Risk Assessment and Management of Runways Construction Operation of Military Airports Using FAHP and ORMIT

Huang Li-Jeng¹, Lin Chi-Hsuan²

¹Associate Professor, Department of Civil Engineering, National Kaohsiung University of Applied Science, 80778, Taiwan, Republic of China
²Captain Civil Engineering Officer, Office of General Services, Air Force Institute of Aviation Technology, 82047, Taiwan, Republic of China

Abstract—Construction sites within domestic military and civil airports are important but possess high risk. Any accident due to construction or management inconsistency would cause giant hazards and financial loss. Two recorded disasters occurred in Taiwan include the crash of Singapore Airlines strayed into the construction runway in Taoyuan International Airport as well as the collision of an aircraft of Transasia Airways with an engineering vehicle during landing in Tainan Airport. This study is proposed to apply the Fuzzy Analytical Hierarchical Process (FAHP) to risk assessment of construction and management of military airports. At first 9 major categories and 27 influence factors on risk of construction of run slide of airports are summarized, then the weighting factors are decided by experienced workers, and finally the overall degree of risk can be evaluated and compared with using MATLAB fuzzy logic toolbox. A construction site of an actual airport in Taiwan is taken as the case study in which the northern runway and the southern runway under construction without and with the risk management using ORMIT (Operational Risk Management Integration Tools) are investigated, respectively. The results show that both FAHP and MATLAB Fuzzy Logic Toolbox result in the same risk assessment for both two runways; furthermore, the usage of ORMIT during the construction of the southern runway really reduce the assessed risk as compared with the northern one.

Keywords—Construction Operation, FAHP, Fuzzy Inference, ORMIT, Risk Assessment, Risk Management

I. INTRODUCTION

Runways of airports are very important for take-off and landing of aircrafts and thus the construction quality of runways plays a significant role in the safety of aviation management. In Taiwan there are three types of airports, i.e., civil airports, military airports and civil-military airports. Civil airports are designed for transportation of people and/or cargos and are managed by civil aviation bureau. Military airports are designed for training of pilots of fighters and conveyers and transportation of military cargos.

Civil-military airports are design in specific area wherein the land for aircraft is limited so that the airports are proposed for combined usage and the administration is the most difficult [1, 2].

There were two well-known recorded accidents of aircraft related to the runways of airports in Taiwan:

(1) Singapore Airlines Flight 006 was a scheduled passenger flight from Singapore Changi Airport to Los Angeles International Airport via Chiang Kai-shek International Airport (now Taiwan Taoyuan International Airport) in Taipei, Taiwan. On 31 October 2000, at 23:17 Taipei local time (15:17 UTC), a Boeing 747-412 operating the flight, attempted to take off from the wrong runway at Chiang Kai-shek International Airport during a typhoon. The aircraft crashed into construction equipment on the runway, killing 83 of the 179 occupants aboard [3].

(2) On 21 March 2003, TransAsia Airways flight 543 (Airbus A321 registration B-22603) on a flight from Taipei Songshan Airport to Taian Airport, collided with a truck that was on runway 36R. None of the 175 passengers and crew were killed or injured but the two occupants in the truck were injured and the aircraft was written off [4].

Though the accidents were caused from many serious coupled factors, it can be seen that runways with safety design, construction and management are very important for takeoff and landing of aircrafts. Correct and quick risk assessment of runways construction operation thus plays a significant role in reducing the accidents related to the runways of airports.

In practical engineering safety or risk assessment there usually arise a situation that vague and ambiguous terms appears where traditional crisp logic or Boolean (binary) logic fair to be applied. In order to conduct the risk or safety assessment, decision making or system analysis there exists many approaches can be employed.
Among these methods, fuzzy inference method based on fuzzy set theory, fuzzy logic and fuzzy linguistics is a famous one [5-7]. This approach has been considered as one of important type of expert systems [8]. A lot of leading research works have been conducted by Zadel, L. A. and others [9, 10].

The application of fuzzy sets to civil engineering has been attempted for many researchers [11-13]. Huang et al. (2007, 2010, 2011) applied fuzzy inference method to safety risk assessment of cable-stayed bridges, hospitals, foundation of bridge and structure subjected to explosive loadings [14-17].

