard operating procedures in crisis management	Interviews 1, 5, 6, 7, 8, and 17
	Structural coordination between operational units and senior management	Interviews 16, 15, 14, 11, 4, and 12
Training and Learning Methodology	Ratio of practical training to theoretical instruction	Interviews 12, 13, and 16
	Practical relevance of training content to current real-world challenges	Interviews 6, 7, and 9
	Diversity of learning methods, including simulation, case studies, and group exercises	Interviews 2, 3, and 8
	Rate of learning transfer from the classroom to the operational environment	Interviews 16, 17, and 19
	Quality of the design and development of training scenarios	Interviews 19, 12, and 22
Navigation-System Resilience	Speed of recovery to normal operations following technical failures in radar systems	Interviews 3, 5, and 9
	Ability to operate manually or through systems with limited functionality	Interviews 12, 11, and 10
	Accuracy of flight-position determination when automated systems are unavailable	Interviews 13, 14, and 19
	Stability of voice and data communications during crisis conditions	Interviews 12, 2, and 4
	Coverage of navigation signals during emergency situations	Interviews 1, 2, 3, and 4
Risk Management and Forecasting	Accuracy of models used to forecast changes in traffic flow	Interviews 5, 4, 3, and 6
	Ability to identify latent risks before they develop into crises	Interviews 2, 7, 2, and 9
	Quality of statistical and data-driven analyses used to identify weaknesses	Interviews 3, 16, 6, and 8
	Speed of identifying hazardous patterns in flight or equipment behavior	Interviews 14, 12, 2, and 11
	Effectiveness of the designed risk-reduction programs	Interviews 16, 13, 18, 19, 9, and 14
Emergency Priority Management	Speed of prioritizing flights experiencing technical failures	Interviews 1, 8, 6, 5, 4, and 18
	Ability to simultaneously manage multiple emergency situations in congested airspace	Interviews 1, 5, 6, 7, 8, and 17
	Accuracy in separating flights in crisis from the normal traffic flow	Interviews 16, 15, 14, 11, 4, and 12
	Effectiveness of conflict-management protocols during emergency situations	Interviews 12, 13, and 16
	Coordination in allocating airspace to emergency flights	Interviews 6, 7, and 9
Crew Resource Management (CRM)	Quality of teamwork among different controllers	Interviews 2, 3, and 8
	Accuracy of nonverbal communication and body language in team management	Interviews 16, 17, and 19
	Level of mutual trust among members of the operational team	Interviews 19, 12, and 22
	Ability to distribute workload during a crisis	Interviews 3, 5, and 9
Meteorological Information Integration	Data response and updating time	Interviews 12, 11, and 10
	Accuracy and reliability of received data	Interviews 13, 14, and 19
	Level of system integration	Interviews 12, 2, and 4
	Visual display capability and ease of comprehension	Interviews 1, 2, 3, and 4
	Integration of short-term forecasts	Interviews 5, 4, 3, and 6
Intelligent Data Analytics	Extent of the use of big data in operational decision-making	Interviews 2, 7, 2, and 9
	Accuracy of intelligent algorithms in identifying traffic anomalies	Interviews 3, 2, 12, and 8
	Speed of processing large datasets to provide real-time reports	Interviews 14, 12, 2, and 11
	System capacity to provide predictive analytics	Interviews 16, 13, 18, 19, 9, and 14
	Quality of the integration of data received from different sources	Interviews 1, 8, 6, 5, 4, and 18
Legal and Ethical Frameworks	Controllers’ familiarity with laws and legal responsibilities during crises	Interviews 1, 5, 6, 7, 8, and 17
	Clarity of legal protocols for addressing ambiguous situations	Interviews 16, 15, 14, 11, 4, and 12
	Speed of aligning emergency decisions with international standards	Interviews 12, 13, and 16
	Quality of documenting implemented actions for subsequent legal review	Interviews 6, 7, and 9
Cybersecurity and Digital Infrastructure	Resistance of air traffic control systems to cyber intrusions	Interviews 2, 3, and 8
	Speed of detecting attacks or disruptions in the data network	Interviews 16, 17, and 19
	Effectiveness of digital system recovery protocols	Interviews 19, 12, and 22
	Security level of user access to sensitive systems	Interviews 3, 5, and 9
	Extent of digital security training provided to operational personnel	Interviews 12, 11, and 10

