

Validation of a Crisis Management Training Model Based on Reducing Air Traffic Control Challenges in Iran

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ABSTRACT

Objective: This study aimed to validate a crisis management training model developed to reduce air traffic control challenges in Iran.

Methods and Materials: This applied quantitative study employed a descriptive-survey design. The statistical population comprised 430 air traffic control personnel, including employees of Mehrabad Airport Control Tower, Tehran Approach Control Unit, and the national Area Control Center. Using Cochran's formula and stratified random sampling, 203 participants were selected. Data were collected using a researcher-made questionnaire developed from findings of the preceding qualitative phase. Face, content, and construct validity were assessed, while reliability was examined using Cronbach's alpha. Average variance extracted, composite reliability, maximum shared variance, and average shared variance were also evaluated. Data were analyzed using SPSS and AMOS through confirmatory factor analysis and structural equation modeling.

Findings: The Kaiser–Meyer–Olkin coefficient was 0.892, and Bartlett's test of sphericity was significant ($\chi^2 = 636789.058$, $df = 203$, $p = .001$), confirming suitability for factor analysis. All standardized component loadings were significant and ranged from 0.70 to 0.81, while the relationships between the main model and its five dimensions ranged from 0.71 to 0.78. The measurement model demonstrated satisfactory convergent and discriminant validity. Model fit indices indicated an acceptable fit to the data, with GFI = 0.92, AGFI = 0.93, CFI = 0.96, CMIN/df = 1.38, and RMSEA = 0.046. Thus, the five-dimensional structure comprising Operational Preparedness and Capability, Crisis Management and Rapid Response, Leadership, Structure, and Resources, Knowledge, Training, and Continuous Learning, and Information and Emerging Technologies was empirically supported.

Conclusion: The validated model provides a coherent and empirically supported framework for crisis management training in Iranian air traffic control and can guide the development of integrated training programs addressing operational, technological, organizational, human, and continuous-learning requirements.

Keywords: Crisis Management Training; Air Traffic Control; Operational Preparedness; Crisis Response; Structural Equation Modeling; Aviation Safety; Iran

1 Introduction

Air traffic control is one of the most safety-critical components of the aviation system because it operates at the intersection of technological complexity, human decision-making, organizational coordination, rapidly changing environmental conditions, and strict operational time constraints. Under normal circumstances, air traffic controllers are required to maintain safe separation between aircraft, manage traffic flows, coordinate with adjacent control sectors and airports, respond to pilot requests, interpret meteorological and navigational information, and maintain situational awareness in a dynamic environment. Under crisis conditions, however, these responsibilities become substantially more demanding because routine procedures may no longer be sufficient, uncertainty increases, available response time decreases, communication channels may become overloaded, and the consequences of delayed or inappropriate decisions may be severe. The aviation sector has repeatedly demonstrated that disruptions caused by technical failures, extreme weather, infrastructure outages, security threats, public-health emergencies, geopolitical instability, and operational congestion can propagate rapidly across interconnected networks. Consequently, crisis management in aviation should not be treated as a peripheral administrative function but as an integral dimension of operational safety, resilience, and continuity (Cook et al., 2024; Taylor, 2026).

The need for effective crisis management is particularly evident in air traffic management because the system depends on continuous coordination among people, technologies, procedures, and institutional structures. Air traffic management is increasingly expected not only to guarantee safety but also to support efficiency, environmental sustainability, capacity optimization, and continuity of service under conditions of growing demand. Sustainable air traffic management therefore requires a balance between operational productivity and resilience, particularly when disturbances threaten the normal functioning of aviation systems (Kale et al., 2021). In this context, crisis management involves far more than responding to a single emergency event. It encompasses preparedness before disruption, rapid identification of threats, coordinated decision-making during abnormal conditions, prioritization of critical operations, allocation of available resources, communication across organizational levels, and systematic learning after the event. A crisis management training model for air traffic control must

consequently reflect the multidimensional nature of the operational environment rather than focus exclusively on isolated emergency procedures.

One of the central characteristics of air traffic control is the constant tension between efficiency and safety. Controllers routinely work toward maintaining smooth traffic flow, minimizing delay, and preserving available airspace capacity, yet crisis or conflict situations can require an immediate shift from efficiency-oriented goals toward more conservative safety-oriented strategies. Research on controller behavior suggests that safety is actively constructed through adaptive changes in goals and operating priorities rather than merely achieved by rigidly following predetermined procedures (Gyles & Bearman, 2025). This adaptive dimension is particularly important under crisis conditions, when controllers may need to revise plans, redistribute attention, reduce workload, increase separation margins, coordinate alternative routes, or adopt temporary operating restrictions. Therefore, training for crisis management should develop not only procedural knowledge but also adaptive judgment, situational awareness, prioritization skills, and the ability to change operational goals appropriately in response to emerging risks.

Modern airspace also introduces new forms of complexity that can increase the probability and consequences of crisis situations. The growing use of unmanned aerial vehicles, the expansion of low-altitude operations, the potential integration of new aerial mobility platforms, and the increasing heterogeneity of airspace users create additional coordination requirements. Research on hybrid centralized-decentralized control architectures for unmanned aerial vehicles highlights the need to combine central oversight with distributed decision-making mechanisms in increasingly complex low-altitude environments (Chen et al., 2025). Similarly, studies examining the combination of centralized and decentralized solutions in air traffic control indicate that effective traffic management increasingly depends on architectures capable of distributing decision-making while maintaining overall system coordination (Raziq et al., 2025). From a crisis-management perspective, these developments suggest that controllers and managers must be trained to operate in environments where authority, information, and control may be distributed across multiple technological and organizational nodes.

The management of aircraft conflicts represents another core challenge in air traffic control. Conflict detection and resolution have traditionally relied on standardized

procedures and controller expertise, but the increasing density and complexity of traffic have generated greater interest in personalized and adaptive resolution strategies. Research examining personalized conflict-resolution approaches emphasizes that controller characteristics, decision preferences, contextual factors, and operational constraints can influence how conflicts are detected and managed (Renkhoff et al., 2025). This issue is directly relevant to crisis training because emergencies frequently increase the number of simultaneous constraints affecting decision-making. Under such conditions, controllers must not only identify a technically valid solution but must also determine whether that solution remains feasible under reduced system capacity, communication disruption, equipment degradation, or rapidly changing traffic patterns. Training models must therefore prepare personnel to evaluate multiple alternatives under uncertainty rather than merely reproduce standard responses.

Traffic congestion and network scale also present important operational challenges. Large air traffic networks can become increasingly difficult to coordinate as the number of interactions among flights, sectors, routes, and airports rises. Network-based approaches to improving operational efficiency have shown that reducing unnecessary complexity in air traffic networks can contribute to more efficient traffic management (Zhao et al., 2024). Similarly, optimization methods have been applied to flight scheduling in order to improve the allocation of limited airspace and operational resources (Wu, 2024). Although these approaches are primarily associated with efficiency, they also have implications for crisis preparedness. When a disruption occurs, the capacity to simplify traffic structures, prioritize essential movements, reschedule flights, and redistribute demand can reduce cascading operational consequences. Thus, crisis management training should familiarize air traffic personnel with the logic of traffic prioritization, scheduling adaptation, capacity reduction, and network reconfiguration during abnormal situations.

The rapid digitalization of aviation creates both opportunities and vulnerabilities for crisis management. Contemporary air traffic control systems depend heavily on digital communication, surveillance, navigation, data processing, automated decision support, and interconnected information infrastructures. Broader crisis-management research has increasingly focused on the role of digital technologies in disaster preparedness, response, recovery, and organizational resilience (Kabra et al., 2024). Emerging

technologies such as the Internet of Things, edge computing, and large language models are also being discussed as tools capable of supporting real-time situational awareness, distributed information processing, decision support, and crisis coordination (Ignjatović et al., 2024). In air traffic management, however, increased technological dependence simultaneously expands exposure to cyber disruption, system interoperability problems, data-quality failures, communication outages, and infrastructure malfunction. Crisis management training must therefore include not only operational use of technology but also the ability to continue critical functions when technological systems become degraded, unavailable, or unreliable.

