Application of a hybrid model for mitigating skill-based errors in military flight operations

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Abstract. Flight safety should not be compromised. Thus, administrative units of military aviation should constantly develop safety management strategies to mitigate the diverse hazardous factors in flight operations. Given the constraint of organizational resource, a flight unit may not have sufficient resources to implement all the necessary strategies simultaneously. The study uses a well-structured process to develop a qualitative evaluation model that will enable air force officers to identify human errors and select an intervention strategy with the highest success potential. To clarify the decision problem, the Human Factors Intervention Matrix framework is utilized to construct the decision hierarchy. The Analytic Hierarchy Process is then used to attain the priorities of potential alternative approaches for various unsafe acts. Finally, Zero-One Goal Programming models are formulated to select an optimal solution based on the specific target and the available organizational resources. An empirical study is presented to illustrate the application of the proposed model. According to the results, the approach of human/crew can be adopted as intervention strategy for mitigating skill-based errors in flight operations.

Keywords: skill-based error; military aviation; Human Factor Intervention Matrix; Analytic Hierarchy Process; Zero-One Goal Programming

1. Introduction

Maintaining flight safety is highly prioritized within the aviation domains. Thus, tools are continuously being developed and diversified to satisfy this priority. According to investigation of NATO, merely during 2000-2010, the Hellenic Air Force (HAF) suffered a fatal loss of 35 pilots and 60 aircrafts, which is equivalent to two of its fighter squadrons (Panagopoulos and Bond, 2011). Literature reviews reported that human error contributed to 70% to 80% of aviation accidents (Federal aviation administration, 2011). Furthermore, Li and Harris (2006) analyzed 523 accidents in the Republic of China Air Force (ROCAF) and found that over 43% of accidents can be directly attributed to skill-based errors including breakdowns in visual scan, failure in prioritizing attention, inadvertent usage of flight controls, omitted steps in procedures, omitted checklist items, poor techniques, and over-controlled aircrafts.

While the mission capability rate and air dominance were eroded by mishaps, protecting the safety of aircrew members is placed as the top priority in flight operations. To reduce human errors, structured methods through management mechanisms are often implemented in military aviation in order to identify and mitigate the risk. However, due to declining budgets and downsizing, the air force may not have a sufficient amount of resources to implement the necessary intervention strategies while simultaneously improving safety-of-flight operations. A rationalization process becomes crucial to select potentially successful strategies and achieve the optimal cost benefit of the available resources of the flight units. The present study proposes a structuring model that integrates Human Factors Intervention matrix (HFIX), Analytic Hierarchy Process (AHP), and Zero-One Goal Programming (ZOGP) to attain the optimal solution for mitigating skill-based errors in military aviation.

1.1 Human Factor Intervention Matrix (HFIX)

HFIX was proposed by Shappell and Wiegmann (2009) to evaluate human errors intervention strategies in aviation. The HFIX is a three-dimensional framework that pits four unsafe acts against five intervention approaches and five evaluation criteria. The unsafe acts were described as operators who commit errors, including decision errors, skill-based errors, perceptual errors, and violations; the five approaches, namely, human-centered, technology-centered, environment-centered, task-centered, and organization-centered approaches, can be applied to develop human error remedies; the five criteria were utilized to evaluate the feasibility, acceptability, cost, effectiveness, and sustainability of human factor intervention strategies (Shappell and Wiegmann, 2009). The HFIX framework is described diagrammatically in Figure 1.

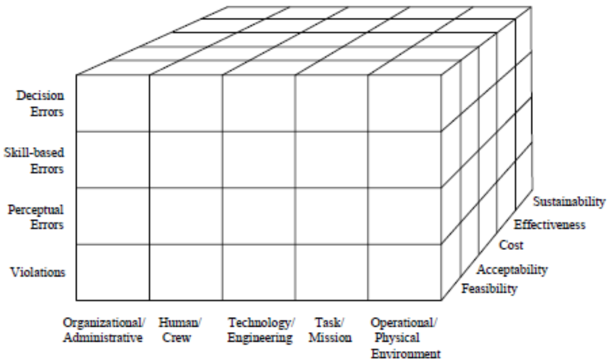

Figure 1. Human Factor Intervention Matrix (HFIX)

1.2 Analytic Hierarchy Process (AHP)

AHP is a flexible tool that can be used in multi-criteria decision making (MCDM) process. A systematic decision approach developed by Saaty in 1971, AHP has been extensively applied in the aviation industry for planning, selecting a best alternative, resource allocation, resolving conflict, and optimization. The wide applicability of AHP is attributed to its simplicity, ease of use, and flexibility. Additionally, AHP can be integrated with other techniques, such as goal programming (GP), to consider both qualitative and quantitative factors and real-world resource limitations (Ho, 2008).

