The Analysis of Human Error Prevention Strategies in Military Aviation

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Abstract. The study applied Human Factors Intervention Matrix (HFIX) framework and Analytic Hierarchy Process (AHP) to analyze human errors intervention strategy. Our questionnaire, designed based on 15 significant accidents of Republic of China Air Force (ROCAF), was distributed to ROCAF related personnel and was completed by eight commanders of flight unit and 14 subordinators consisted of ten pilots and four maintenance staffs. Questionnaire results specified that each approach in HFIX framework possesses its unique characteristics. This study has demonstrated that the HFIX framework can serve as a tool to develop human errors intervention strategies in military aviation, and AHP can be applied to assist decision makers to evaluate these diversified strategies. The study suggests that each flight unit of air force selects appropriate intervention strategies in accordance with its own demands and resource limitations.

Keywords: Accident prevention · Human errors · Human factors intervention matrix · Military aviation

1 Introduction

Keeping flight safety is the utmost goal in aviation domains and thus diversifying tools are being continually developed to satisfy the need [1]. According to Panagopoulos and Bond [2], the Hellenic Air Force (HAF) counted fatal losses of 35 pilots and 60 aircrafts during 2000-2010, which was equivalent to two of HAF's fighter squadrons. Literature reviews reported that human error contributed to 70 % to 80 % of aviation accidents [3].

Whereas the mission capability rate and air dominance were eroded by mishaps, protecting the safety of aircrew members is placed as the top priority in the military aviation. To reduce human errors, structured methods to identify and mitigate the risk through management mechanisms [4] are often implemented in aviation industries. Safety recommendations typically propose tighter procedures and recommend introducing advanced technology to monitor pilots' work in order to reduce the bandwidth for human errors as well as to extinguish the erratic human behaviours [5]. However, due to declining budgets and downsizing of the military units, military aviation might

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not have sufficient resources to simultaneously implement all the necessary intervention strategies to improve safety of flight operations. A rationalization process becomes critical in order to prioritize the importance and likely success of the strategies to make the best cost-benefit usage of the flight unit's available resources [6]. The study applied Human Factors Intervention Matrix (HFIX) framework and Analytic Hierarchy Process (AHP) to analyze human errors intervention strategy in military aviation.

HFIX was proposed by Shappell and Wiegmann [7] to evaluate human errors intervention strategies in aviation (see Fig. 1). HFIX framework pits five unsafe acts against five different safety approaches and five evaluating criteria. Specifically, unsafe acts were described as operators commit errors or violation that includes decision errors, skill-based errors, perceptual errors and violations. These unsafe acts can be mitigated by following five approaches, namely organizational/administrative approach, human/crew approach, technology/engineering approach, task/mission approach, and operational/physical environment approach. Recommendations of safety intervention strategies can be further evaluated by five criteria that consist of feasibility, acceptability, cost, effectiveness and sustainability.

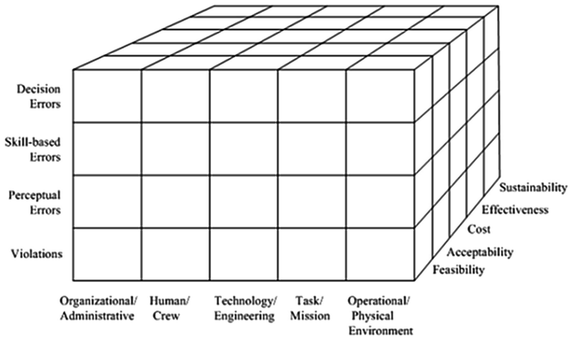

Fig. 1. Human factors intervention matrix (HFIX) framework [7]

Analytic Hierarchy Process (AHP) is a flexible tool that is used in multiple criteria decision-making process. It has been applied extensively in different fields such as planning, selecting a best alternative, resource allocations resolving conflict, and optimization. In AHP analysis, pairwise comparison and nine-point scale are applied to evaluate the relative importance among considering elements. AHP uses geometric mean approach combining individual judgment and obtaining the consensus judgment of the entire team. As suggested by Saaty [8], consistency ratio (CR) of the survey can be regarded as reliability of the responses. When CR is 0.1 or below, it is logically practicable; when the ratio is 0.2 or below, it is acceptable; but when the ratio exceeds 0.2, it can be regarded as deficient in consistency. The basic steps of AHP methodology involved four phases and presented as follows [9]:

1. Structuring: Create an appropriate AHP hierarchy model that contains the goal, criteria, subcriteria and the decision alternatives.