Cybersecurity has consequently become inseparable from operational resilience. Air traffic control increasingly relies on integrated digital infrastructure, and failures or deliberate attacks affecting communication, navigation, surveillance, or data systems can create immediate safety implications. A resilient training model should prepare personnel for situations in which digital information becomes incomplete, contradictory, delayed, or inaccessible. This requires familiarity with backup systems, alternative communication procedures, manual or degraded-mode operations, escalation protocols, and coordinated response across technical and operational teams. The objective is not to transform controllers into cybersecurity specialists but to ensure that operational personnel understand the crisis implications of digital failures and can respond appropriately when technological dependencies are disrupted. This dimension is particularly important because technological crises may unfold differently from conventional emergencies: they may be difficult to detect initially, may simultaneously affect multiple operational units, and may undermine confidence in the information on which controllers depend.

Meteorological conditions constitute another major source of operational disruption. Severe weather can reduce airport capacity, restrict routes, alter separation requirements, increase workload, create diversions, and produce rapid changes in flight demand across multiple sectors. In such situations, effective crisis management depends on the integration of meteorological information with operational decision-making. Controllers must interpret evolving weather information, communicate risks clearly, coordinate rerouting, and anticipate secondary congestion effects. Training should therefore emphasize not only access to meteorological information but also its operational interpretation and incorporation into crisis decision-making. This is especially important because environmental crises

can develop progressively, requiring anticipatory action before conditions reach a critical threshold. A crisis management framework that incorporates forecasting, risk assessment, and early operational adjustment can improve preparedness and reduce the need for purely reactive responses.

Human factors remain equally central. Air traffic control is cognitively demanding even in routine conditions, and crisis situations can intensify workload, stress, fatigue, attentional demands, communication pressure, and decision uncertainty. Occupational health and psychological resilience should therefore be considered fundamental components of crisis preparedness. Organizational structures that ignore stress management, fatigue, team coordination, and psychological recovery may undermine otherwise effective technical procedures. The adaptive safety behavior identified in controller research demonstrates that safe performance depends on the ability of operators to interpret changing conditions and reorganize priorities (Gyles & Bearman, 2025). Accordingly, crisis management training should include psychological preparedness, stress regulation, decision-making under pressure, teamwork, and methods for preserving cognitive performance during prolonged or high-intensity disruptions.

Effective crisis response also depends on organizational command and communication. Air traffic control emergencies may require simultaneous coordination among control towers, approach units, area control centers, airport operations, airline operators, emergency services, meteorological units, technical departments, security organizations, and national aviation authorities. Ambiguity in authority or communication channels can delay decisions and increase operational risk. Crisis management research outside aviation similarly emphasizes that effective response depends on institutional coordination, integrated management, defined responsibilities, and the alignment of multiple organizational actors (Mousavi et al., 2024; Shirini et al., 2026). These considerations indicate that a training model should address not merely individual controller competence but also command structures, inter-unit coordination, communication protocols, responsibility allocation, and mechanisms for escalating decisions during emergencies.

The role of organizational preparedness has also been emphasized in studies of crisis-management mechanisms in other high-risk sectors. Research on the development of crisis management mechanisms in hospitals has demonstrated the importance of organizational, managerial,

structural, and preparedness-related factors in establishing effective crisis response capacity (Moharekpour et al., 2022). Although healthcare and aviation differ operationally, both environments share important characteristics: they involve safety-critical decision-making, dependence on multidisciplinary coordination, high consequences of error, limited tolerance for service interruption, and the need to maintain essential functions during crises. These similarities reinforce the argument that effective crisis management cannot be reduced to technical response procedures alone; instead, it requires a coordinated system that integrates human resources, infrastructure, training, governance, communication, and continuous evaluation.

Evaluation is a further essential but sometimes underestimated component of crisis management. Organizations frequently conduct exercises, simulations, or post-event reviews, yet evaluation has limited value unless its findings are translated into measurable improvements in procedures, training, and organizational capability. Recent research has drawn attention to the importance of assessing the actual impact of crisis-management evaluations rather than assuming that evaluation itself automatically produces improvement (Björnqvist et al., 2025). For air traffic control, this issue is especially relevant because simulation and scenario-based training are already deeply embedded in professional preparation. Crisis-management training should therefore include systematic evaluation of exercises, structured feedback, identification of performance gaps, and mechanisms for incorporating lessons learned into future training cycles. Continuous learning is necessary because airspace structures, technologies, traffic patterns, threats, and organizational requirements evolve over time.

Simulation is particularly important because many high-risk aviation crises cannot ethically or practically be experienced through real-world training. Scenario-based exercises allow personnel to rehearse rare but consequential events under controlled conditions. Effective simulation can expose controllers to combinations of technical failure, communication disruption, severe weather, traffic overload, security threats, and conflicting operational priorities. Such training can also assess how teams communicate, distribute tasks, preserve situational awareness, and recover from unexpected events. However, simulation should not be treated as a one-time educational intervention. Its value depends on continuity, progressive complexity, realistic scenarios, objective evaluation, and the integration of results into organizational learning. The emphasis on systematic

crisis evaluation (Björnqvist et al., 2025) supports the development of training systems in which simulation, assessment, feedback, and revision form a continuous cycle.

The aviation industry's experience with large-scale crises further demonstrates the importance of resilience. Reviews of aviation responses to crises show that airlines and aviation organizations must repeatedly adapt their operations, structures, resources, and strategies in order to survive major disruptions (Cook et al., 2024). Airport and airline crisis management similarly requires coordinated planning across operational, security, communication, business-continuity, and emergency-response domains (Taylor, 2026). Air traffic control occupies a central position in this ecosystem because disruptions affecting airlines or airports quickly become traffic-management problems, while air traffic control failures can themselves generate wider systemic disruption. Therefore, crisis management training for controllers should be aligned with broader aviation resilience and should prepare personnel to understand the system-wide consequences of local operational decisions.

Local and national context also matters. Crisis management systems are shaped by governance arrangements, infrastructure conditions, resource availability, institutional culture, regulatory frameworks, and patterns of interorganizational cooperation. Research on local crisis management has shown that the realization of effective crisis-management systems depends on multiple structural, managerial, institutional, and contextual factors (Mousavi et al., 2024). Likewise, integrated management approaches emphasizing coordinated authority and passive-defense considerations underline the importance of institutional integration in crisis preparedness (Shirini et al., 2026). These findings are relevant to the Iranian air traffic control environment, where crisis-management training must correspond to existing organizational structures, national aviation regulations, technological infrastructure, operational constraints, and patterns of coordination among aviation agencies. A model developed without attention to these contextual characteristics may be theoretically sound but difficult to implement.

The legal and ethical dimensions of crisis response are also significant. Controllers and managers may face situations requiring rapid decisions about prioritization, restriction of airspace, diversion, emergency access, information sharing, and allocation of limited operational capacity. These decisions may carry legal, ethical, and safety implications. Clear frameworks are therefore necessary to define authority, responsibility, accountability, and

acceptable operational discretion. Crisis management training should enable personnel to understand the boundaries of their professional authority while also preparing them to exercise judgment in situations where established procedures do not fully anticipate the circumstances encountered. This is especially important in environments characterized by technological change, emerging airspace users, and new forms of distributed traffic management (Chen et al., 2025; Raziq et al., 2025).