Training Continuity and Sustainability	Number of refresher training courses conducted annually	Interviews 13, 14, and 19
	Modularity of training programs, including short and focused training modules	Interviews 12, 2, and 4
	Extent of periodic updates to training content based on new incidents	Interviews 1, 2, 3, and 4
	Personnel participation rate in voluntary and mandatory training courses	Interviews 5, 4, 3, and 6
	Retention of acquired skills over time	Interviews 2, 7, 2, and 9
Emerging Airspace Interference Management	Accuracy in separating commercial aircraft from unmanned aerial vehicles	Interviews 3, 9, 15, and 8
	Speed of detecting unauthorized aerial vehicles within controlled airspace	Interviews 14, 12, 2, and 11
	Ability to manage frequency and signal interference associated with emerging technologies	Interviews 15, 14, 18, 19, 9, and 14
	Alignment of control protocols with regulations governing unmanned aircraft operations	Interviews 19, 8, 3, 5, 4, and 18
	Effectiveness of automated systems for detecting small aerial vehicles	Interviews 1, 5, 6, 7, 8, and 17
Macro-Level and Strategic Management	Alignment of internal protocols with the country's national crisis-management system	Interviews 19, 18, 14, 11, 4, and 12
	Ability to integrate the air traffic control unit with other national emergency-response organizations	Interviews 12, 13, and 16
	Clarity of the unit's role in cross-border or regional crises	Interviews 6, 7, and 9
	Quality of strategic planning for responding to large-scale crises	Interviews 2, 3, and 8
	Coordination in the use of shared national resources during crises	Interviews 12, 17, and 19

Based on the results of open and axial coding, selective coding constitutes the principal stage of theory development and model construction. In this process, the core category is systematically related to the other categories, these relationships are presented within a coherent narrative framework, and categories requiring further improvement and development are refined. At this stage, the components are integrated to form the dimensions. The principal dimensions represent the central phenomenon of the study. Through expert evaluation, five dimensions, 19 components, and 93 indicators were ultimately finalized for the crisis management training model intended to reduce air traffic control challenges in Iran.

Table 3

Selective Coding

Dimension	Component	Indicator
Operational Preparedness and Capability	Operational Training and Simulation	Extent of the use of high-fidelity simulators
		Variety of crisis scenarios—traffic-related, technical, and meteorological—in training courses
		Success rate in completing exercises under time pressure and cognitive workload
		Extent of operational feedback provided after each simulation session
		Alignment of training scenarios with the operational realities of the aviation domain
	Safety and Human Error Management	Controllers' level of situational awareness regarding the surrounding environment
		Incidence rate of operational errors resulting from incorrect decision-making
		Accuracy in complying with standard safety protocols under abnormal conditions
		Ability to rapidly identify warning signs of a crisis
		Quality of the error-reporting process for organizational learning
	Infrastructure and Technology Management	Degree to which navigation and radar systems are up to date
		Speed of system response to sudden changes in traffic conditions
		Capacity to integrate different types of data, including radar, meteorological, and flight data

