Risk Assessment of Mountain Accidents Using AHP – Case Study of Four Accidents Occurred in Taiwan

Huang Li-Jeng ¹, Chen Yung-Ting ²

¹Associate Professor, ²Master Students, Department of Civil Engineering, National Kaohsiung University of Applied Science, 80778, Taiwan, Republic of China

Abstract—This paper presents risk assessment of mountain accidents using analytical hierarchy process (AHP). Three layers are involved in the structure of AHP, the goal layer, criteria layer and the sub-criteria layer. In the criteria layer and sub-criteria layer we consider seven major influence factors grouped into three categories: (1) natural factors including climate, geomorphology, animal and/or plants; (2) human factors including internal and external; (3) hybrid factors including acute mountain sickness (AMS) and downhill delay. The relative judgment among each influence factor is built up based upon 9-scale to form the reciprocal judgment matrices for evaluating weighting vectors and maximal eigen-values for each layer. Consistency of the AHP will be checked and assured. Totally four cases of mountain accidents occurred in Taiwan are tested by the use of AHP. The results show that the proposed AHP model and the associated influence factors and criteria can successfully predict the risk of mountain accidents occurrence.

Keywords—Analytical Hierarchy Process (AHP), Case Study, Mountain accidents, Multi-criteria, Risk Assessment.

I. INTRODUCTION

Mountain accidents frequently occur in Taiwan and all the countries with mountains in the world. In recent years the mountaineering has become one of the most important recreation activities in holiday. There are three fundamental types of mountaineers: (1) suburban hills, (2) intermediate mountain hiking routes; and (3) higher than 3000 meters climbing. Mountain-climbers challenging mountains of the second and third types usually bit by exposure to serious environmental, topological, geomorphological, and atmospheric conditions. Many mountain accidents occur also due to lack of experience and equipments [1]. Statistical data collected from National Fire Agency, Ministry of the Interior, R. O. C. show that the number of accidents and sufferers are increasing gradually in recent years as shown in Table I and Figure 1 [2].

![Figure 1 Diagram for number of accidents and sufferers in mountain accidents occurred in Taiwan from 2007 to 2013.](image-url)
Chang et al. (2007) has studied mountaineering sightseeing participation in behavior patterns, e.g. physical and mental release, challenge, social interaction, enjoy of nature, group relationship, skills and achievements, and improvement of knowledge and health, etc. [3].

Cheron and Ritchie (1982)[4] had pointed out 7 kinds of feeling of risk that leading to reduce the participation of entire adventure: (1) financial risk; (2) functional risk; (3) physical risk; (4) psychological risk; (5) social risk; (6) time risk; and (7) satisfaction risk. However the third risk usually cause and lead to long-term injury or death. Wen and Lin (2012) [5] attempted to study the relationship between mountaineering participation motivation and risk perception.

On the study of risk in mountaineering, Ewert (1994) investigated the motivation and risk taking in a high-altitude wilderness environment; Grant et al. (1996) studied the risk and responsibility in outdoor recreation; Slanger and Rudestam (1997) considered the motivation, disinhibition in high-risk sports, especially on the sensation seeking and self-efficacy; Schrader and Wann (1999) examined the high-risk recreation with the relationship between participant characteristics and degree of involvement; Sokoloska and Pohirille (2000) then built models of risk and choice: change or danger; Davis-Berman and Berman (2002) analyzed risk and anxiety in adventure programming; Demirhan (2005) conducted research on mountaineers’ risk perception in outdoor -adventure sports with a study of sex and sports experience; Pomfret (2006) summarized the mountaineering adventure tourists with a conceptual framework for research [6-13].

Risk and uncertainty management in general includes three tasks: (1) risk identification: includes the recognition of potential sources of risk. (2) risk assessment: includes calculation of risk indices; and (3) risk mitigation: includes launch of plans for risk mitigation. We can know that risk assessment task is a multi-level and multi-criteria complicated process. The method based on probability theory requires a lot of statistical data, prior probability, model evidence, and likelihood function, are required for validity of Bayesian inference. In many real cases and especially for mountain accidents this is very difficult.

