

A Comparative Evaluation of Human Factors Intervention Approaches in Aviation Safety Management

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Abstract. In the Human Factors Intervention Matrix (HFIX) framework, human factors interventions are categorized into five different approaches and each of these approaches can be evaluated by five different evaluation criteria of *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability*. Although the outcome of evaluations can assist safety management practitioners in the selection of more viable safety recommendations, there exists a research gap on how the five different approaches differ with each other. In this study, overall comparisons of the five approaches in HFIX were carried out using the five evaluation criteria. Each intervention approach was also compared independently with other approaches in a pairwise manner to highlight comparative strengths. It was discovered that amongst the five evaluation criteria, only *feasibility*, *cost*, and *effectiveness* differed across the five approaches. Task- and human-based interventions were more *feasible*, whereas task- and organization-based interventions were rated more highly on *cost*, reflective of better cost-efficiency. Subjective differences in evaluation were also identified in *effectiveness*, showcasing that cognitive biases can exist within evaluative frameworks. The findings will benefit safety practitioners and managers in the selection and application of human factors intervention strategies, especially in resource constrained situations in the real world.

Keywords: Human Factors Intervention, Evaluation, Safety Management

1 Introduction

Although human error is partly attributable to between 60-80% of aviation accidents, it is widely considered inappropriate to simply attribute causes of aircraft accidents to aircrew error [1]. The Human Factors Analysis and Classification System (HFACS) is a popular framework for the categorization of human factors errors in the wider organizational perspective [2]. HFACS addresses human factors over four levels, with unsafe acts and active failures of frontline operators at Level 1, active and latent preconditions at Level 2, latent failures created by unsafe supervision at Level 3, and latent failures originating from organizational-level influences at Level 4. Mishaps and accidents attributable to human errors at Level 1 are considered to occur when the higher levels fail to provide suitable conditions to promote and enable safe practices. As active failures can be generated from latent failures across the organizational levels, the corresponding human factors interventions and safety recommendations to rectify these failures will be equally spread out. Consequently, safety managers are required to identify and

prioritize human factors interventions which can be implemented through a variety of approaches at different parts of the system [3].

1.1 Different Approaches to Human Factors Intervention

To assist in the development of efficient intervention strategies for the reduction of human error, Wiegmann & Shappell (2007) proposed the Human Factors Intervention Matrix (HFIX) framework. Unsafe acts of frontline operators, including decision errors, skill-based errors, perceptual errors, and violations, are pitted against five different intervention approaches (see Table 1). The organizational/administrative approach covers areas such as reviewing human resource management and reviewing rules and regulations; the task/mission approach includes amendments to procedures and manuals; the technology/engineering approach includes the design, repair, and inspection of parts and equipment; the operational/physical environment approach focuses on modifications to the operational or ambient environment (e.g. weather, heat, lighting, etc.); and the human/crew approach involves the review, development, and implementation of personnel training programs [5].

Table 1. Examples of HFIX categories of intervention approaches [5]

Human Factors Intervention Approaches	Examples
Organisational/ Administrative	<ul style="list-style-type: none"> Human resource management evaluations Reviewing and issuing rules, regulations, and policies Improving information management and communication Conduct research and study on safety culture improvements
Task/ Mission	<ul style="list-style-type: none"> Amending, reviewing, and modifying procedures and manuals
Technology/ Engineering	<ul style="list-style-type: none"> Design, repair, or inspect parts and equipment
Operational/ Physical Environment	<ul style="list-style-type: none"> Modifications to the operational or ambient environment (e.g. weather, altitude, terrain, heat, vibration, lighting)
Human/ Crew	<ul style="list-style-type: none"> Reviewing, developing, and implementing training programs

By setting active failures against the different intervention approaches, the HFIX is beneficial for safety practitioners by ensuring that a wide array of prospective interventions extending through the multiple HFACS levels are considered. Realistically, however, resource limitations (e.g. financial, time, etc.) within each organization can limit the viability of prospective interventions. This necessitates the evaluation of prospective intervention approaches on criteria such as *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability* (see Table 2) [6]. These evaluations are beneficial in assisting safety managers to select interventions based on likelihood of success, and to minimize

the risk of workforce disengagement by implementing intervention approaches that are perceived negatively.