Taken together, the contemporary air traffic control environment requires a multidimensional crisis-management training architecture. Such an architecture should integrate operational training and simulation, safety and human error management, infrastructure and technology management, navigation-system resilience, management of emerging airspace interactions, cybersecurity, crisis communication, environmental-condition management, emergency prioritization, risk forecasting, command structures, occupational health, human resource management, legal and ethical frameworks, strategic management, instructional methodology, continuity of learning, meteorological information integration, and intelligent data analysis. The literature supports each of these domains individually, yet the challenge lies in integrating them into a coherent model capable of supporting air traffic personnel before, during, and after crises. Developments in digital crisis management (Ignjatović et al., 2024; Kabra et al., 2024), optimization and traffic efficiency (Wu, 2024; Zhao et al., 2024), conflict resolution (Renkhoff et al., 2025), adaptive controller behavior (Gyles & Bearman, 2025), organizational crisis structures (Moharekpour et al., 2022; Mousavi et al., 2024), and aviation resilience (Cook et al., 2024; Taylor, 2026) collectively point toward the need for integrated rather than fragmented approaches to crisis preparedness.

Despite these advances, the available literature remains distributed across distinct fields such as aviation safety, traffic optimization, digital technologies, disaster management, organizational resilience, and human factors. Many studies address particular technical or managerial dimensions without providing a comprehensive training framework specifically designed for the operational realities of air traffic control. Moreover, emerging airspace technologies, increasing digital dependence, cyber vulnerabilities, changing traffic patterns, and the need for continuous operational resilience are expanding the competencies required of air traffic personnel (Chen et al., 2025; Kale et al., 2021; Raziq et al., 2025). A contextually

validated model is therefore necessary to determine which dimensions and components should form the core of crisis management training in Iran and whether the proposed structure is empirically supported by personnel working directly within the national air traffic control system.

Accordingly, the aim of this study was to validate a crisis management training model based on reducing air traffic control challenges in Iran.

2 Methods and Materials

This study was applied in terms of its purpose and employed a quantitative research approach. A descriptive-survey design was used to validate the proposed crisis management training model developed with an emphasis on reducing challenges associated with air traffic control in Iran. The statistical population consisted of 430 air traffic control personnel working in major air traffic control units in Iran. Of these, 100 personnel were employed at the Mehrabad Airport Control Tower, 100 worked in the Tehran Approach Control Unit, and 230 were employed at the national Area Control Center. Considering the distribution of personnel across these operational units and the need to ensure adequate representation of each subgroup, stratified random sampling was employed. The required sample size was determined using Cochran's sample size formula, resulting in a final sample of 203 participants. Participants were proportionally selected from the defined strata to reflect the composition of the target population as closely as possible. The use of a quantitative descriptive-survey design was considered appropriate because the principal objective of this phase of the study was to empirically assess and validate the structure of the proposed crisis management training model among personnel directly involved in air traffic control operations. Data were collected using both library-based and field-based procedures. The library phase was used to review the theoretical foundations and relevant literature concerning crisis management training, operational challenges, and air traffic control, whereas the field phase involved administering the study questionnaire to the selected participants.

Data were collected using a researcher-made questionnaire developed on the basis of findings obtained from the preceding qualitative interviews and the components identified during the model-development phase. Accordingly, the questionnaire items were formulated to represent the dimensions, components, and indicators of the proposed crisis management training model and its

relationship with reducing air traffic control challenges. The psychometric properties of the instrument were evaluated before its use in the main quantitative phase. The validity of the questionnaire was examined through face, content, and construct validity procedures. For face validity, the preliminary questionnaire was provided to a group of experts familiar with crisis management, aviation, air traffic control, training, and research methodology, who evaluated the clarity, comprehensibility, relevance, appropriateness, and wording of the items. Their comments were considered in refining the final version of the instrument. Content and construct validity were subsequently assessed within the measurement-model evaluation process. In particular, the average variance extracted (AVE) was examined to determine the extent to which the indicators adequately represented their corresponding latent constructs, while composite reliability (CR) was calculated to assess the internal consistency of the constructs. The obtained AVE and CR values indicated that the questionnaire items and underlying constructs demonstrated acceptable measurement quality and adequately represented the conceptual dimensions of the proposed model. The reliability of the questionnaire was additionally assessed using Cronbach's alpha coefficient. The resulting coefficients demonstrated satisfactory internal consistency, indicating that the instrument provided sufficiently reliable measurements for evaluating the proposed crisis management training model among air traffic control personnel.

Following data collection, the completed questionnaires were reviewed and prepared for statistical analysis. Data analysis was conducted using SPSS and AMOS software. Descriptive statistical procedures were initially applied to summarize the characteristics of the collected data and provide an overview of participants' responses to the questionnaire items and study constructs. The principal inferential analytical procedure was structural equation modeling (SEM), which was employed to assess the empirical validity of the proposed crisis management training model and examine the relationships among its latent variables, dimensions, and observed indicators. Within the SEM framework, the measurement model was evaluated to determine whether the observed indicators appropriately represented the latent constructs included in the conceptual model, while construct validity and internal consistency were examined using indicators such as average variance extracted and composite reliability. Subsequently, the structural model was assessed to determine the strength

and statistical adequacy of the hypothesized relationships among the components of the proposed model. AMOS was used for estimating the structural equation model and evaluating the correspondence between the conceptual model derived from the qualitative phase and the empirical data obtained from the sample of air traffic control personnel. SPSS was used for preliminary data management, descriptive analyses, reliability assessment, and preparation of the dataset for structural equation modeling. Through this analytical procedure, the quantitative phase provided the empirical basis for determining whether the proposed crisis management training model possessed sufficient validity and reliability for application in the context of reducing air traffic control challenges in Iran.

3 Findings and Results

Descriptive and inferential analyses were conducted to evaluate the empirical adequacy of the proposed crisis

management training model for reducing air traffic control challenges in Iran. The descriptive analysis examined the central tendency, dispersion, skewness, and kurtosis of the study components. Responses were scored on a five-point Likert scale ranging from completely disagree to completely agree, with a theoretical midpoint of 3. As presented in Table 1, the mean scores of all 19 components exceeded the theoretical midpoint, ranging from 3.289 to 4.520. The highest mean was observed for management of emerging airspace interactions ($M = 4.520$, $SD = 0.137$), followed closely by cybersecurity and digital infrastructure ($M = 4.517$, $SD = 0.138$), whereas human resource management had the lowest mean ($M = 3.289$, $SD = 0.114$). Nevertheless, even the lowest mean remained above the midpoint of the scale. Furthermore, the skewness and kurtosis coefficients were within acceptable ranges for all components, providing preliminary evidence that the distributions did not exhibit substantial departures from normality.