In AHP analysis, pairwise comparisons and a nine-point scale are applied to evaluate the relative importance among considering elements, along with a geometric mean approach in order to combine individual judgement and obtain the consensus judgement of the entire team. As suggested by Saaty (2008), consistency ratio (CR) of the survey can be regarded as reliability of the responses. When CR is 0.1 or below, it is practicable logically, and when the ratio is 0.2 or below, it is acceptable. However, when the ratio exceeds 0.2, it can be regarded as deficient in consistency.

The basic steps of AHP methodology involve four phases, which are shown as followed (Saaty, 2008):

a) Structuring: Create an appropriate AHP hierarchy model, which contains the goal, criteria, sub-criteria, and the decision alternatives.
b) Data collection: Organize a team of evaluators to assign pairwise comparisons to the criteria in the AHP hierarchy model.
c) Normalized weights in different hierarchies: Merge the pairwise judgement matrices of each hierarchy level with the geometric mean approach to find the corresponding consensus pairwise comparison judgement matrices.
d) Synthesis: synthesize the solutions for the decision problem.

1.3 Zero-One Goal Programming (ZOGP)

To make preferable decisions, the aviation domain prevalently applies operations research (OR) on aviation safety, aviation security, airline fleet planning, airline staffing, airline maintenance planning, aircraft loading, and decision support tools for the management of airport operations (Barnhart et al., 2003). Along with the context, goal programming (GP), which is a prominent branch of OR, is employed to facilitate decision-making in the strategy selection for human-error intervention. GP, which was initiated by Charnes and Cooper in 1961 (Chang and Lee, 2010), is one of the models developed to deal with problems in the MCDM process (Sen and Nandi, 2012).

The purpose of GP does not establish the question of maximizing multiple objectives, but rather, it pursues the specific goal values of these objectives. The study adopted a weighted zero-one goal programming (ZOGP) as a decision-making tool, as it can process MCDM and attain the objectives of an organization. The information obtained from the AHP is used to formulate a ZOGP model as a weight. However, the weights are not preemptive and are a reflection of the decision-makers' preferences regarding the relative importance of each targeting goal.

The ZOGP model for human error intervention strategy selection can be described as follows:

$$\text{Minimize } Z = \sum_{i=1}^{l} \left(w_i^g d_i^+ , w_i^g d_i^- \right) \quad (1)$$

Subject to

$$\sum_{k=1}^{k} w_{ki}^{AHP} x_k + d_i^- - d_i^+ = b_i \quad for \quad i = 1,2,\cdots,i. \quad (2)$$

$$\sum_{k=1}^{k} x_k = 1 \quad (3)$$

$$\forall x_i \in (0,1); \quad \forall d_i^{+/-} \geq 0$$

Where:

w_i^g: global weight of subcriteria i ;

d_i^+, d_i^-: deviation variable for subcriteria *i* that can be desirable or undesirable;

x_k : binary selection variable of the k^{th} intervention approach (1 = selection, 0 = non-selection);

w_{ki}^{AHP}: relative importance of the k^{th} intervention approach with respect to subcriteria *i* obtained from AHP;

b_i: greatest relative importance of intervention approach with regard to subcriteria *i* obtained from AHP.

Eq. (1) is the objective function that minimizes the undesirable deviation of the variable with regard to the i^{th} subcriteria. Each deviation variable is multiplied by the global weight of its corresponding subcriteria. Eq. (2) represents the subcriteria constraints. Its target value is the greatest relative importance of intervention approach when they are compared with a subcriteria. The selection is represented in Eq. (3). The selection variable is binary in nature and all of the deviation variables must be equal to or greater than zero.

2. Proposed HFIX-AHP-ZOGP Methodology

To remediate skill-based errors in military flight operations, the proposed methodology includes the following steps:

a) Identify the decision problem;
b) Apply HFIX framework to define the criteria, subcriteria and intervention approaches;
c) Apply AHP method to build decision hierarchy and perform pairwise comparison to determine the weight of each considering elements.
d) Adopt the global weights of each subcriteria along with the performance of the intervention approach with regarding subcriteria as inputs to the ZOGP model.
e) Apply ZOGP model to determine the optimal solutions for mitigating skill-based errors in flight operations.

3. Application

The data needed for the study includes identifying and ranking of the criteria, subcriteria, and the intervention approach of HFIX framework. The following sections describe the methods used in data collection.