Table 2. HFIX categories of intervention approaches pitted against five evaluation criteria.

Evaluation criteria	Intervention approaches				
	Organisational/ Administrative	Task/ Mission	Technology/ Engineering	Operational/ Physical Environment	Human/ Crew
Feasibility					
Acceptability					
Cost					
Effectiveness					
Sustainability					

1.2 Workforce Preferences and Recommended Interventions

Previous studies have discovered that aviation professionals had overwhelmingly greater preferences towards organizational (62.4%) and human (26.7%) approaches to human factors interventions [3]. These preferences were similar to safety recommendations proposed by previous accident and incident investigation reports. The U.S. FAA Safer Skies initiative, for example, categorized 614 safety recommendations and found organizational (36.6%) and human (32.6%) approaches to be the first and second-most common [6]. Similarly, in a categorization of 182 safety recommendations drawn from commercial airline incident narratives, organizational (41.1%) and human (35.2%) interventions were the most common [7].

Although the coordination between aviation professionals' selective preferences and the recommendations proposed in accident and incident investigations places great emphasis on organizational and human interventions, there is little information on what actually makes these intervention approaches more viable. Chen, Lin & Li [8] used the Analytical Hierarchy Process (AHP) to assess the five intervention approaches using the five evaluation criteria in HFIX, and compared the evaluation results from commercial airline pilots, airline managers, and aviation accident investigation authority officers. Whilst they concluded that each intervention approach possessed unique characteristics in relation to the various evaluation criteria, their study looked at each intervention independently (i.e. on a column-by-column basis in Table 2). It therefore lacks the ability to provide comparisons of evaluative ratings across the five approaches. To illustrate, whilst Chen and colleagues found that the organizational approach had a higher score on *acceptability* than it did on *feasibility*, *cost*, *effectiveness*, or *sustainability*, their research does not enable the comparison of these criteria with the other intervention approaches – what made organizational interventions more acceptable than the other approaches?

In addition, the similarity between the preferences of aviation professionals and the recommendations suggested by previous investigations may be instigated by “mitigation myopia”. Rather than objectively evaluating interventions for the likelihood of success, a possibility is that investigators simply made recommendations for interventions based on their own preferences [4]. Unless the criterion/criteria which made these intervention approaches more desirable can be determined, the “mitigation myopia” effect cannot be ruled out.

The present study consisted of two research objectives. The first objective was to determine whether the five intervention approaches differed significantly on their scores based on the respective evaluation criteria of *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability*. The second objective adds to the first by determining whether certain intervention approaches were particularly strong or weak on any of the five evaluation criteria. Building on the previous findings on workforce preferences and recommendations by accident investigation reports, this paper attempts to answer the following questions: do certain intervention approaches have better or worse *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability*?; and if so, what were the comparative strengths and weaknesses of each intervention approach? It was envisioned that the findings will help safety managers in selecting and creating different types of human factors interventions.

2 Method

2.1 Participants

Aviation professionals involved in safety management within an airline were recruited through their participation in a wider program on air safety investigations. A total of N=14 responses were included in the present analysis. Specific roles include safety managers (n = 7), engineers (n = 3), ground safety officer (n = 1), safety executive (n = 1), airline manager (n = 1), and airline executive (n = 1). Participation was voluntary, with no identifying information collected, and participants had the option to discontinue the survey at any time. The Cranfield University Research Ethics System provided ethics approval (CURES/12950/2021).

2.2 Research Design

Safety recommendations proposed in the official accident report of the TransAsia Airways GE235 crash into Keelung River, Taiwan, on 4th Feb 2015 [9] were utilized as the basis for evaluation. These recommendations were categorized by two subject matter experts into the five HFIX intervention approaches. They were then imported onto a web-based survey hosted on Microsoft Forms for data collection. The participants were asked to rate the safety recommendations on the HFIX evaluation criteria of *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability* on a five-point Likert scale from poor (1) to excellent (5).