In the field of operational research, Saaty, T. L. (1980) had proposed the so-called Analytic Hierarchy Process (AHP) for multiple criteria decision making problems [18]. A lot of researchers employed this technique to commercial and engineering applications [19-21]. Then some researchers tried to combine fuzzy logic with analytic hierarchy process, termed Fuzzy Analytic Hierarchy Process (FAHP), and applied to decision making, safety or risk assessment for commercial and engineering practices [22-34]. In the application to civil engineering, Pan (2006) has attempted to apply FAHP to assessment of construction techniques for deep excavation and soil-retaining in Kaohsiung Area [28]; Huang and Fu (2014) applied two fuzzy inference methods for safety assessment of construction operation of contractors for industrial buildings [34].

This paper is therefore mainly focused in the application of both fuzzy inference methods using FAHP and MATLAB Fuzzy Logic Toolbox for risk assessment of construction operation of runways of military airports. Risk management of one of the two runways will be executed by the use of software ORMIT (Operational Risk Management Integration Tools) while the other is not. Analysis approaches are first built up and then case study is investigated in detail.

II. HIERARCHY MODEL OF RISK FACTORS

![Diagram](image.png)

Figure 1 Typical diagram of hierarchical structure for risk assessment of runways construction operation for military airports using FAHP
The hierarchical structure of risk assessment and the influence factors can be observed in Figure 1 when FAHP is employed. The influence factors related to the construction operation can be completed either by consulting with highly experienced managers and/or conducting questionnaire survey from employees. However, after collecting these data the final influence factors for investigation should be arranged and organized well (e.g. they are exclusive to each other; most of influence factors have been included, etc.). For the runways construction operation problem, these influence factors can be classified into four levels with three major sub-divisions: (A) personnel management, (B) operational conditions, and (C) operational quality; each also contains some sub-factors (e.g. A1.1, A1.2, A1.3 and A1.4, etc.) and sub-sub-factors (e.g. A1.1, A1.2, A1.3 and A1.4, etc.) All influence factors include 3 major risk factors, 9 sub-factors and 27 sub-sub factors are all list in Table I. It is noticed that the analysis items list in table form is very convenient for FAHP analysis.

In practical application all the influence factors can be adapted into those appropriate for the airports under consideration. Some factors maybe included, e.g. the frequency of take-off and landing, maintenance frequency, the materials quality employed for construction. In the preliminary risk assessment analysis of runways construction operation for a typical military airports the factors shown in Figure 1 and Table I are representative and in general enough for conducting the risk assessment.

**Tools for Analysis**

Two different approaches are employed for the study and comparison, i.e. the fuzzy inference method with the aid of MATLAB Fuzzy Logic Toolbox as well as Fuzzy Analytic Hierarchy Process (FAHP).

**A. MATLAB Fuzzy Logic Toolbox**

In this approach we adopt standard scheme of fuzzy inference method. The major tasks in this risk assessment method can be divided into the following steps [35]:

(1) **Fuzzification of the influence factors:**

Totally 27 items are included.

(2) **Selecting of membership functions:**

Trapezoidal functions are employed for input and output variables which can be expressed as

\[
 f(x; a, b, c, d) = \max\{ \min(\frac{x-a}{b-a}, \frac{d-x}{d-c}), 0 \} \tag{1}
\]

in which the parameters \(a\) and \(d\) locate the feet of the trapezoid and \(b\) and \(c\) locate the shoulders.