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		Resilience of digital infrastructure to power fluctuations or traffic loads
		Availability of backup systems for critical equipment
	Navigation-System Resilience	Speed of recovery to normal operations following technical failures in radar systems
		Ability to operate manually or through systems with limited functionality
		Accuracy of flight-position determination when automated systems are unavailable
		Stability of voice and data communications during crisis conditions
		Coverage of navigation signals during emergency situations
	Emerging Airspace Interference Management	Accuracy in separating commercial aircraft from unmanned aerial vehicles
		Speed of detecting unauthorized aerial vehicles within controlled airspace
		Ability to manage frequency and signal interference associated with emerging technologies
		Alignment of control protocols with regulations governing unmanned aircraft operations
		Effectiveness of automated systems for detecting small aerial vehicles
	Cybersecurity and Digital Infrastructure	Resistance of air traffic control systems to cyber intrusions
		Speed of detecting attacks or disruptions in the data network
		Effectiveness of digital system recovery protocols
		Security level of user access to sensitive systems
		Extent of digital security training provided to operational personnel
Crisis Management and Rapid Response	Crisis Communication Management	Speed of information transfer among different units, including air traffic control, firefighting, and emergency response services
		Clarity and accuracy of voice and text messages during emergency situations
		Availability of predetermined protocols for emergency communications
		Extent of the use of backup communication systems when the primary system is unavailable
		Coordination in the use of standard phraseology
	Environmental and Climatic Conditions Management	Accuracy of meteorological data integration into decision-support systems
		Speed of response to sudden changes in weather conditions, such as squalls or storms
		Ability to manage alternative routes under adverse weather conditions
		Accuracy of forecasting the effects of weather conditions on airport acceptance capacity
		Coordination between the meteorological unit and the air traffic control unit
	Emergency Priority Management	Speed of prioritizing flights experiencing technical failures
		Ability to simultaneously manage multiple emergency situations in congested airspace
		Accuracy in separating flights in crisis from the normal traffic flow
		Effectiveness of conflict-management protocols during emergency situations
		Coordination in allocating airspace to emergency flights
	Risk Management and Forecasting	Accuracy of models used to forecast changes in traffic flow
		Ability to identify latent risks before they develop into crises
		Quality of statistical and data-driven analyses used to identify weaknesses
		Speed of identifying hazardous patterns in flight or equipment behavior
		Effectiveness of the designed risk-reduction programs
Leadership, Structure, and Resources	Management and Command Structure	Clarity of the decision-making hierarchy during crises
		Response speed of the chain of command
		Clarity of each individual’s roles and responsibilities during a crisis
		Effectiveness of standard operating procedures in crisis management
		Structural coordination between operational units and senior management

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	Occupational Psychology and Health	Controllers' psychological resilience when confronting crises
		Incidence rate of occupational burnout among specialized personnel
		Ability to manage stress and regulate emotions during critical moments
		Quality of psychological support and mental health programs for operational personnel
		Level of concentration and performance accuracy during extended work shifts
	Crew Resource Management	Quality of teamwork among different controllers
		Accuracy of nonverbal communication and body language in team management
		Level of mutual trust among members of the operational team
		Ability to distribute workload during a crisis
	Legal and Ethical Frameworks	Controllers' familiarity with laws and legal responsibilities during crises
		Clarity of legal protocols for addressing ambiguous situations
		Speed of aligning emergency decisions with international standards
		Quality of documenting implemented actions for subsequent legal review
	Macro-Level and Strategic Management	Alignment of internal protocols with the country's national crisis-management system
		Ability to integrate the air traffic control unit with other national emergency-response organizations
		Clarity of the unit's role in cross-border or regional crises
		Quality of strategic planning for responding to large-scale crises
		Coordination in the use of shared national resources during crises
Knowledge, Training, and Continuous Learning	Training and Learning Methodology	Ratio of practical training to theoretical instruction
		Practical relevance of training content to current real-world challenges
		Diversity of learning methods, including simulation, case studies, and group exercises
		Rate of learning transfer from the classroom to the operational environment
		Quality of the design and development of training scenarios
	Training Continuity and Sustainability	Number of refresher training courses conducted annually
		Modularity of training programs, including short and focused training modules
		Extent of periodic updates to training content based on new incidents
		Personnel participation rate in voluntary and mandatory training courses
		Retention of acquired skills over time
Information and Emerging Technologies	Meteorological Information Integration	Data response and updating time
		Accuracy and reliability of received data
		Level of system integration
		Visual display capability and ease of comprehension
		Integration of short-term forecasts
	Intelligent Data Analytics	Extent of the use of big data in operational decision-making
		Accuracy of intelligent algorithms in identifying traffic anomalies
		Speed of processing large datasets to provide real-time reports
		System capacity to provide predictive analytics
		Quality of the integration of data received from different sources