Table 1

Descriptive Statistics for the Components of the Crisis Management Training Model

Dimension	Component	No. of Indicators	Mean	SD	Skewness	Kurtosis
Operational Preparedness and Capability	Operational Training and Simulation	5	3.681	0.119	0.59	0.47
Operational Preparedness and Capability	Safety and Human Error Management	5	3.555	0.131	0.42	0.37
Operational Preparedness and Capability	Infrastructure and Technology Management	5	4.102	0.138	0.60	0.49
Operational Preparedness and Capability	Navigation Systems Resilience	5	4.210	0.121	0.62	0.52
Operational Preparedness and Capability	Management of Emerging Airspace Interactions	5	4.520	0.137	0.53	0.50
Operational Preparedness and Capability	Cybersecurity and Digital Infrastructure	5	4.517	0.138	0.58	0.47
Crisis Management and Rapid Response	Crisis Communication Management	5	4.258	0.137	0.55	0.45
Crisis Management and Rapid Response	Environmental and Climatic Condition Management	5	3.952	0.125	0.54	0.50
Crisis Management and Rapid Response	Priority Management in Emergency Conditions	5	3.901	0.138	0.52	0.41
Crisis Management and Rapid Response	Risk Management and Forecasting	5	3.882	0.127	0.63	0.53
Leadership, Structure, and Resources	Management and Command Structure	5	3.907	0.125	0.57	0.49
Leadership, Structure, and Resources	Occupational Psychology and Health	5	3.521	0.122	0.61	0.51
Leadership, Structure, and Resources	Human Resource Management	4	3.289	0.114	0.51	0.42
Leadership, Structure, and Resources	Legal and Ethical Frameworks	4	3.782	0.122	0.54	0.43
Leadership, Structure, and Resources	Macro and Strategic Management	5	3.638	0.142	0.56	0.46
Knowledge, Training, and Continuous Learning	Training and Learning Methodology	4	3.778	0.133	0.50	0.41
Knowledge, Training, and Continuous Learning	Continuity and Sustainability of Training	5	3.789	0.129	0.64	0.59
Information and Emerging Technologies	Integration of Meteorological Information	5	3.663	0.132	0.62	0.55
Information and Emerging Technologies	Intelligent Data Analysis	5	3.320	0.117	0.63	0.53

Before conducting confirmatory factor analysis and structural equation modeling, the normality of the research variables was examined using the Kolmogorov–Smirnov test. In this analysis, the null hypothesis indicated that the

observed data followed a normal distribution. As shown in Table 2, the significance levels for all components were greater than .05. Therefore, the null hypothesis of normality was not rejected for any component. These results, together

with the observed skewness and kurtosis coefficients, supported the use of parametric statistical procedures and

covariance-based structural equation modeling for subsequent analyses.

Table 2

Kolmogorov–Smirnov Normality Test Results

Dimension	Component	No. of Indicators	K–S Statistic	p
Operational Preparedness and Capability	Operational Training and Simulation	5	0.187	0.609
Operational Preparedness and Capability	Safety and Human Error Management	5	0.128	0.588
Operational Preparedness and Capability	Infrastructure and Technology Management	5	0.137	0.591
Operational Preparedness and Capability	Navigation Systems Resilience	5	0.139	0.569
Operational Preparedness and Capability	Management of Emerging Airspace Interactions	5	0.148	0.602
Operational Preparedness and Capability	Cybersecurity and Digital Infrastructure	5	0.151	0.687
Crisis Management and Rapid Response	Crisis Communication Management	5	0.201	0.705
Crisis Management and Rapid Response	Environmental and Climatic Condition Management	5	0.115	0.641
Crisis Management and Rapid Response	Priority Management in Emergency Conditions	5	0.117	0.617
Crisis Management and Rapid Response	Risk Management and Forecasting	5	0.119	0.618
Leadership, Structure, and Resources	Management and Command Structure	5	0.101	0.625
Leadership, Structure, and Resources	Occupational Psychology and Health	5	0.251	0.725
Leadership, Structure, and Resources	Human Resource Management	4	0.321	0.633
Leadership, Structure, and Resources	Legal and Ethical Frameworks	4	0.223	0.620
Leadership, Structure, and Resources	Macro and Strategic Management	5	0.244	0.833
Knowledge, Training, and Continuous Learning	Training and Learning Methodology	4	0.345	0.701
Knowledge, Training, and Continuous Learning	Continuity and Sustainability of Training	5	0.236	0.620
Information and Emerging Technologies	Integration of Meteorological Information	5	0.347	0.609
Information and Emerging Technologies	Intelligent Data Analysis	5	0.217	0.714

Following confirmation of the distributional assumptions, the measurement properties of the proposed model were examined before assessment of the structural relationships. Because the model included multiple latent constructs, the measurement models were first evaluated separately to ensure that the latent variables were measured with sufficient psychometric quality before their incorporation into the overall structural model. Internal consistency was assessed using Cronbach's alpha, while item–total correlations were examined to determine the consistency of the indicators with their respective constructs. Confirmatory factor analysis was subsequently used to assess the measurement structure. Average variance extracted (AVE), composite reliability (CR), maximum shared variance (MSV), and average shared variance (ASV) were also calculated to assess convergent and discriminant validity.

As presented in Table 3, Cronbach's alpha coefficients ranged from 0.718 to 0.950, exceeding the commonly used

minimum criterion of 0.60 and indicating satisfactory internal consistency across all components. Item–total correlations ranged from 0.59 to 0.91 and were therefore well above the minimum criterion of 0.30. The AVE coefficients ranged from 0.501 to 0.630, with all values exceeding 0.50, indicating that the latent constructs explained an adequate proportion of variance in their respective indicators. The reported composite reliability coefficients ranged from 0.608 to 0.697. Moreover, AVE exceeded both MSV and ASV for every construct. Specifically, MSV was 0.004 and ASV was 0.020 across the components, thereby providing evidence that the constructs were empirically distinguishable from one another. Collectively, these findings supported the internal consistency, convergent validity, and discriminant validity of the measurement structure.

Table 3*Reliability, Convergent Validity, and Discriminant Validity of the Model Components*

Dimension	Component	Cronbach's α	Item–Total Correlation	AVE	CR	MSV	ASV
Operational Preparedness and Capability	Operational Training and Simulation	0.770	0.72	0.509	0.611	0.004	0.020
Operational Preparedness and Capability	Safety and Human Error Management	0.781	0.77	0.590	0.628	0.004	0.020
Operational Preparedness and Capability	Infrastructure and Technology Management	0.882	0.79	0.601	0.691	0.004	0.020
Operational Preparedness and Capability	Navigation Systems Resilience	0.796	0.80	0.604	0.685	0.004	0.020
Operational Preparedness and Capability	Management of Emerging Airspace Interactions	0.811	0.82	0.610	0.697	0.004	0.020
Operational Preparedness and Capability	Cybersecurity and Digital Infrastructure	0.880	0.69	0.557	0.608	0.004	0.020
Crisis Management and Rapid Response	Crisis Communication Management	0.950	0.66	0.550	0.691	0.004	0.020
Crisis Management and Rapid Response	Environmental and Climatic Condition Management	0.890	0.67	0.507	0.625	0.004	0.020
Crisis Management and Rapid Response	Priority Management in Emergency Conditions	0.780	0.71	0.531	0.631	0.004	0.020
Crisis Management and Rapid Response	Risk Management and Forecasting	0.729	0.80	0.597	0.652	0.004	0.020
Leadership, Structure, and Resources	Management and Command Structure	0.763	0.78	0.501	0.608	0.004	0.020
Leadership, Structure, and Resources	Occupational Psychology and Health	0.829	0.63	0.630	0.697	0.004	0.020
Leadership, Structure, and Resources	Human Resource Management	0.808	0.91	0.524	0.622	0.004	0.020
Leadership, Structure, and Resources	Legal and Ethical Frameworks	0.793	0.82	0.511	0.637	0.004	0.020
Leadership, Structure, and Resources	Macro and Strategic Management	0.718	0.60	0.523	0.638	0.004	0.020
Knowledge, Training, and Continuous Learning	Training and Learning Methodology	0.729	0.59	0.543	0.644	0.004	0.020
Knowledge, Training, and Continuous Learning	Continuity and Sustainability of Training	0.719	0.63	0.576	0.628	0.004	0.020
Information and Emerging Technologies	Integration of Meteorological Information	0.803	0.71	0.505	0.633	0.004	0.020
Information and Emerging Technologies	Intelligent Data Analysis	0.888	0.75	0.587	0.678	0.004	0.020

The adequacy of the data for factor analysis was further evaluated using the Kaiser–Meyer–Olkin measure of sampling adequacy and Bartlett's test of sphericity. The KMO statistic assesses whether the pattern of correlations is sufficiently compact to permit reliable factor extraction, with values above 0.60 generally considered acceptable. Bartlett's test determines whether the observed correlation

matrix differs significantly from an identity matrix. As shown in Table 4, the KMO coefficient was 0.892, indicating a high degree of sampling adequacy. Bartlett's test of sphericity was also statistically significant, $\chi^2 = 636789.058$, $df = 203$, $p = .001$. Therefore, the correlation structure among the indicators was considered suitable for factor analysis.