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**Table I**

Classification of Influence Factors and Weights for Risk Assessment of Runways Construction Operation

<table>
<thead>
<tr>
<th>Sub-factors</th>
<th>Weight</th>
<th>W.R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-SOP</td>
<td>0.306</td>
<td>0.120934</td>
</tr>
<tr>
<td>Machine Operation</td>
<td>0.07</td>
<td>0.01673</td>
</tr>
<tr>
<td>Education Lack</td>
<td>0.126</td>
<td>0.030114</td>
</tr>
<tr>
<td>Human Factors</td>
<td>0.298</td>
<td>0.071222</td>
</tr>
<tr>
<td>Task Movement</td>
<td>0.07</td>
<td>0.02244</td>
</tr>
<tr>
<td>Operation Sequence</td>
<td>0.129</td>
<td>0.04128</td>
</tr>
<tr>
<td>Incorrect Concepts</td>
<td>0.258</td>
<td>0.08256</td>
</tr>
<tr>
<td>Postponed Response</td>
<td>0.543</td>
<td>0.17376</td>
</tr>
<tr>
<td>Ill-defined Tasks</td>
<td>0.136</td>
<td>0.005848</td>
</tr>
<tr>
<td>Safety Equipments</td>
<td>0.281</td>
<td>0.012083</td>
</tr>
<tr>
<td>Operation Line Overlapped</td>
<td>0.583</td>
<td>0.025069</td>
</tr>
<tr>
<td>Ill Negotiation</td>
<td>0.287</td>
<td>0.046255</td>
</tr>
<tr>
<td>Bad planning</td>
<td>0.585</td>
<td>0.094249</td>
</tr>
<tr>
<td>Ill Conditions</td>
<td>0.127</td>
<td>0.020495</td>
</tr>
<tr>
<td>Strong Wind</td>
<td>0.134</td>
<td>0.003752</td>
</tr>
<tr>
<td>Long Raining</td>
<td>0.597</td>
<td>0.016716</td>
</tr>
<tr>
<td>Rapid Temp. Change</td>
<td>0.269</td>
<td>0.007532</td>
</tr>
<tr>
<td>Unclearance</td>
<td>0.695</td>
<td>0.047267</td>
</tr>
<tr>
<td>Unfamiliar Environment</td>
<td>0.305</td>
<td>0.02074</td>
</tr>
<tr>
<td>Machine Breakdown</td>
<td>0.6</td>
<td>0.0642</td>
</tr>
<tr>
<td>Apparatus Allocation</td>
<td>0.274</td>
<td>0.029318</td>
</tr>
<tr>
<td>Lack of Awareness</td>
<td>0.126</td>
<td>0.013482</td>
</tr>
<tr>
<td>Bad Design</td>
<td>0.6</td>
<td>0.0108</td>
</tr>
<tr>
<td>Ill Contents</td>
<td>0.274</td>
<td>0.004932</td>
</tr>
<tr>
<td>Bad Quality</td>
<td>0.126</td>
<td>0.002268</td>
</tr>
<tr>
<td>Crack Control</td>
<td>0.695</td>
<td>0.01112</td>
</tr>
<tr>
<td>Settlement</td>
<td>0.305</td>
<td>0.00488</td>
</tr>
</tbody>
</table>
The number of membership functions for each input and output can be decided by the analyst. In the present preliminary study we choose four levels (Excellent, Good, Fair and Bad) for inputs and three levels (Low, Medium and High) for output with trapezoidal functions.

(3) Building the rule banks:
And/or logic inference rules are built up for each input to output at each level. For example in the first level there are three inputs and single output with four membership functions, we have totally $4^3 = 64$ rules. If the varied characteristic of influence factor is not linear, smooth functions such as Gaussian distribution can also be employed as the membership functions.

(4) Aggregation of implication:
Maximal areas are employed for accumulating each result of implication.

(5) Defuzzification of output of risk assessment:
There are many schemes for defuzzification, e.g. centroid, bisector, mom, lom and som, etc. In this study centroid method is taken into account for obtaining the final crisp value of risk of the construction operation project.

The parameters selected for the usage of MATLAB Fuzzy Logic Toolbox employed in the inference process is summarized as follows [35]:
(1) FIS Type: Mamdani
(2) And Method: Minimal
(3) Or Method: Maximal
(4) Implication: Minimal
(5) Aggregation: Maximal
(6) Defuzzification: Centroid
(7) Rules: 64
(8) MFs: Trapmf (Trapezoidal)
(9) Range of MFs : 0-1

B. FAHP
In this approach we first build up the hierarchical structure of risk evaluation system for all the influence factors and then assign each influence factors appropriate weights based on practical experience in risk management. From the data in the grouped and classified influence factors, we can calculate the assessment results in each level from down to top. And finally we can obtain the overall risk assessment for the construction operation of industrial buildings. This calculation process can be conducted by trained engineers or managers manually and regularly. The basic steps are summarized as follows:

1. Clarifying the final goal;
2. Identifying influence factors and building up the hierarchical structure of FAHP;
3. Setting up appropriate membership functions;
4. Assigning and calculating fuzzy matrices and weights for attributes and targets (positive reciprocal matrix);
5. Calculating the evaluation values for each target;
6. Evaluating the consistency.
7. Assuring the final target.