2. Data collection: Organize a team of evaluators to assign pairwise comparisons to the criteria in the AHP hierarchy model.
3. Normalized weights in different hierarchies: Merge the pairwise judgment matrices of each hierarchy level with geometric mean approach to find the corresponding consensus pairwise comparison judgment matrices.
4. Synthesis: synthesize the solutions for the decision problem.

2 Methods

The empirical study adopted AHP methodology to calibrate the numeric scale for the relative importance of five criteria in HFIX framework.

Analytical framework. The study used both y and z axes of HFIX framework, which pits five different human error intervention approaches against five evaluation criteria. The components are described as follows:

1. Y-axes of HFIX- human error intervention approaches

   - *Organizational/administrative* approach focuses on the way of modifying the mechanism of management and supervision to improve flight safety. The approach has four subcategories: rule, regulations and policies, information management and communication, research and special study, and human resource management.
   - *Human/crew* approach focuses on changing or improving the individual worker or work team to enhance situation awareness and job satisfaction. There are five subcategories: selection, training, job assignment, motivation, and crew interaction, are involved the approach.
   - *Technology/engineering* approach focuses on change or improvement in tools, technology, and job aids to remediate human errors. The subcategories of the approach are design/repair and inspection.
   - *Task/mission* approach focuses on ways of rearranging task to reduce operators' both physical and mental workload. It has two subcategories: procedure and manual.
   - *Operational/physical environment* approach focuses on improving both subcategories of technological environment. Examples are workspace layout, design, and physical environment such as heat, lighting, and noise level.

2. Z-axes of HFIX- the evaluation criteria

   - *Feasibility* evaluates whether a strategy is liable to be successful in current situation [10]. The study adopted factors of logistic capacity, resource allocation and timing to evaluate feasibility of human error intervention strategy.
   - *Acceptability* evaluates whether the organization's stakeholders are likely to support the new strategy [10]. The consideration for evaluating acceptability focuses on the influence of combat readiness and risk involved. Culture awareness is also required in order to determine the likely acceptance of the strategy by the organization itself.

- *Cost* examines the tangible and intangible expenses of implementing a strategy. When organization carries out a human error intervention strategy, it may incur both financial cost and opportunity cost; benefits could be emerged, too [11]. The study adapted cost-benefit analysis (CBA) to assess the intervention strategy.
- *Effectiveness* evaluates whether a strategy facilitates to achieve the goal [12]. The goal of implementing human error intervention strategy includes direct goal, e.g. mitigating human errors, and indirect goal such as enhancing job satisfaction and image. The study evaluated the effectiveness of strategy by examining whether the strategy can achieve the goal.
- *Sustainability* evaluates whether a strategy satisfies the needs of stakeholders [13]. The study took into consideration the economic, social and environmental aspects and examined sustainability of a human errors intervention strategy.

Building the Hierarchy. The hierarchy for the research problem was structured in three levels. The first level is the goal to be achieved by the decision; the next level is constituted by the five criteria that were defined in the HFIX framework: feasibility, acceptability, cost, effectiveness, and sustainability; the third level is constituted by the five human error intervention approaches that were individually assessed and were compared based on the five criteria addressed in the previous level. The hierarchy is described diagrammatically in Fig. 2.