Figure 1

Research model based on the path coefficients

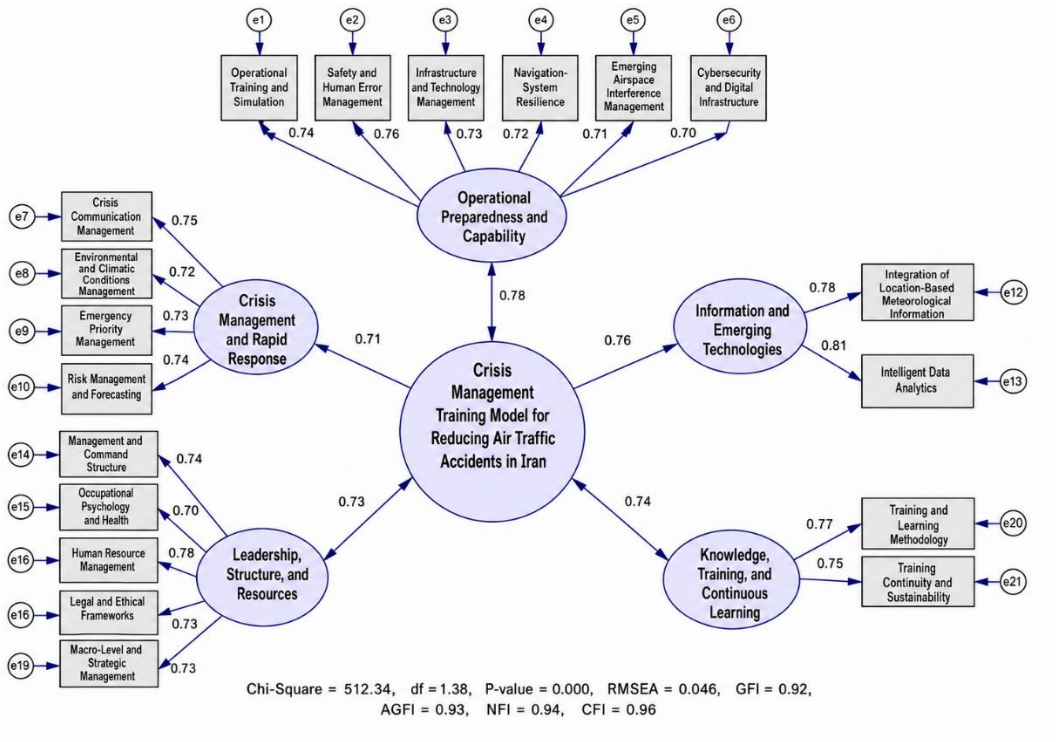
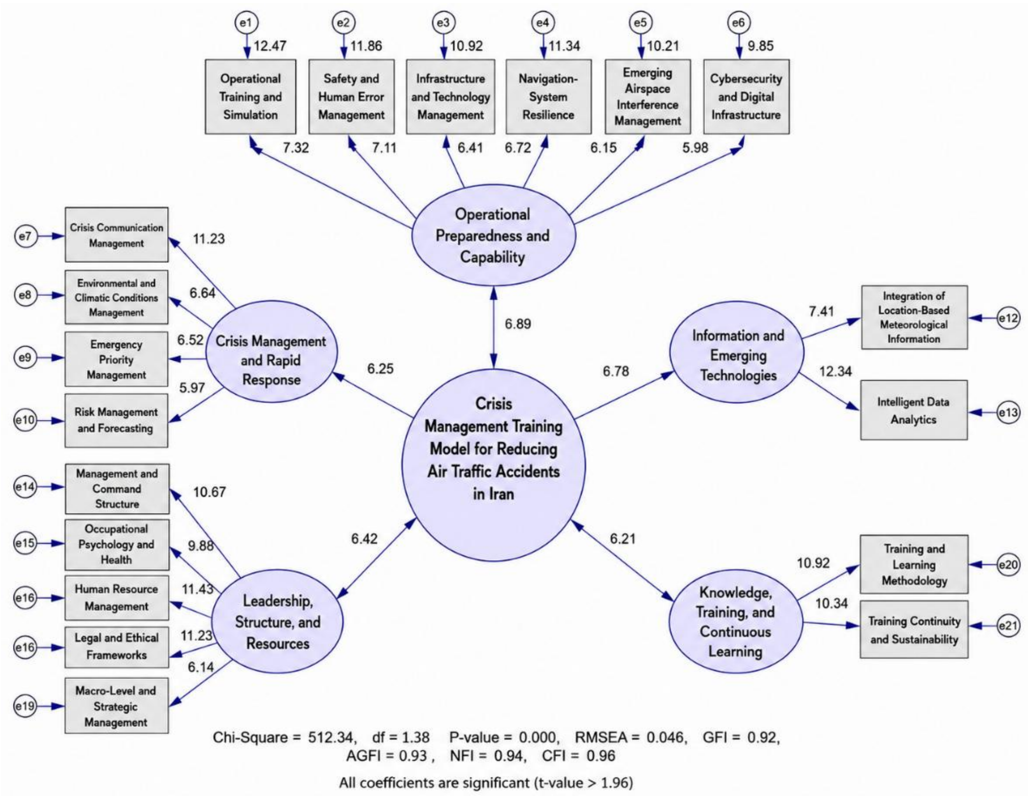