The risk assessment value can be calculated as

$$ RAV_i = \sum_{j=1}^{C} \alpha_{ij}W_j, \quad i = 1,2,\cdots,T; \quad j = 1,2,\cdots,C \quad (2) $$

Where $C$ denotes the number of criteria (influence factors), $T$ denotes the number of targets; $\alpha_{ij}$ denotes the relative weights for the $j$-th criterion to the $i$-th target; $W_j$ denotes the weight for the $j$-th criterion.

C. ORMIT
ORMIT is an well-developed software with graphical user interface for risk identification, assessment, management and decision-making, etc. Some major features are:
(1) ISO AS9100 specification is satisfied;
(2) Dynamic linkage with MS EXCEL is available;
(3) Many databases are included;
(4) Automatic analysis, flexible modelling, simplified problem.
(5) Easy to use, maintain and extend.

Five frequently used modules along with ORMIT are:
(1) Hazard Identification Module;
(2) Risks Assessment Module;
(3) Risk Management and Control Module;
(4) Decision-Making Module;
(5) Risk Control Implementation Module;
(6) Monitoring and Reporting Module.
(7) Assuring the final target.

In the usage of ORMIT, the degree of risk ($R$) can be calculated by the following formula [36]:

$$ R = P \cdot S \quad (3) $$

Where $P$ denotes the probability decided by the occurrence frequency:
(a) Frequently: $P = 0.81-1$
(b) Probably: $P = 0.61-0.80$
(c) Sometimes: $P = 0.41-0.60$
(d) Seldom: \( P = 0.21 \sim 0.40 \)
(e) Almost not: \( P = 0 \sim 0.20 \)

and \( S \) denotes the severity divided into four levels:
(I) Disaster (Hazard) Level: serial weight sequence 1–7
(II) Serious Level: serial weight sequence 8–14
(III) Medium Level: serial weight sequence 15–21
(IV) Light Level: serial weight sequence 22–27

After evaluating the risk of each construction factor, we then conduct the following tasks:
(a) Propose risk control strategies;
(b) Implement the risk control policies;
(c) Check the risk control results.

III. CASE STUDY AND RESULTS

A. Case Description

A real case of runways construction operation of a military airport located in southern Taiwan is taken for case study. Two cases are considered to be the two targets in the hierarchy process:
(a) N-Runway: the northern runway of the military airport wherein both MATLAB Fuzzy Logic ToolBox and FAHP are employed for risk assessment without using ORMIT for risk management.
(b) S-Runway: the southern runway of the military airport wherein both MATLAB Fuzzy Logic ToolBox and FAHP are employed after risk assessment using ORMIT for risk management.

The key points of interest are the effect of application of ORMIT on the reduction of risk value of runways construction operation.

B. Risk Assessment based on MATLAB Fuzzy Logic Toolbox

The top level framework of risk assessment of construction operation using MATLAB Fuzzy Logic Toolbox is shown in Figure 2. Three inputs are the criteria, i.e., major influence factors, A, B and C, and single output is the final purpose results of risk of construction. Typically four trapezoidal membership functions (Excellent, Good, Fair and Bad) are selected for all the inputs (relating to the risk from low to high) and three membership functions (Low, Medium and High) for output for convenience of inference analysis as shown in Figure 3 and 4.