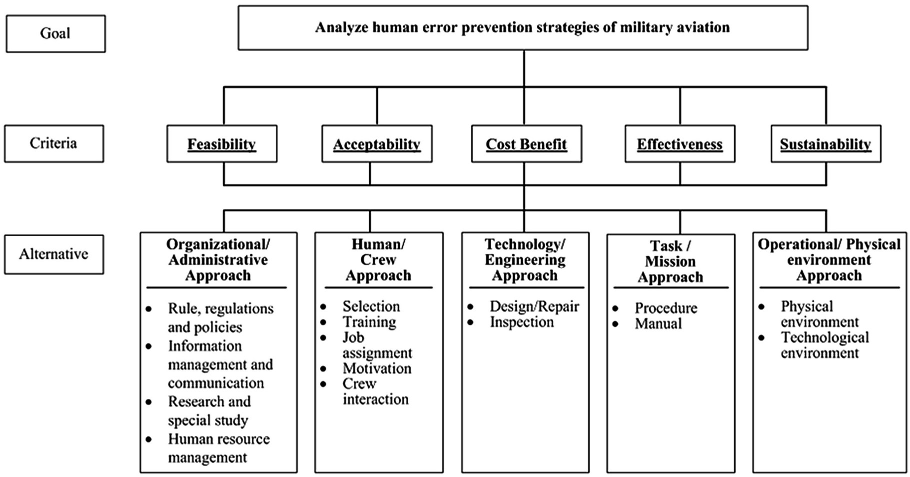

Fig. 2. The hierarchy model for analyzing human errors prevention strategy of military aviation

Questionnaire Design. This study applied above mentioned hierarchy model and several significant accidents of Republic of China Air Force (ROCAF) to develop a questionnaire that contains fifteen scenarios. It was used to assess the weight of the intervention approaches based on the five evaluation criteria in HFIX framework.

3 Results

The questionnaire was distributed to ROCAF related personnel. A total of 25 questionnaires was completed and returned. Export Choice software was used to test the respondents' consistency ratio (CR). Three responses were eliminated because their CR were higher than 0.1. The remaining respondents consist of eight commanders of flight unit and 14 subordinates, which include ten pilots and four maintenance staffs.

The analyzed results are summarized in Tables 1 and 2.

Table 1. Weight and order of human error intervention approaches

Intervention approach	Weight (order)	
	command	subordinate
Organizational/administrative	0.214 (2)	0.199 (4)
Human/crew	0.206 (3)	0.201 (2)
Technology/engineering	0.199 (4)	0.197 (5)
Task/mission	0.215 (1)	0.203 (1)
Operational/Physical environment	0.166 (5)	0.200 (3)

For the top three weight approaches, the commanders' sequence was task/mission (0.215), organizational/administrative (0.214) and human/crew (0.206); and the subordinates' consideration was task/mission (0.203), human/crew (0.201), and operational/physical environment (0.2). Furthermore, both the weights of task/mission and human/crew approach were higher than 0.2, which means both commanders and their subordinates perceived the two approaches as more important than other three approaches. While the human/crew approach focuses on improving human resource management practice such as selection, training, job assignment, motivation, and crew interaction, The task/mission approach mitigates frequency and impact of human errors via adjusting first-line operators' task arrangement such as work shift, stress, and loading [14]. On the other hand, for organizational/administrative approach and physical/operational environment approach, commanders' and subordinates' judgments were contradicted to each other. Commanders placed higher priority on organizational/administrative approach, which concentrates on changing the management process such as planning, organizing, staffing, leading, and controlling to improve safety. The subordinators preferred operational/physical environment approach, which focuses on getting a better working environment. . While the front-line operators consider the utmost importance of improving their workspace conditions in order to remedy human errors efficiently, it is not easy to get consensus and support from their commanders that take into consideration of available policies and cost-benefit balances seriously (see Table 2).

The characteristics of the five human factors intervention approaches were shown in Table 2 and were summarized as follows:

Organizational/Administrative Approach. The approach has four subcategories and several workable strategies. Example strategies are changing supervisors involvement