Figure 2

Research model based on the t statistics



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The quantitative findings based on structural equation modeling for the data obtained from 203 air traffic control personnel confirmed the adequacy of the proposed crisis management training model. All standardized path coefficients were positive and statistically significant, with t values exceeding 1.96. Operational preparedness and capability had the strongest relationship with the overall model (β = .78), followed by information and emerging technologies (β = .76), knowledge, training, and continuous learning (β = .74), leadership, structure, and resources (β = .73), and crisis management and rapid response (β = .71). The factor loadings of the 19 components ranged from .70 to .81, indicating satisfactory relationships between the components and their corresponding dimensions. Intelligent data analytics had the highest factor loading (β = .81), whereas cybersecurity and digital infrastructure and occupational psychology and health had the lowest loadings (β = .70). The model-fit indices also demonstrated an acceptable fit between the proposed model and the observed data ($\chi^2/df = 1.38$, $p < .001$, RMSEA = .046, GFI = .92, AGFI = .93, NFI = .94, and CFI = .96). Therefore, the quantitative results supported the validity of the five-dimensional crisis management training model for reducing air traffic control challenges in Iran.

4. Discussion and Conclusion

The present study developed and validated a crisis management training model intended to reduce air traffic control challenges in Iran. The qualitative phase resulted in the identification of five overarching dimensions, 19 components, and 93 indicators, indicating that effective crisis-management training in air traffic control is a multidimensional construct that extends beyond conventional emergency-response instruction. The five dimensions were operational preparedness and capability; crisis management and rapid response; leadership, structure, and resources; knowledge, training, and continuous learning; and information and emerging technologies. The quantitative findings supported the proposed model, as all structural coefficients were statistically significant and the reported fit indices indicated an acceptable correspondence between the conceptual framework and the observed data. Operational preparedness and capability had the strongest relationship with the overall crisis-management training model, followed by information and emerging technologies, knowledge, training, and continuous learning, leadership, structure, and resources, and crisis management and rapid response. These findings suggest that the effectiveness of crisis-management education in air traffic control depends on the integration of operational, technological, human, organizational, and educational capacities rather than on any single intervention.

The strongest dimension was operational preparedness and capability, which included operational training and simulation, safety and human error management, infrastructure and technology management, navigation-system resilience, emerging airspace interference management, and cybersecurity and digital infrastructure. This result indicates that crisis-management training must first prepare air traffic control personnel to maintain safe and effective performance under realistic abnormal and emergency conditions. High-fidelity simulations, diversified crisis scenarios, performance under time and cognitive pressure, operational feedback, and alignment between training exercises and actual airspace conditions emerged as central indicators. This finding is consistent with the view that aviation crisis management should prioritize preparedness, operational continuity, rapid adaptation, and the ability to function under degraded conditions (Abdallah et al., 2025; Taylor, 2026). It also supports broader crisis-management perspectives emphasizing that organizational resilience is developed before a crisis through planning, scenario preparation, competency development, and resource readiness rather than exclusively during emergency response (Jarašūnienė & Gelžinis, 2025; Safari et al., 2025).

The importance of operational training and simulation can be explained by the highly dynamic and safety-critical nature of air traffic control. Controllers must continuously interpret complex information, anticipate conflicts, and make rapid decisions with minimal tolerance for error. Simulation provides an environment in which rare but potentially catastrophic events can be practiced without placing actual aircraft or passengers at risk. The identified emphasis on time pressure, cognitive workload, situational awareness, and error detection is aligned with research showing that air traffic complexity cannot be explained solely by traffic volume, because it also involves aircraft interactions, route convergence, uncertainty, sector configuration, and temporal changes in traffic structure (Pérez Moreno et al., 2024). Likewise, studies on controller workload have demonstrated that workload, fatigue, automation, cognitive demand, and human–machine interaction are closely related to safety outcomes (Zamarreño Suárez et al., 2024). Therefore, simulation-based crisis education should reproduce not only technical

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failures but also the cognitive, communicative, and emotional demands that controllers experience during high-complexity operations.