Table 4*KMO and Bartlett's Test Results*

Model	Test	Statistic	Result
Crisis Management Training Model Based on Reducing Air Traffic Control Challenges in Iran	Kaiser–Meyer–Olkin Measure	KMO	0.892
Crisis Management Training Model Based on Reducing Air Traffic Control Challenges in Iran	Bartlett's Test of Sphericity	Chi-square	636789.058
		df	203
		p	0.001

The adequacy of the sample size was additionally examined through statistical power analysis of the measurement model. At the achieved sample size of 203 participants, the statistical power of the model reached 1.00, which was above the conventional minimum criterion of 0.80. This finding indicated that the sample size was sufficient for estimation of the unknown model parameters. Accordingly, failure to reject a null hypothesis in any subsequent test could not reasonably be attributed to inadequate statistical power arising from an insufficient sample. Taken together with the KMO and Bartlett results, the power analysis confirmed the adequacy of the dataset for confirmatory factor analysis.

Confirmatory factor analysis was subsequently performed to determine whether the theoretically specified components adequately represented their corresponding latent dimensions. In this procedure, the hypothesized relationships between observed indicators and latent constructs were tested based on the conceptual structure identified in the preceding model-development phase. The standardized estimates and corresponding t statistics are reported in Table 5. All standardized path coefficients were positive and substantial, ranging from 0.70 to 0.81. The associated t statistics ranged from 5.97 to 12.34 and

exceeded the critical threshold for statistical significance. Consequently, all 19 components were retained as statistically significant indicators of their respective dimensions.

Within the Operational Preparedness and Capability dimension, standardized coefficients ranged from 0.70 for cybersecurity and digital infrastructure to 0.76 for safety and human error management. Within Crisis Management and Rapid Response, coefficients ranged from 0.72 for environmental and climatic condition management to 0.75 for crisis communication management. Within Leadership, Structure, and Resources, human resource management yielded the largest coefficient ($\beta = 0.78$), whereas occupational psychology and health yielded the smallest ($\beta = 0.70$). In the Knowledge, Training, and Continuous Learning dimension, training and learning methodology ($\beta = 0.77$) and continuity and sustainability of training ($\beta = 0.75$) both demonstrated strong standardized loadings. Finally, the Information and Emerging Technologies dimension exhibited particularly strong coefficients for integration of meteorological information ($\beta = 0.78$) and intelligent data analysis ($\beta = 0.81$), with intelligent data analysis showing the highest standardized coefficient among all model components.

Table 5

Standardized Path Coefficients and Significance of the Estimated Parameters

Dimension	Component	Standardized Estimate (β)	t	p	Result
Operational Preparedness and Capability	Operational Training and Simulation	0.74	7.32	.003	Supported
Operational Preparedness and Capability	Safety and Human Error Management	0.76	7.11	<.001	Supported
Operational Preparedness and Capability	Infrastructure and Technology Management	0.73	6.41	<.001	Supported
Operational Preparedness and Capability	Navigation Systems Resilience	0.72	6.72	<.001	Supported
Operational Preparedness and Capability	Management of Emerging Airspace Interactions	0.71	6.15	<.001	Supported
Operational Preparedness and Capability	Cybersecurity and Digital Infrastructure	0.70	5.98	<.001	Supported
Crisis Management and Rapid Response	Crisis Communication Management	0.75	11.23	.002	Supported
Crisis Management and Rapid Response	Environmental and Climatic Condition Management	0.72	6.64	<.001	Supported
Crisis Management and Rapid Response	Priority Management in Emergency Conditions	0.73	6.82	<.001	Supported
Crisis Management and Rapid Response	Risk Management and Forecasting	0.74	5.97	<.001	Supported
Leadership, Structure, and Resources	Management and Command Structure	0.74	10.67	.003	Supported
Leadership, Structure, and Resources	Occupational Psychology and Health	0.70	9.89	<.001	Supported
Leadership, Structure, and Resources	Human Resource Management	0.78	11.45	<.001	Supported
Leadership, Structure, and Resources	Legal and Ethical Frameworks	0.73	11.23	<.001	Supported
Leadership, Structure, and Resources	Macro and Strategic Management	0.73	6.14	<.001	Supported
Knowledge, Training, and Continuous Learning	Training and Learning Methodology	0.77	10.92	<.001	Supported
Knowledge, Training, and Continuous Learning	Continuity and Sustainability of Training	0.75	10.34	.002	Supported
Information and Emerging Technologies	Integration of Meteorological Information	0.78	7.41	<.001	Supported
Information and Emerging Technologies	Intelligent Data Analysis	0.81	12.34	<.001	Supported