Table 2. Weights of human error intervention approaches in evaluation criteria

Intervention approach of HFIX		Evaluation criteria				
		F	A	CB	E	S
O.A.	•Rule, regulations & policies	0.290	0.226	0.193	0.152	0.139
	•Information management & communication	0.296	0.208	0.199	0.158	0.140
	•Research & special study	0.302	0.236	0.135	0.163	0.165
	•Human resource management	0.263	0.213	0.220	0.168	0.136
	Geometric mean	0.287	0.220	0.184	0.160	0.144
	Order	1	2	3	4	5
H.C.	•Selection	0.238	0.239	0.191	0.159	0.174
	•Training	0.266	0.235	0.143	0.156	0.200
	•Job assignment	0.257	0.265	0.144	0.156	0.178
	•Motivation	0.247	0.178	0.267	0.149	0.159
	•Crew interaction	0.271	0.223	0.178	0.159	0.169
	Geometric mean	0.255	0.226	0.180	0.156	0.175
	Order	1	2	3	5	4
T.E.	•Design/Repair	0.202	0.191	0.097	0.263	0.247
	•Inspection	0.244	0.168	0.067	0.264	0.257
	Geometric mean	0.222	0.179	0.080	0.263	0.252
	Order	3	4	5	1	2
T.M.	•Procedure	0.267	0.212	0.080	0.253	0.189
	•Manual	0.228	0.124	0.197	0.223	0.228
	Geometric mean	0.246	0.162	0.126	0.238	0.207
	Order	1	4	5	2	3
O.P.E	•Physical environment	0.263	0.271	0.081	0.216	0.169
	•Technological environment	0.272	0.248	0.091	0.221	0.168
	Geometric mean	0.169	0.218	0.086	0.267	0.259
	Order	4	3	5	1	2

Note: O.A. = Organizational/Administrative; H.C. = Human/Crew; T.E. = Technology/Engineering; T.M. = Task/Mission; O.P.E. = Operational/Physical Environment; F=Feasibility; A=Acceptability; CB=Cost Benefit; E=Effectiveness; S=Sustainability;

and oversight/monitor; paying concentration on establishing, issuing, modifying and revising the navigation route map; standard operation process (SOP) and regulations; and applying policies of human resource management such as selection, incentive, and promotion to build upon safety culture of organization [14]. Since these strategies not only can be implemented quickly but also require lower cost, the approach received higher weight in feasibility (0.287). It also got higher weight in acceptability (0.22), which indicates it apt to get supports from superior officers. Its low weight in sustainability (0.144) means when considering influence of interfering conditions or the changing of administrative personnel may hinder the continuity of the approach.

Human/Crew Approach. There are five subcategories in this approach. The implementable recommendations include holding training courses with qualified trainers periodically, enhancing front-line operators situation awareness and professional skill with scenario-based training, building objective and workable apprising system, and rewards for safe behavior [14]. Since the approach benefits teamwork and creates harmonious collaborations, it received higher weight in criteria of feasibility (0.255) and acceptability (0.226). In contrast, the weight of cost-benefit (0.156) is lower because human resource management may incur higher cost.

Technology/Engineering Approach. Several implementable strategies [14] were deducted from two subcategories. Examples of the approach include improving warning or alarms to increase operators' awareness of abnormal conditions, developing new system to enter into "failsafe" mode when problems occur, scheduling survey new technologies or products in market, and proving adequate spare parts or redundancy and SOP to prevent breakdown or interference during operation. This approach got higher weight in effectiveness (0.263) and sustainability (0.252). The result means that improving performance and stability of equipment can significantly enhance flight safety.

Task/Mission Approach. Implementable strategies of this approach [14] may include using checklist or automatic facilities to reduce requirement for human memory, performing double-check with team member to avoid errors occurring in important steps, developing reward system to reinforce the behaviors of compliance with safe work practices, redesigning procedure and checklist to be clearer or more user-friendly, and rewriting procedure to delete ambiguous or inapplicable safety criteria. Since the approach can be used to discipline pilots during their operation, and to modify task to reduce aircrew's work-load as well as chances of human error, it got higher weight in criteria of feasibility (0.246), effectiveness (0.238), and sustainability (0.207), but lower weight in cost-benefit criterion.

Operational/Physical Environment Approach. The approach focuses on improving both operational environment and physical environment. Since the approach facilitates safety and comfort of workplace and reduces workers' pressure, it got higher weight in effectiveness (0.267) and sustainability (0.259). The values of feasibility (0.169) and cost-benefit (0.086) are lower, which indicate the approach costs highly.

4 Conclusions

This research provides an empirical study of applying Human Factors Intervention matrix (HFIX) to identify intervention strategies and evaluations in military aviation. The study revealed each approach's unique characteristics. For example, although technology/engineering approach catches and mitigates human errors via advanced equipment and technology and has higher weight in terms of its effectiveness and its sustainability, it incurs higher cost. Our findings provide the strengths and drawbacks for the five approaches, and AHP can assist decision makers to evaluate and determine which strategy or which combination of the diversified strategies will best fit for their military units in order to mitigate human errors in military aviation.

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