Safety and human error management was another important component of operational preparedness. Its indicators included controllers' situational awareness, the incidence of decision-related errors, compliance with safety protocols under abnormal conditions, rapid identification of warning signs, and the quality of error reporting for learning purposes. These findings show that crisis-management training should not treat human error merely as individual negligence. Instead, errors should be understood as outcomes that may arise from workload, inadequate information, system design, organizational weaknesses, communication failure, and insufficient preparation. The system-dynamics analysis of air accident crisis management similarly indicates that aviation accidents emerge from interacting causal factors and that effective prevention policies must address the broader system rather than isolated behaviors (Moradi et al., 2024). The present findings therefore support the development of a learning-oriented safety culture in which incidents and near misses are systematically reported, analyzed, and converted into updated training scenarios.

Infrastructure and technology management, navigation-system resilience, and cybersecurity also formed major elements of operational capability. The relevant indicators included the modernization of radar and navigation systems, integration of radar, meteorological, and flight data, digital infrastructure stability, availability of backup systems, recovery following system failure, manual-operation capability, communication continuity, and resistance to cyber intrusion. These findings reflect the increasing dependence of air traffic control on interconnected digital technologies. Although advanced technologies can increase efficiency and accuracy, they can also create new vulnerabilities if controllers are unable to operate when automated systems are disrupted. The aviation resilience literature emphasizes the need for redundancy, operational flexibility, rapid recovery, and adaptation during major disruptions (Cook et al., 2024). Similarly, artificial intelligence applications in aviation crisis management require reskilling and upskilling so that personnel can appropriately use intelligent systems, evaluate algorithmic outputs, and maintain effective human oversight (Gupta & Bethapudi, 2026). Therefore, technological modernization should be accompanied by recurrent training in system limitations, degraded-mode operations, cybersecurity protocols, and recovery procedures.

The inclusion of emerging airspace interference management further demonstrates that air traffic control training must respond to changes in the contemporary aviation environment. The indicators in this component addressed the separation of commercial aircraft from unmanned aerial vehicles, detection of unauthorized aerial vehicles, management of frequency and signal interference, alignment with unmanned-flight regulations, and automated detection of small aircraft. These findings indicate that conventional air traffic control procedures may be insufficient for increasingly heterogeneous airspace. The growing complexity of traffic patterns and the interaction of different airspace users require adaptive control strategies and advanced monitoring capacities (Pérez Moreno et al., 2024). Research on improving operational efficiency through network-scale reduction also suggests that controlling structural complexity can facilitate safer and more manageable air traffic operations (Zhao et al., 2024). The identified component therefore highlights the need to incorporate unmanned aviation, new communication technologies, and interference-management scenarios into crisis training.

The second strongest dimension was information and emerging technologies, comprising meteorological information integration and intelligent data analytics. The high contribution of this dimension indicates that crisis preparedness increasingly depends on the timely acquisition, integration, visualization, interpretation, and predictive use of data. The indicators emphasized data updating speed, accuracy and reliability, system integration, visual comprehensibility, short-term forecast integration, use of big data, anomaly detection, rapid processing of large datasets, predictive analytics, and data integration across multiple sources. These findings align with recent developments in air traffic flow management, where data-driven forecasting, optimization, collaborative decision-making, and intelligent decision-support tools are increasingly used to balance traffic demand and available capacity (Chen et al., 2024). They also correspond with research emphasizing the role of intelligent systems and integrated information in improving traffic crisis management (Adibi Saadi-Nejad & Seif, 2023).

The importance of meteorological information integration is especially understandable because sudden weather changes can alter traffic flows, reduce airport capacity, necessitate rerouting, and increase controller workload. Inadequate integration of weather information

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may delay decisions or lead to inconsistent operational responses. The findings suggest that controllers require training not only in accessing meteorological information but also in interpreting its operational implications, estimating its effects on airport acceptance capacity, and coordinating with meteorological units. Air traffic flow management research indicates that weather-related disruptions must be addressed through predictive planning, dynamic capacity allocation, and coordinated network decisions (Chen et al., 2024). Scheduling research also shows that delays, stopovers, and operational restrictions interact in complex ways and require multi-operator solutions (Ding et al., 2025). Thus, crisis-management training should include scenarios in which changing weather conditions create cascading effects across routes, airports, schedules, and control sectors.