2.3 Statistical Analysis

Data collection took place in December 2021 and was analyzed using SPSS (version 28). One-way repeated measures ANOVAs were conducted to examine the effect that the type of intervention approach had on evaluation scores across five criteria. The intervention approaches (organization, task, technology, operational environment, and human) were entered as the test attributes, and the evaluation rating scores (*feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability*) were the dependencies. Mauchly's sphericity tests were used to evaluate the assumption of sphericity for ANOVA testing, and where this had been violated, the Greenhouse-Geisser correction was applied.

For evaluation criteria where the ANOVA results were significant ($p < 0.05$), suggesting that the intervention approaches differed in *feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability* ratings, post-hoc analyses were performed on pairwise groups to find out if any of the intervention approaches (organization, task, technology, operational environment, and human) were particularly strong or weak on the evaluation criteria when compared with the other available approaches.

3 Results and Discussion

3.1 Evaluative Differences Amongst Intervention Approaches

The mean rating scores for each intervention approach and the ANOVA results are presented in Table 3. The ANOVA results showed that amongst the five evaluation criteria, only *feasibility*, *cost*, and *effectiveness* scores differed significantly across the intervention approaches. For scoring on *feasibility* ($F_{4, 48} = 6.01$, $p < .001$), human approaches were considered to be the most feasible, followed respectively by task, organization, operational environment, and lastly technological interventions. For the *cost* criterion ($F_{4, 40} = 6.82$, $p < .001$), task-based interventions had the highest score (representing a high level of perceived cost-efficiency), followed by organization, human, operational environment, and lastly technology interventions. The respondent scores also differed significantly on the *effectiveness* criterion ($F_{2.09, 22.98} = 4.16$, $p < .05$). In this case, task-based interventions had the highest mean score, followed by human, technology, organization, and operational environment interventions. These findings will benefit safety managers in their selection of human factors interventions. When the organization or the safety management system is limited by resource constraints, and hence a choice has to be made as to which of the five approaches should be implemented, the present results encourage managers to place greater emphasis on comparing the factors of *feasibility*, *cost*, and *effectiveness*. These are the evaluative metrics which were found to be most significant in differentiating between the five intervention approaches.

Table 3. Evaluation scores and ANOVA results for safety interventions related to the five HFIX intervention approaches.

Evaluation criteria	Intervention approaches					ANOVA Results
	Organizational/ Administrative	Task/ Mission	Technology/ Engineering	Operational/ Physical Environment	Human/ Crew	
Feasibility	M = 3.15, SD = 1.07	M = 3.57, SD = 1.09	M = 2.64, SD = 1.08	M = 3.07, SD = 0.92	M = 3.79, SD = 1.05	$F_{4,48} = 6.01$, $p < .001$
Acceptability	M = 3.00, SD = 0.60	M = 3.85, SD = 0.80	M = 3.42, SD = 0.79	M = 3.25, SD = 0.75	M = 3.50, SD = 1.00	n.s.
Cost	M = 3.64, SD = 0.67	M = 3.92, SD = 0.79	M = 2.42, SD = 0.90	M = 2.58, SD = 1.08	M = 3.17, SD = 0.94	$F_{4,40} = 6.82$, $p < .001$
Effectiveness	M = 3.17, SD = 1.27	M = 4.08, SD = 0.51	M = 3.33, SD = 0.78	M = 3.00, SD = 1.13	M = 4.08, SD = 0.49	n.s.
Sustainability	M = 3.10, SD = 1.20	M = 3.92, SD = 0.79	M = 3.69, SD = 0.75	M = 3.36, SD = 1.03	M = 3.92, SD = 0.67	$F_{2,09,22.98} = 4.16$, $p < .05$

The finding of non-significant differences in the *acceptability* and *sustainability* criteria was also interesting. Firstly, it suggests that the use of simple point-scores as the evaluative basis for different human factors intervention approaches may be insufficient. Point-scores may only portray insignificant deviations from the mean, denoting that apparent comparative differences between the organization, task, technology, operational environment, and human approaches may not be statistically significant. Secondly, it also suggests that the application of HFIX framework can possibly be simplified. For example, safety managers can attempt to assure early on whether the criteria of *acceptability* and *sustainability* are applicable for the target audience within their organizations. If they are confirmed to be inapplicable, then a possibility is that these evaluative criteria can be discounted for expediency.