Figure 1

Model with Beta Value

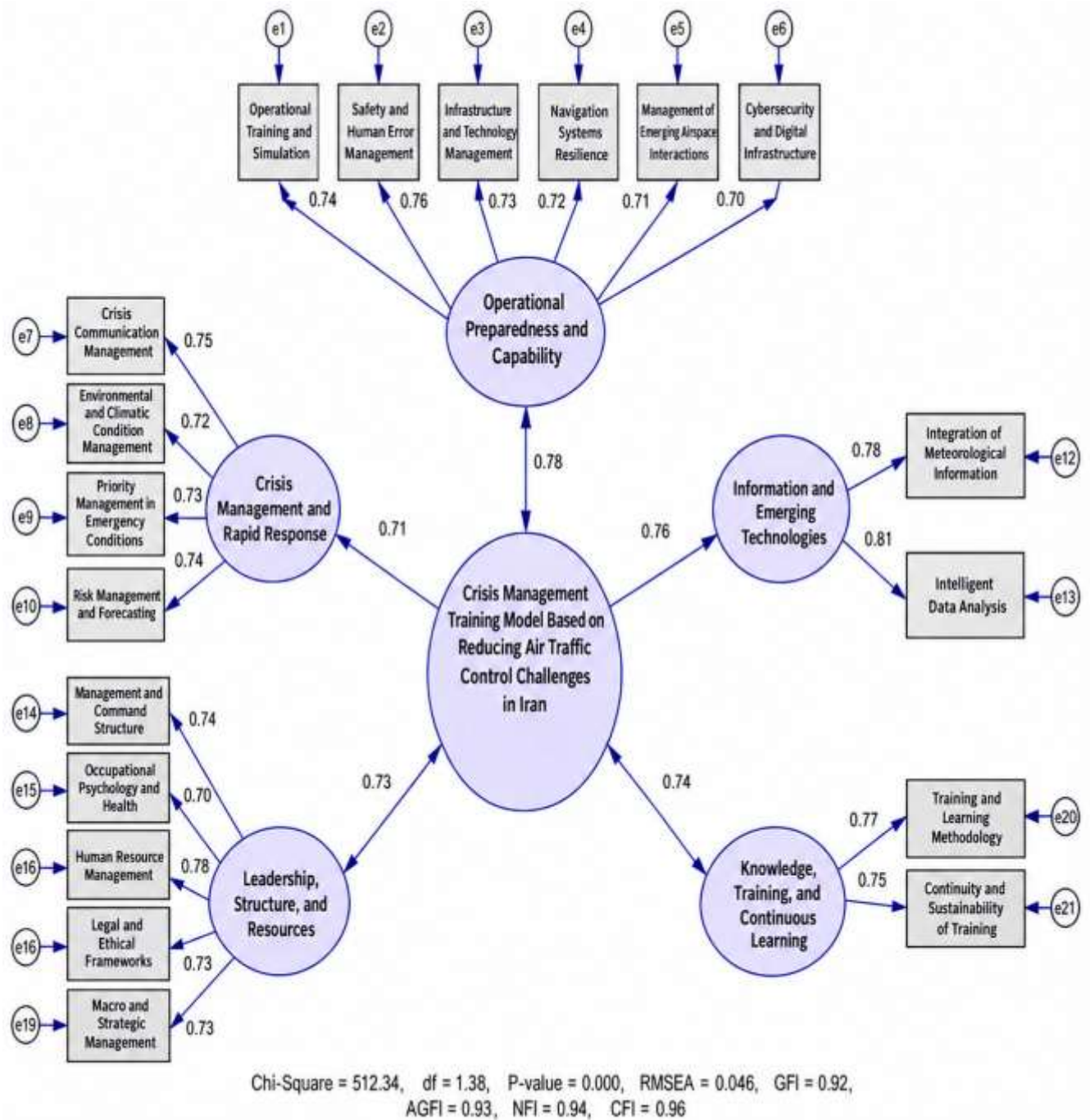
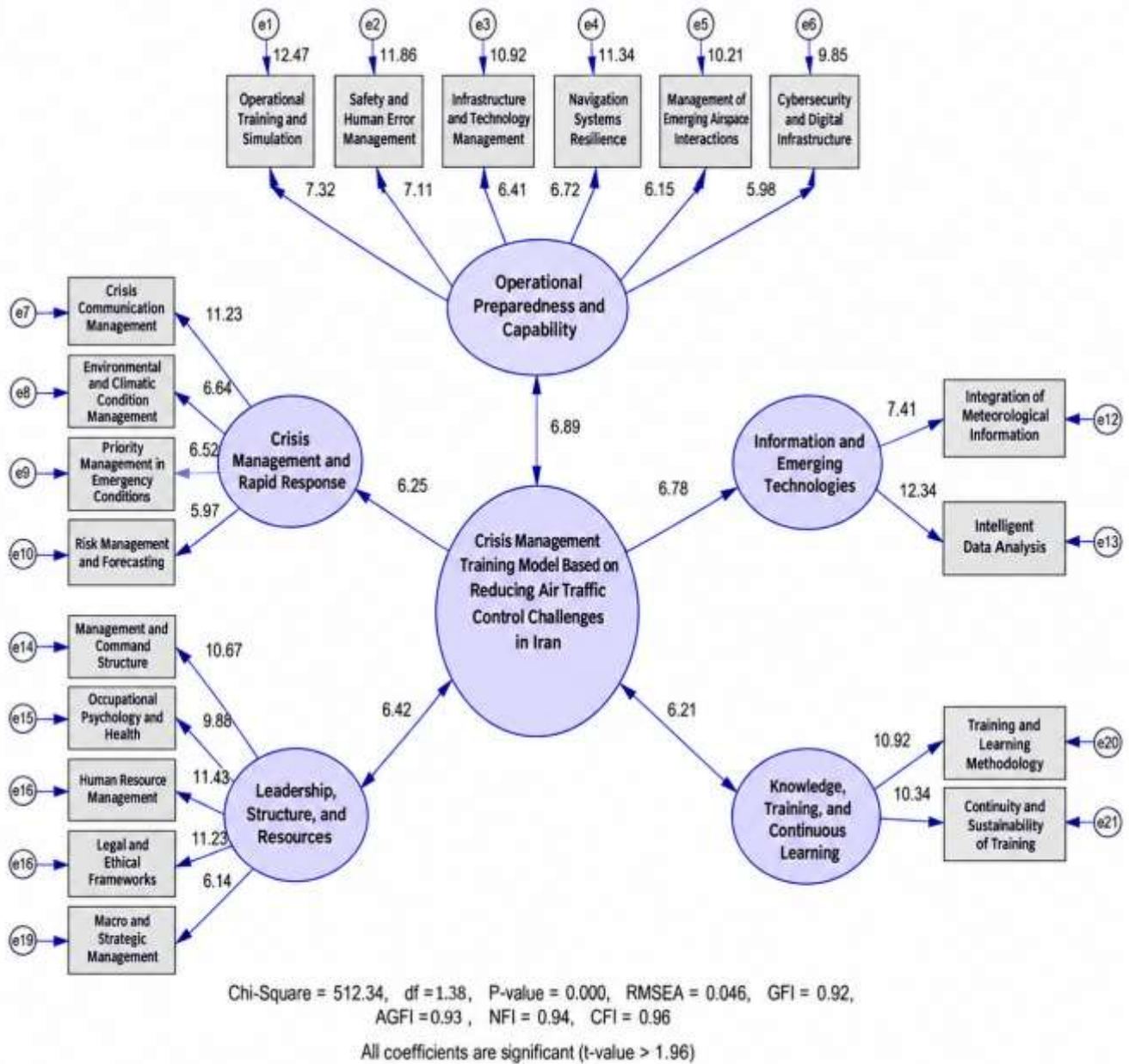


Figure 2

Model with T-Value



The overall goodness of fit of the confirmatory factor model was evaluated before interpreting the structural relationships. Several absolute, incremental, and parsimonious fit indices were considered. The goodness-of-fit index (GFI), which represents the relative proportion of observed variances and covariances reproduced by the model, exceeded the recommended threshold of 0.90. The adjusted goodness-of-fit index (AGFI) likewise exceeded 0.90. The comparative fit index (CFI) was also substantially above its recommended minimum level. In addition, the ratio of chi-square to degrees of freedom was considerably below

3, indicating satisfactory parsimonious fit. The root mean square error of approximation (RMSEA), which evaluates approximate model misfit per degree of freedom, was below 0.08 and therefore indicated a low level of approximation error. The broader evaluation also considered incremental indices such as the normed fit index (NFI), non-normed fit index (NNFI), and incremental fit index (IFI), which were interpreted as supporting the adequacy of the specified model.

As presented in Table 6, GFI was 0.92, AGFI was 0.93, CFI was 0.96, CMIN/df was 1.38, and RMSEA was 0.046.

All reported indices satisfied their respective acceptance criteria. Therefore, the empirical covariance structure

demonstrated satisfactory correspondence with the theoretically specified measurement structure.

Table 6

Goodness-of-Fit Indices for the Confirmatory Factor Model

Fit Index	Obtained Value	Acceptable Criterion	Status
GFI	0.92	> 0.90	Acceptable
AGFI	0.93	> 0.90	Acceptable
CFI	0.96	> 0.90 and < 1.00	Acceptable
CMIN/df	1.38	< 3.00	Acceptable
RMSEA	0.046	< 0.10	Acceptable

The standardized structural solution further demonstrated that all estimated relationships in the proposed model were positive and statistically significant. Likewise, the corresponding t statistics for the model paths were sufficiently large to support the statistical significance of the estimated parameters. Thus, both the standardized path coefficients and their significance statistics provided empirical support for the proposed structure. The results of

the confirmatory factor analysis, reliability assessment, convergent and discriminant validity analyses, sampling adequacy tests, statistical power analysis, and goodness-of-fit evaluation collectively indicated that the proposed crisis management training model had an acceptable empirical structure for application to the reduction of air traffic control challenges in Iran.