Knowledge, training, and continuous learning constituted the third major dimension and included training and learning methodology as well as training continuity and sustainability. The identified indicators emphasized the ratio of practical to theoretical instruction, practical relevance of course content, diversity of learning methods, transfer of learning to the workplace, quality of scenario development, frequency of refresher courses, modularity of training, periodic content revision, participation in voluntary and mandatory programs, and retention of acquired skills. This finding confirms that crisis preparedness cannot be created through isolated or one-time courses. Rather, it requires a sustained educational system in which content is regularly updated and performance is repeatedly assessed. Educational guidance concerning crisis intervention emphasizes the importance of structured preparation, recognition of risk signs, practical intervention competencies, and the ability to respond under psychological pressure (Jazayeri, 2023). In the aviation context, continuous professional learning is particularly necessary because technologies, regulations, operational threats, and airspace structures evolve rapidly (Gupta & Bethapudi, 2026).

The importance of learning transfer suggests that the effectiveness of a training program should not be judged solely by participant satisfaction or theoretical examination scores. Training should produce observable improvements in operational behavior, communication, decision-making, coordination, and recovery performance. This requires realistic simulations, case-based learning, team exercises, after-action reviews, and feedback based on measurable competencies. The findings also imply that training scenarios should be revised after actual incidents, near misses, technical failures, cyber events, and changes in traffic patterns. Reviews of aviation resilience have emphasized organizational learning as a central mechanism through which aviation organizations improve their responses to subsequent crises (Cook et al., 2024). Similarly, comprehensive airport and airline crisis-management frameworks emphasize continuous revision of plans and recurrent exercises rather than static emergency manuals (Taylor, 2026).

Leadership, structure, and resources represented another validated dimension and included management and command structure, occupational psychology and health, human resource management, legal and ethical frameworks, and macro-level strategic management. This result shows that technically competent personnel cannot manage crises effectively in the absence of clear authority, defined responsibilities, appropriate resource allocation, interorganizational coordination, and strategic support. The importance of command hierarchy, standard operating procedures, senior-management coordination, and role clarity is consistent with studies emphasizing leadership and organizational integration in aviation crisis response (Abdallah et al., 2025). Broader risk and crisis-management models likewise identify governance structures, responsibility allocation, resource coordination, and continuity planning as prerequisites for effective response (Jarašūnienė & Gelžinis, 2025).

Occupational psychology and health was included within this dimension because crisis response is influenced by controllers' resilience, stress-management capacity, emotional regulation, fatigue, concentration, and occupational burnout. Air traffic control is cognitively intensive, and extended shifts or repeated exposure to high-pressure situations may impair performance. Research on controller workload supports the importance of addressing psychological demands, fatigue, attention, and cognitive overload as safety-related concerns (Zamarreño Suárez et al., 2024). The present findings therefore indicate that crisis-management education should include stress inoculation, fatigue awareness, emotional self-regulation, peer support, workload redistribution, and access to occupational mental health services. Such measures should not be considered peripheral welfare initiatives; they are essential components of operational safety.

Human resource management, particularly crew resource management, was also identified through indicators such as teamwork, nonverbal communication, mutual trust, and workload distribution. These findings demonstrate that crisis

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performance depends on collective rather than purely individual competence. Controllers must coordinate with colleagues, supervisors, pilots, airport units, emergency services, and adjacent sectors. The media and communication literature similarly shows that aviation crises require coordinated institutional messaging and structured communication among multiple actors (Saremi et al., 2023). Social media research further indicates that crisis communication now occurs in fast-moving information environments in which rumors, incomplete information, and public reactions must be managed systematically (Selvakumar & Babu, 2023). Although the present model focuses primarily on operational personnel, these studies reinforce the need for coordinated communication, role clarity, and trust across organizational boundaries.

Legal, ethical, macro-level, and strategic components reflected the need to align operational decisions with national crisis-management structures and international aviation requirements. Controllers must understand their legal responsibilities, document emergency decisions, follow applicable standards, and operate within defined authority. At the strategic level, air traffic control should be integrated with national emergency-response organizations and prepared for regional or cross-border crises. Iranian studies on traffic crisis management have similarly emphasized prioritization, interagency coordination, and integrated response during natural disasters (Hosseinian et al., 2023). Smart traffic-management research also highlights the importance of institutional integration, data sharing, and intelligent governance in addressing complex traffic crises (Adibi Saadi-Nejad & Seif, 2023). The current findings extend these principles to the air traffic control environment and emphasize that crisis-management training should involve not only individual controllers but also senior managers, legal units, emergency agencies, and national policymakers.