3.2 Task, Human, and Organization Interventions More Feasible and Cost-Efficient

For the evaluation criteria which significantly differed across the five intervention approaches, pairwise comparisons were carried out between intervention approach categories to identify comparative differences.

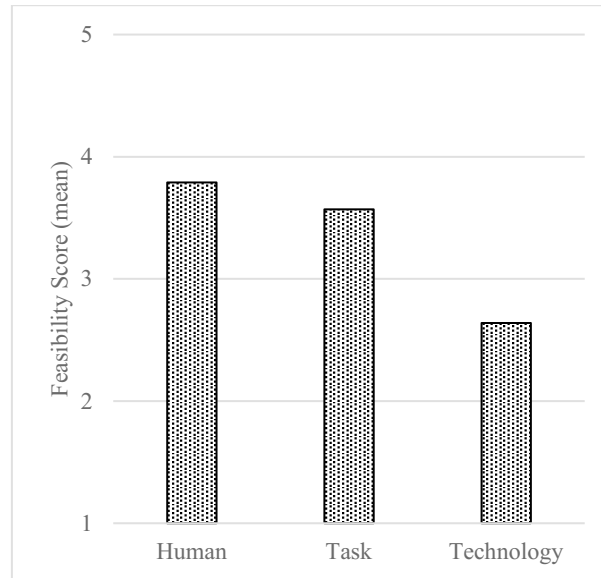


Fig. 1. Scores for human-, task-, and technology-based intervention approaches on the evaluation criteria of *feasibility*. Significant pairwise differences were found between these four approaches.

For the *feasibility* criterion, the task – technology (MD = 1.15, $p < .05$) and human – technology (MD = 1.39, $p < .05$) pairs had statistically significant differences. Task-based and human-based intervention approaches were rated as more feasible by the respondents than technology-based interventions (see Table 3, Figure 1). Interventions related to task and human changes, such as modifications to the standard operating procedures and enhanced training programs for personnel were more desirable than changes to the technological hardware. This finding complements the argument, from previous literature, that the benefits of functional changes will be ringfenced unless other supportive resources are provided [10]. To illustrate, technology-based interventions may have limited impact unless they are supported by corresponding procedural adaptations and operator training programs. On the other hand, for the *cost* criterion (high scores representing cost-efficiency), significant pairwise differences were found between the organization – technology (MD = 1.09, $p < .05$), task – technology, (MD = 1.27, $p < .01$), and task – operational environment (MD = 1.27, $p < .05$) pairs. Human factors interventions involving organization and task changes were rated higher than modifications to the technology and operational environment (see Table 3, Figure 2).

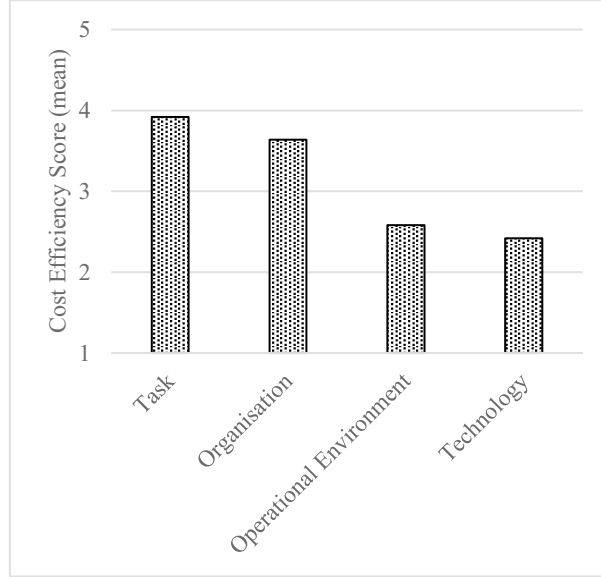


Fig. 2. Scores for task-, organization, operational environment, and technology-based intervention approaches on the evaluation criteria of *cost*. Significant pairwise differences were found between these four approaches.