In this level totally \( 4^3 = 64 \) rules were employed for inference, and the typical surface view for the relationship of risk assessment to two selected influence factors can be observed from a 3D plot as shown in Figure 5.
Figure 5 Typical results of surface viewer

The results of fuzzy risk assessment using MATLAB Fuzzy Logic Toolbox are summarized in Table II and III and shown in Figure 6 to 8. The final risk evaluations for two runways, from the results of MATLAB Fuzzy Logic Toolbox, are

N-Runway (without using ORMIT): 0.562
S-Runway (aft using ORMIT): 0.362

C. Risk Assessment based on FAHP

The results of risk assessment based on FAHP are summarized in Table II to III and shown in Figure 6 to 8. The final risk evaluations for two runways, based on FAHP, are

N-Runway (without using ORMIT): 0.593
S-Runway (aft using ORMIT): 0.324

D. Final Result of Risk Assessment

Based on the assessment results from MATLAB Fuzzy Logic Toolbox (0.362) and FAHP (0.324), the southern runway (S-Runway) is more safe than the northern runway (N-Runway), the results can be observed from Figure 7. The results validate the effect of usage and implementation of ORMIT for risk management and control on the reduction of risk of runway construction operation in practical engineering application.

<table>
<thead>
<tr>
<th>Item</th>
<th>Major Factors</th>
<th>N-Runway MATLAB</th>
<th>N-Runway FAHP</th>
<th>S-Runway MATLAB</th>
<th>S-Runway FAHP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1. Professional Training</td>
<td>0.443</td>
<td>0.37</td>
<td>0.427</td>
<td>0.3068</td>
</tr>
<tr>
<td>2</td>
<td>A2. Worker Attitude</td>
<td>0.826</td>
<td>0.80315</td>
<td>0.5</td>
<td>0.5075</td>
</tr>
<tr>
<td>3</td>
<td>A3. Task Management</td>
<td>0.847</td>
<td>0.6583</td>
<td>0.174</td>
<td>0.1698</td>
</tr>
<tr>
<td>4</td>
<td>A4. Labor Administration</td>
<td>0.627</td>
<td>0.61708</td>
<td>0.174</td>
<td>0.18727</td>
</tr>
<tr>
<td>5</td>
<td>B1. Atmosphere Conditions</td>
<td>0.5</td>
<td>0.533</td>
<td>0.174</td>
<td>0.1866</td>
</tr>
<tr>
<td>6</td>
<td>B2. Environmental Conditions</td>
<td>0.627</td>
<td>0.4525</td>
<td>0.373</td>
<td>0.2695</td>
</tr>
<tr>
<td>7</td>
<td>C1. Machine Management</td>
<td>0.5</td>
<td>0.5526</td>
<td>0.373</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>C2. Quality Control</td>
<td>0.373</td>
<td>0.3096</td>
<td>0.373</td>
<td>0.2</td>
</tr>
<tr>
<td>9</td>
<td>C3. Construction Skill</td>
<td>0.424</td>
<td>0.5865</td>
<td>0.153</td>
<td>0.1695</td>
</tr>
</tbody>
</table>

Table III Final Risk Evaluation from MATLAB and FAHP

<table>
<thead>
<tr>
<th>Factors</th>
<th>MATLAB Fuzzy Logic Toolbox</th>
<th>FAHP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N-Runway</td>
<td>S-Runway</td>
</tr>
<tr>
<td>Overall</td>
<td>0.562</td>
<td>0.362</td>
</tr>
<tr>
<td>A</td>
<td>0.654</td>
<td>0.354</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>0.153</td>
</tr>
<tr>
<td>C</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

IV. CONCLUDING REMARKS

Both fuzzy inference method using MATLAB fuzzy logic toolbox and FAHP are employed for risk assessment of runways construction operation of military airport has been successfully conducted. Overall typical 27 influence factors are included for risk assessment. Four and three trapezoidal membership functions are adopted for input and output in the fuzzy inference. Results show that these two approaches results in similar results and can be employed for comparison study. Case study reveals that the risk of S-Runway with the help of ORMIT for risk management is lower than the N-Runway without using risk management.
Figure 6 Typical diagram of hierarchical structure for risk assessment of runways construction operation for military airports using FAHA

Figure 7 Typical diagram of hierarchical structure for risk assessment of runways construction operation for military airports using FAHA
REFERENCES


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