4 Discussion

The present study sought to validate a crisis management training model designed to reduce air traffic control challenges in Iran. The findings provided empirical support for a multidimensional model consisting of five major dimensions: Operational Preparedness and Capability; Crisis Management and Rapid Response; Leadership, Structure, and Resources; Knowledge, Training, and Continuous Learning; and Information and Emerging Technologies. These dimensions were represented by 19 components covering operational simulation, safety and human error, infrastructure and technology, navigation-system resilience, emerging airspace interactions, cybersecurity, crisis communication, environmental conditions, emergency prioritization, risk management, command structures, occupational health, human resources, legal and ethical considerations, strategic management, training methodology, continuity of learning, meteorological information integration, and intelligent data analysis. The mean scores of all components exceeded the theoretical midpoint of the scale, indicating that air traffic control personnel generally regarded all identified components as relevant to crisis management training. This broad endorsement supports the premise that crisis preparedness in air traffic control cannot be reduced to a single technical or behavioral capability but instead requires an integrated

system of operational, human, organizational, educational, and technological competencies.

Among the components, management of emerging airspace interactions obtained the highest mean, closely followed by cybersecurity and digital infrastructure. This pattern is particularly meaningful in view of the rapid transformation of contemporary airspace. Increasing use of unmanned aerial vehicles, low-altitude mobility systems, digitally interconnected aviation infrastructure, and new traffic-management architectures have created operational conditions that differ substantially from conventional air traffic environments. Chen et al. emphasized that emerging airspace increasingly requires hybrid centralized-decentralized control frameworks capable of coordinating complex and heterogeneous traffic (Chen et al., 2025). Similarly, Raziq et al. highlighted the potential importance of combining centralized and decentralized solutions in improving air traffic control performance (Raziq et al., 2025). The high importance assigned to emerging airspace interaction management in the present study can therefore be interpreted as a recognition by air traffic personnel that crisis-management competence must evolve alongside the changing structure of airspace rather than remain limited to conventional aircraft operations.

The prominence of cybersecurity and digital infrastructure is likewise consistent with the growing dependence of aviation systems on interconnected digital

technologies. Air traffic control operations increasingly rely on digital surveillance, navigation, communication, automated decision support, meteorological information systems, and real-time data exchange. This creates substantial advantages in terms of precision and efficiency, but it also introduces new vulnerabilities. Crisis-management research increasingly recognizes digital technologies as central components of disaster preparedness, response, and organizational resilience (Kabra et al., 2024). Likewise, the integration of the Internet of Things, edge computing, and large language models into crisis-management environments demonstrates the growing role of distributed data processing and intelligent decision support (Ignjatović et al., 2024). The present findings therefore suggest that crisis-management training for Iranian air traffic controllers should include not only routine use of digital systems but also preparation for degraded-system operations, information uncertainty, cyber disruption, communication failure, and continuity of critical functions when technological infrastructure becomes compromised.

Navigation systems resilience also received a comparatively high mean. This result reflects the safety-critical nature of communication, navigation, and surveillance infrastructure in air traffic management. A crisis involving system degradation can immediately increase controller workload, reduce situational awareness, constrain available routes, and require transition to backup or procedural control mechanisms. The importance assigned to this component is consistent with broader arguments that sustainable air traffic management depends on resilience as well as efficiency (Kale et al., 2021). Resilience in this context should be understood as the capacity of the operational system to absorb disturbance, maintain essential functions, adapt to degraded conditions, and recover without compromising safety. Therefore, training should not focus exclusively on optimal system performance under normal conditions but should also develop competence in fallback procedures, redundancy management, coordination under degraded modes, and rapid recovery.

Crisis communication management also emerged as a highly rated component. Effective communication is fundamental during aviation emergencies because crisis events typically require simultaneous coordination among controllers, pilots, supervisors, adjacent sectors, airport authorities, airline operations, technical departments, security personnel, and emergency services. Any ambiguity, delay, or inconsistency in the transfer of information can compound operational risk. This finding aligns with research

emphasizing integrated management and interorganizational coordination as prerequisites for effective crisis response (Mousavi et al., 2024; Shirini et al., 2026). The result further indicates that crisis communication should be treated as an operational competency rather than merely an administrative function. Training programs should therefore include communication under time pressure, standardized phraseology during abnormal situations, escalation procedures, inter-unit coordination, and mechanisms for maintaining a common operational picture.

The dimension of Crisis Management and Rapid Response was also strongly supported by the confirmatory model. Its components included crisis communication, environmental and climatic condition management, emergency prioritization, and risk management and forecasting. These components reflect the essential temporal characteristics of crisis management: crises require both rapid response and anticipatory judgment. Environmental disruptions such as severe weather frequently generate cascading effects across air traffic networks, producing rerouting, congestion, capacity reduction, diversion, and increased workload. Similarly, risk forecasting is essential because many operational crises can be mitigated more effectively when actions are taken before the situation reaches a critical threshold. The findings are compatible with broader crisis-management literature emphasizing the importance of preparedness, coordinated response, risk assessment, and organizational adaptability (Moharekpour et al., 2022; Mousavi et al., 2024). In air traffic control, this implies that crisis training should cultivate the ability to recognize weak signals, anticipate secondary effects, and prioritize safety-critical actions when multiple problems occur simultaneously.

The structural results further demonstrated that Operational Preparedness and Capability had a strong relationship with the overall crisis management training model. At the component level, standardized coefficients within this dimension ranged from 0.70 to 0.76, indicating that operational training and simulation, safety and human error management, infrastructure and technology management, navigation resilience, emerging airspace interaction management, and cybersecurity all contributed substantially to the construct. This finding is consistent with the inherent characteristics of air traffic control, where safety depends on the interaction between human performance and technological systems. Gyles and Bearman showed that air traffic controllers dynamically modify their goals from efficiency toward safety as operational conditions change

(Gyles & Bearman, 2025). Their findings help explain why operational preparedness should include adaptive decision-making rather than procedural compliance alone. During crisis conditions, controllers may need to expand separation, modify traffic flow, suspend routine efficiency goals, and adopt more conservative operating strategies. Thus, simulation-based training should expose personnel to uncertain and evolving scenarios that require adaptation rather than simply rehearsal of predictable procedures.

The importance of conflict management and adaptive decision-making is further supported by research on personalized conflict-resolution strategies in air traffic control. Renkhoff et al. showed that conflict resolution is increasingly examined in terms of approaches that recognize differences in operational context and decision patterns (Renkhoff et al., 2025). This perspective is consistent with the present model because crisis situations often produce conflicts that cannot be resolved through a single standardized solution. Controllers must consider aircraft performance, sector workload, airspace restrictions, weather, system availability, and the consequences of alternative actions. Crisis-management training should therefore develop flexible problem solving and expose controllers to multiple resolution pathways rather than overemphasizing one predetermined response.

The results concerning Information and Emerging Technologies were particularly noteworthy. Intelligent data analysis produced the highest standardized coefficient among the 19 components, while integration of meteorological information also displayed a strong loading. These results suggest that the validated model recognizes information quality and analytical capability as central to contemporary crisis management. Air traffic management increasingly generates large volumes of operational data, and the ability to interpret these data rapidly can support early detection of risk, traffic forecasting, capacity management, and adaptive scheduling. Optimization research has demonstrated the potential contribution of computational approaches to air traffic scheduling and resource allocation (Wu, 2024), while network-based approaches have shown that reducing operational complexity can improve traffic efficiency (Zhao et al., 2024). In crisis conditions, such capabilities may support controllers and managers in identifying bottlenecks, prioritizing flights, redistributing traffic, and preventing localized disruptions from developing into broader network failures.

At the same time, the results should not be interpreted as suggesting that technology can substitute for human expertise. Rather, intelligent data and digital technologies should function as decision-support resources within a broader socio-technical system. The role of the controller remains critical, especially when automated recommendations become unreliable or when unexpected conditions fall outside predefined system parameters. This interpretation is supported by the broader aviation resilience literature, which emphasizes adaptation across technological, organizational, and human domains rather than reliance on any single element (Cook et al., 2024). Thus, training should include both effective use of intelligent systems and the ability to critically evaluate automated outputs, detect anomalies, and maintain operational control when technological support is reduced.