Although it is understandable that technology and operational environment changes are likely to be costlier than changes to organizational processes and operating procedures, the present findings are nonetheless relevant for safety management when resources are limited. When cost is a limitation, then the perceived cost-efficiency is important. In this case task-based intervention approaches will be preferable as it scores highly on both *feasibility* and *cost* criteria. Contrarily, if cost was less of a concern, then the prioritization of *feasibility* through the implementation of *human*-based interventions may be more viable.

3.3 Assessed Effectiveness Subject to Mitigation Myopia

Similarly, as the *effectiveness* rating was found to differ significantly across the five intervention approaches, pairwise comparisons were conducted to determine which specific pairs amongst the five approaches were comparatively different. However, none of the pairwise comparisons amongst the five approaches returned significant results. This highlights the trap of “mitigation myopia”, where recommendations for human factors interventions are made based on accident investigators’ own subjective preferences, rather than on objective evaluations of the likelihood of success [4]. In the case of the present results, differences in *effectiveness* cannot be objectively substantiated. We can tell that that *effectiveness* varied across the five approaches, but the results do not provide objective information on how the respective approaches compared with each other on the *effectiveness* rating.

HFIX has conventionally been touted as a tool to minimize the effect of cognitive biases by providing safety managers and investigators with a taxonomic framework of viable intervention options and objective evaluation criteria [6]. However, the current finding suggests that although the framework does successfully encourage the consideration of a wider array of viable recommendations, the application of the framework for evaluative purposes remains subject to cognitive biases. Therefore, there is an urgent need for further research on the practical application of the HFIX, especially in the determination of which specific approaches are most relevant to the intended purpose, and how the evaluation of these approaches may be affected by interpersonal differences. Safety practitioners should also be mindful that despite their use of tools like HFIX which are touted as a tool for objectivity, subjective differences in evaluation can still affect the analysis and recommendation of human factors interventions.

4 Conclusion

The Human Factors Intervention Matrix (HFIX) is a framework which assists safety practitioners to come up human factors interventions and safety recommendations. It ensures that a wide array of prospective intervention approaches across five categories are considered, and also provides five evaluation criteria on which the various approaches can be rated. However, whilst the evaluated scores of the respective intervention approaches have been assessed in previous research, there is little information on how the intervention approaches compare with each other on these ratings, and which of the evaluation criteria are more relevant in the detection of differences between the various intervention approaches. In this study, airline safety managers' ratings of five intervention approaches (organization, task, technology, operational environment, and human) based on five evaluation criteria (*feasibility*, *acceptability*, *cost*, *effectiveness*, and *sustainability*) were assessed for differences. Overall, it was discovered that only the evaluation criteria of *feasibility*, *cost*, and *effectiveness* differed significantly across the intervention approaches. Safety recommendations and interventions related to task and human changes, such as revisions to standard operating procedures and associated training programs for personnel, scored higher on *feasibility* than technological modifications. Similarly, organization and task changes, such as changes to supervisory oversight and operational processes and regulations, were assessed as more *cost-efficient* than changes to the technology and operational environment. These findings are beneficial for safety practitioners in selecting interventions in the real world. For example, when cost is a limiting factor, then according to the present results task-based interventions are preferable as it is concurrently more *cost-efficient* and more *feasible* than the other approaches. Although the HFIX encompasses a range of viable intervention approaches and provides the criteria on which these approaches can be evaluated, the finding of overall variances in *effectiveness* with no associated significant pairwise differences between intervention approaches suggests that the rating scores based on the HFIX evaluation criteria may nevertheless be subject to cognitive biases. Whilst this presents an opportunity for further research, in the meantime safety practitioners

should be aware of these issues to ensure appropriate and objective application of the framework.

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