3.1 Criteria, Subcriteria and Intervention Approach Identification

The proper determination of applicable evaluation criteria is vital, as they significantly influence the outcome of the selection process. To remediate skill-based errors, the HFIX framework proposed five intervention approaches, which advantages and disadvantages are described as followed:

a) The organizational/administrative approach focuses on amending management processes such as planning, organizing, staffing, leading, and controlling, in order to improve safety. Organizational changes can have a comprehensive impact, are relatively quick to implement, and have low budget requirement. However, this approach is easily repelled by employees if it is not reinforced or repeated on a regular basis.
b) The human/crew approach focuses on enhancing human resource management through selection, staffing, training, and promotion. This approach is relatively inexpensive to implement and has a relatively quick impact. However, this impact is limited by the nature of human limitations, abilities, and capabilities along with the subsequent reinforcement of management.
c) The technology/engineering approach elucidates human error intervention strategies by investing in advanced operational facilities, advanced technologies, job aids, and user-friendly man−machine interfaces. Although human errors can be efficiently and accurately remedied by the approach, these measures require an extensive amount of spending and a longer period of time to implement.
d) The task/mission approach focuses on rearranging the procedure and tasks in order to reduce the physical and mental workload of the operators. The strategies of this approach can be implemented with relatively low cost, and the impact can be recognized quickly. However, its effectiveness may be limited by the complexity of the task, work environment, and the compliance of the workers.
e) The operational/physical environment approach focuses on improving the technological environment (e.g. the hardware and software of the equipment used) and the physical environment (e.g. workspace layout/design, heating, lighting, and noise-canceling). The approach is effective in eliminating tangible hazardous factors, but these measures can be very costly and sometimes impractical.

To evaluate the intervention strategies effectively, HFIX framework provides five criteria to aid managers for making decisions.

a) Feasibility: evaluates whether a strategy has the potential to succeed in the current situation.
b) Acceptability: evaluates whether the organization's stakeholders are likely to support the new strategy.
c) Cost: examines the financial costs and opportunity costs when exercising a human error intervention strategy.

d) Effectiveness: evaluates whether a strategy facilitates the achievement of organization's objective.
e) Sustainability: evaluates whether a strategy satisfies the needs of diversified stakeholders.

In order to better evaluate the intervention approach for mitigating skill-based error, the study conducted a literature review to identify the subcriteria. These subcriteria were then discussed with four experts that are active ROCAF officers. After many discussions with the experts, a refined list of subcriteria were obtained.

The experts were then asked to perform pairwise comparisons among the considering the overall significance of the elements based on a scale of 1 to 9 in order to analyze the relative importance of human error intervention approaches in skill-based errors. The study invited four experts from distinct fields to determine realistic difference weights and the priority of the five approaches to see whether or not each intervention approach has unique importance in the targeting object.

The study utilized the Expert Choice software to examine the consistency ratio (CR) and to calculate the performance of five intervention approaches. The local weights of intervention approaches and global weights of subcriteria are summarized in Table 1.

Table 1. AHP weight of intervention approaches and subcriteria for mitigating skill-based error

Evaluation criteria		Intervention approach of HFIX					
		Local weight *					Global weight
Criteria	Subcriteria	OA	HC	TE	TM	OPE	Relative importance
Feasibility	Logistic capacity	0.055	0.373	0.209	0.277	0.086	0.109
	Resource allocation	0.037	0.290	0.393	0.176	0.104	0.075
	Timing	0.039	0.265	0.209	0.397	0.092	0.050
Acceptability	Combat readiness	0.033	0.363	0.253	0.243	0.108	0.086
	Risk involved	0.035	0.367	0.192	0.283	0.124	0.067
	Culture awareness	0.149	0.226	0.201	0.251	0.175	0.048
Cost	Tangible expenses	0.078	0.216	0.207	0.266	0.233	0.133
	Intangible expenses	0.129	0.262	0.187	0.233	0.189	0.067
Effectiveness	Aim to direct goal	0.124	0.347	0.192	0.227	0.110	0.109
	Aim to indirect goal	0.313	0.243	0.242	0.122	0.080	0.091
Sustainability	Economic aspect	0.315	0.214	0.299	0.098	0.073	0.036
	Social aspect	0.318	0.226	0.202	0.047	0.207	0.075
	Environmental aspect	0.349	0.215	0.179	0.067	0.189	0.055

*: O.A.=Organizational/Administrative; H.C.=Human/Crew; T.E.=Technology/ Engineering; T.M.=Task/Mission; O.P.E.=Operational/Physical Environment

3.2. Application of ZOGP to select the intervention strategy

When the priority weights of intervention approaches for mitigating skill-based error have been determined, the AHP weights will be considered as preferences for intervention approaches. Similarly, the AHP weights can be deployed as a constrained condition of GP in the ZOGP model.