The Leadership, Structure, and Resources dimension was also empirically supported. Human resource management showed the strongest component loading within this dimension, while management and command structure, occupational psychology and health, legal and ethical frameworks, and macro-level strategic management also demonstrated meaningful relationships. These findings indicate that crisis-management effectiveness is not determined solely at the controller workstation. Organizational preparedness depends on appropriate staffing, clear command arrangements, psychological readiness, regulatory clarity, strategic planning, and the capacity to mobilize resources during disruption. Similar conclusions have been reported in crisis-management research emphasizing the importance of managerial and structural mechanisms in institutional preparedness (Moharekpour et al., 2022). Integrated management approaches also underscore the need for coordinated authority and clearly defined responsibilities during crises (Shirini et al., 2026). Therefore, the training model should extend beyond frontline personnel and incorporate supervisory, managerial, and organizational levels.

The inclusion of occupational psychology and health is especially important in air traffic control because high workload, fatigue, sustained attention, and time pressure can directly affect operational performance. Crisis conditions can intensify all of these demands, particularly when emergencies continue for extended periods. Controllers may be required to process large amounts of information while maintaining communication accuracy and anticipating future traffic states. The adaptive behavior described by Gyles and Bearman suggests that safe control requires

continual adjustment of goals and strategies under changing circumstances (Gyles & Bearman, 2025). Such adaptation depends on cognitive and psychological capacity. Crisis-management training should therefore incorporate stress management, workload regulation, fatigue awareness, team support, and methods for preserving performance during prolonged high-intensity operations.

The dimension of Knowledge, Training, and Continuous Learning also demonstrated strong empirical support. Both training and learning methodology and continuity and sustainability of training had substantial standardized coefficients. This finding indicates that crisis competence cannot be established through isolated training courses. Aviation threats, technologies, regulations, and operational patterns change continuously, requiring recurrent training and structured updating of professional knowledge. Simulation, scenario-based learning, after-action review, and periodic reassessment should therefore constitute an ongoing training cycle. Björnqvist et al. emphasized that crisis-management evaluations should be assessed in terms of their actual impact on organizational capability rather than merely conducted as procedural exercises (Björnqvist et al., 2025). This provides an important explanation for the present findings: effective training requires mechanisms through which evaluation leads to modification of procedures, identification of skill gaps, and revision of subsequent training activities.

The broader literature on aviation crises similarly supports the need for continuous learning. Aviation organizations must repeatedly adapt to crises that differ in origin, scope, duration, and systemic impact (Cook et al., 2024). Airport and airline crisis management therefore requires preparedness that extends across operational continuity, emergency response, communications, safety, and organizational coordination (Taylor, 2026). Air traffic control represents a central node in this system because it must continue to manage traffic even when airports, airlines, communications, or infrastructure are themselves disrupted. Continuous training allows controllers and managers to update crisis scenarios in accordance with changes in the broader aviation ecosystem and thereby avoid preparing exclusively for past forms of disruption.

The measurement results also supported the overall adequacy of the proposed model. Cronbach's alpha coefficients were satisfactory across the identified components, item-total correlations were above accepted minimum levels, and average variance extracted values exceeded 0.50 for all constructs. In addition, AVE exceeded

MSV and ASV, supporting discriminant validity and indicating that the dimensions represented related but empirically distinct aspects of crisis management training. Although the reported composite reliability values were somewhat below the stricter 0.70 criterion in several components, the broader pattern of Cronbach's alpha, item-total correlations, AVE, and discriminant-validity indicators provided overall support for the measurement structure. The KMO value of 0.892 and the significant Bartlett's test further confirmed that the correlation matrix was suitable for factor analysis.

The confirmatory factor analysis produced satisfactory global model fit. GFI was 0.92, AGFI was 0.93, CFI was 0.96, CMIN/df was 1.38, and RMSEA was 0.046. Collectively, these indices indicate that the proposed theoretical structure corresponded well with the empirical data. The standardized coefficients of all 19 components were also substantial and statistically significant. These findings support the interpretation that the proposed model captures multiple complementary elements of crisis preparedness rather than representing a collection of redundant constructs. This multidimensionality is consistent with contemporary crisis-management research, which increasingly views resilience as dependent on the integration of technology, organizational structures, human capabilities, information systems, and continuous learning (Ignjatović et al., 2024; Kabra et al., 2024). It is also consistent with the aviation literature emphasizing the interaction of efficiency, resilience, safety, and adaptation in modern air traffic management (Cook et al., 2024; Kale et al., 2021).

5 Conclusion

Overall, the findings suggest that an effective crisis management training system for Iranian air traffic control should be conceived as an integrated capability-development framework. It should prepare personnel not only for recognizable emergencies but also for uncertain and emerging threats. The increasing complexity of low-altitude and mixed airspace (Chen et al., 2025; Raziq et al., 2025), the need for adaptive conflict resolution (Renkhoff et al., 2025), the importance of controller-driven safety adaptation (Gyles & Bearman, 2025), the growing role of digital technologies (Ignjatović et al., 2024; Kabra et al., 2024), and the necessity of organizational resilience in aviation crises (Cook et al., 2024; Taylor, 2026) all reinforce the central conclusion of this study: crisis management training in air traffic control must simultaneously address operational,

technological, human, organizational, and learning dimensions.

This study has several limitations that should be considered when interpreting its findings. First, the study was conducted among air traffic control personnel from Mehrabad Airport Control Tower, Tehran Approach Control Unit, and the national Area Control Center, and although these units represent important components of the Iranian air traffic control system, the sample may not fully represent personnel working in all airports, regional facilities, military-civil coordination environments, or geographically dispersed operational contexts. Second, the study relied on a researcher-made questionnaire and self-reported responses; therefore, responses may have been influenced by individual perceptions, organizational expectations, or socially desirable judgments. Third, the cross-sectional design captured participants' assessments at a single point in time and did not determine whether the proposed training model improves actual crisis performance over time. Finally, the statistical validation focused primarily on the structural adequacy of the model and did not include direct behavioral measures obtained from simulated or real crisis events.

Future studies should test the model in broader and more diverse samples of air traffic control personnel across different airports, control towers, approach units, and regional control centers to assess the stability and generalizability of its structure. Longitudinal research is recommended to determine whether implementation of the training model produces sustained improvements in crisis preparedness, decision-making, communication, resilience, and safety performance. Experimental and quasi-experimental studies could compare personnel receiving model-based training with those receiving conventional training and evaluate outcomes through standardized simulation scenarios. Future research should also integrate objective indicators such as response time, conflict-resolution accuracy, workload, communication errors, recovery time, and performance under degraded technological conditions. Cross-national comparisons could further determine which components are universal and which require adaptation to regulatory, technological, and organizational conditions in different aviation systems.

In practice, aviation authorities and air navigation service organizations should use the validated model as a framework for developing an integrated and recurrent crisis-management training program for air traffic control personnel. Training should combine high-fidelity simulation, severe-weather scenarios, communication

breakdowns, navigation-system failures, cyber incidents, emerging airspace conflicts, traffic overload, and multi-agency emergency coordination. Special attention should be given to intelligent data analysis, digital-system resilience, human resource management, adaptive decision-making, and crisis communication because these components showed strong empirical importance in the model. Training should also be extended to supervisors and managers so that operational responses are supported by clear command structures and resource-allocation procedures. Finally, each exercise should be followed by structured evaluation and feedback, with identified weaknesses translated into revised procedures, updated scenarios, and subsequent training cycles so that crisis preparedness becomes a continuous organizational capability rather than an episodic training activity.

Authors' Contributions

All authors have contributed significantly to the research process and the development of the manuscript.

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

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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