The crisis management and rapid response dimension included crisis communication management, environmental and climatic conditions management, emergency priority management, and risk management and forecasting. Although this dimension had the smallest structural coefficient among the five dimensions, its relationship with the overall model remained significant and practically important. Its comparatively lower coefficient may reflect the fact that rapid response is dependent on the prior development of operational readiness, leadership capacity, training continuity, and information infrastructure. In other words, effective response during a crisis is likely to be the outcome of preparedness developed across the other dimensions. The identified components correspond with established crisis-management principles emphasizing communication, prioritization, risk analysis, environmental awareness, and coordinated action (Safari et al., 2025; Taylor, 2026).

Emergency priority management was reflected in the ability to prioritize technically impaired flights, simultaneously manage multiple emergencies, separate emergency traffic from normal traffic flows, implement conflict-management procedures, and allocate airspace to emergency aircraft. These tasks are especially challenging in congested airspace, where one emergency may affect the movement of many other flights. Research on traffic-flow management and network efficiency supports the importance of balancing demand, capacity, and operational constraints while limiting cascading disruptions (Chen et al., 2024; Zhao et al., 2024). Similarly, flight-loop scheduling models demonstrate that disruption management requires coordinated decisions across multiple operators and constraints (Ding et al., 2025). The present study therefore suggests that emergency training should include multi-event scenarios and network-level consequences rather than focusing only on isolated aircraft emergencies.

Overall, the model provides a comprehensive framework that connects prevention, preparedness, response, recovery, technology, leadership, and organizational learning. Its five dimensions should be understood as interdependent. Operational preparedness cannot be achieved without continuous training; intelligent technology cannot improve safety without competent users; rapid response cannot occur without clear leadership and communication; and organizational learning cannot be sustained without strategic support and error-reporting systems. The consistency of the model with national and international studies supports its conceptual validity, while its context-specific components reflect the operational realities of air traffic control in Iran. The model may therefore serve as a basis for designing competency-based curricula, evaluating organizational preparedness, developing simulation exercises, and aligning crisis-management education with technological and strategic changes in aviation.

This study had several limitations. The qualitative findings were based on interviews with 19 experts, and although sampling continued to achieve sufficient conceptual depth, the views of other stakeholders—such as pilots, airport firefighters, meteorological personnel, airline operations managers, cybersecurity specialists, and national

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emergency officials—may not have been fully represented. The quantitative phase was limited to personnel from Mehrabad Airport Control Tower, Tehran Approach Control, and the Area Control Center, which may restrict the generalizability of the model to other airports, regional control units, military aviation settings, or air navigation systems with different organizational and technological characteristics. The use of a researcher-developed questionnaire may also have introduced self-report and common-method biases. Moreover, the cross-sectional design did not permit the assessment of whether implementing the proposed model produces sustained improvements in crisis performance, safety indicators, or operational outcomes over time.

Future studies should validate the model among larger and more geographically diverse samples of air traffic control personnel and compare its structure across airport towers, approach-control units, and area-control centers. Researchers should also include representatives from airlines, airports, meteorological services, emergency-response organizations, aviation regulators, and cybersecurity units to examine the model from an interorganizational perspective. Longitudinal and experimental studies are recommended to evaluate whether training programs based on the model improve simulation performance, response time, communication accuracy, situational awareness, error detection, teamwork, and resilience. Future research could also develop standardized measurement instruments for each dimension, test alternative structural models, examine moderating variables such as professional experience and workload, and compare the Iranian model with crisis-management training frameworks used in other national aviation systems.

Air navigation authorities and aviation training centers should use the proposed dimensions and components to revise crisis-management curricula and establish competency-based assessment systems. Training should combine theoretical instruction with recurrent high-fidelity simulation, multi-crisis scenarios, degraded-system operations, cybersecurity exercises, adverse-weather management, unmanned-aircraft interference, and interagency coordination drills. Clear command structures, backup communication procedures, psychological support services, fatigue-management programs, and structured after-action reviews should be institutionalized. Training content should be updated following incidents, near misses, technological changes, and revisions to aviation regulations. In addition, integrated data platforms, intelligent analytics, meteorological decision-support systems, and predictive tools should be introduced alongside training that enables controllers to interpret, verify, and appropriately use their outputs.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in studies involving human participants were under the ethical standards of the institutional and, or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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