The appropriate model was developed using the global weight and local weight in Table 1, and the model shown in Eqs. (1) to (3).

The ZOGP models were shown as followed:

Minimize $Z = 0.109d_1^- + 0.075d_2^- + 0.05d_3^- + 0.086d_4^- + 0.067d_5^- + 0.048d_6^- + 0.133d_7^+ +$

$$0.067d_8^+ + 0.109d_9^- + 0.091d_{10}^- + 0.036d_{11}^- + 0.075d_{12}^- + 0.055d_{13}^-$$

Subject to

$0.055X_1 + 0.373X_2 + 0.209X_3 + 0.277X_4 + 0.086X_5 + d_1^- - d_1^+ = 0.373$ (Logistic capacity)

$0.037X_1 + 0.290X_2 + 0.393X_3 + 0.176X_4 + 0.104X_5 + d_2^- - d_2^+ = 0.393$ (Resource allocation)

$0.039X_1 + 0.265X_2 + 0.209X_3 + 0.397X_4 + 0.092X_5 + d_3^- - d_3^+ = 0.397$ (Timing)

$0.033X_1 + 0.363X_2 + 0.253X_3 + 0.243X_4 + 0.108X_5 + d_4^- - d_4^+ = 0.363$ (Combat readiness)

$0.035X_1 + 0.367X_2 + 0.192X_3 + 0.283X_4 + 0.124X_5 + d_5^- - d_5^+ = 0.367$ (Risk involved)

$0.149X_1 + 0.226X_2 + 0.201X_3 + 0.251X_4 + 0.175X_5 + d_6^- - d_6^+ = 0.251$ (Culture awareness)

$0.078X_1 + 0.216X_2 + 0.207X_3 + 0.266X_4 + 0.233X_5 + d_7^- - d_7^+ = 0.266$ (Tangible expenses)

$0.129X_1 + 0.262X_2 + 0.187X_3 + 0.233X_4 + 0.189X_5 + d_8^- - d_8^+ = 0.262$ (Intangible expenses)

$0.124X_1 + 0.347X_2 + 0.192X_3 + 0.227X_4 + 0.110X_5 + d_9^- - d_9^+ = 0.347$ (Aim to direct goal)

$0.313X_1 + 0.243X_2 + 0.242X_3 + 0.122X_4 + 0.080X_5 + d_{10}^- - d_{10}^+ = 0.313$ (Aim to indirect goal)

$0.315X_1 + 0.214X_2 + 0.299X_3 + 0.098X_4 + 0.073X_5 + d_{11}^- - d_{11}^+ = 0.315$ (Economic aspect)

$0.318X_1 + 0.226X_2 + 0.202X_3 + 0.047X_4 + 0.207X_5 + d_{12}^- - d_{12}^+ = 0.318$ (Social aspect)

$0.349X_1 + 0.215X_2 + 0.179X_3 + 0.067X_4 + 0.189X_5 + d_{13}^- - d_{13}^+ = 0.349$ (Environmental aspects)

$X_1 + X_2 + X_3 + X_4 + X_5 = 1$

$X_j = 0 \quad or \quad 1, \qquad \forall_j = 1, 2, 3, 4, 5$

The ZOGP model was solved using LINGO software. Base on mitigating skill-based error in flight operation of ROCAF, the results showed that the approach of human/crew was optimal solution for developing intervention strategies.

4. Conclusion

As the utmost priority in the aviation domain, safety cannot be compromised. Therefore, military aviation should constantly develop safety management strategies in order to mitigate the various possible hazardous factors of flight operations and create unique competencies and capabilities that ensure dominance in aviation. Given that an organization may not have the required resources to implement all necessary strategies simultaneously, a rationalization process is crucial to evaluate the relative importance of strategies and select strategies that will most likely assist in the achievement organizational goals.

A human error intervention strategy can be shown to dramatically affect flight safety, as no single model is inherently superior to others in making organizational decisions. The selection is dependent upon the organizational goals, capacity, and resources. In order to evaluate intervention strategies, this study introduced a hybrid model that can handle multiple criteria in decision-making problems. The model, which is an integration of the HFIX framework, the AHP method, and the ZOGP method, is able to identify the characteristics of various human errors using a well-structured process. It can also attain the organizational goals of optimizing intervention strategy by utilizing limited resources.

The process of strategy selection in regards to human-error intervention can be extended and applied to any area of the aviation domain, as well as the current version and possible future versions of the aviation domain. For military aviation, this model may become a dynamic decision model that requires access to an annual budget in order to meet the safety requirements of the stakeholders. A well-constructed evaluation process will conform to real-world decisions

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