In the field of operational research, Saaty (1980, 1987) [14, 15] had proposed the so-called Analytic Hierarchy Process (AHP) for multiple criteria decision making problems.

The basic feature of AHP is its ability of treating risk assessment and decision-making problems with multi-factors, multi-criteria, multi-tasks and multi-layers. A lot of researchers employed this technique to risk assessment for commercial and engineering applications (Golden, et al. 1989; Forman and Gass, 2001; Dey, 2002; Mota-Sanchez, 2007; Li, 2007; Zayed et al., 2008; Pang et al., 2008; Huang and Shen, 2009; Nguyen, 2009; Brito and de Almeida, 2009; Dawotola, et al, 2009; Zhang, 2010; Toledo et al., 2011; Ouma and Tateishi, 2014) [16-29].

This paper presents risk assessment of mountain accidents occurrence using analytical hierarchy process (AHP). Three layers and seven influence factors (criteria) are involved in the structure of AHP. These seven major influence factors grouped into three categories: (1) natural factors including climate, geomorphology, animal and/or plants; (2) human factors including internal and external; (3) hybrid factors including acute mountain sickness (AMS) and downhill delay. The relative judgment among each influence factor is built up based upon 9-level to form the reciprocal judgment matrices for evaluating weighting vectors and maximal eigen-values for each layer. Consistency of the AHP will be checked and assured. Four cases of mountain accidents occurred in Taiwan during past years were employed for check the validity of the proposed AHP model. The results show that the proposed AHP framework and the associated influence factors and criteria can successfully predict the risk assessment of mountain accidents occurrence.

II. RISK ASSESSMENT OF MOUNTAIN ACCIDENTS -AHP M

AHP method generally includes the following steps: (1) establish a hierarchical model; (2) setup the comparison matrices; (3) calculate relative weights; (4) check the consistency; and (5) evaluate the results (risk indices).

2.1 Establish a hierarchical model

The top of a hierarchical model is the goal to be achieved by AHP. In this research that is the risk assessment of mountain accidents. The second layer (criteria layer) refers to the proposed three major categories of influence factors: (A1) Natural Factors; (B1) Human Factors; and (C1) Hybrid Factors. Factors in the third layer (sub-criteria-layer) support the factors in the second layer and are denoted from $A_{11}, A_{12}, \ldots, C_{12}$ as shown in Figure 1.
2.2 Setup comparison matrices

In general, comparison matrices are obtained through filling in a questionnaire form by some experts in this field. Here we adopt 1-9 scaling method as suggested by Saaty (1980) as shown in Table II. Based on the 1-9 scaling method, we establish the following judgment matrices:

\[
A = \begin{bmatrix}
1 & 2 & 3 \\
1/2 & 1 & 3/2 \\
1/3 & 2/3 & 1
\end{bmatrix},
\]

\[
A_1 = \begin{bmatrix}
1 & 1 & 2 \\
1/2 & 1 & 3/2 \\
1/3 & 2/3 & 1
\end{bmatrix},
\]

\[
B_1 = \begin{bmatrix}
1 & 1/3 \\
3 & 1
\end{bmatrix},
\]

\[
C_1 = \begin{bmatrix}
1 & 3 \\
1/3 & 1
\end{bmatrix}.
\]

2.3 Calculate the relative weights and the maximal eigenvalues

Denote the relative weights for factors at lower layer contributing to the upper layer as \( \{w\} \) and the comparison matrix as \( [A] \), we can solve the following eigen-value problem to obtain the maximal eigen-value \( \lambda_{\text{max}} \):

\[
[A] \{w\} = \lambda \{w\} \quad (1)
\]

The corresponding eigen-vector is the single-sort weights to the influence factors.

The calculated results are:

(1) From layer-B to layer-A:

\[
\{w_0\}^T = (0.5455, 0.2727, 0.1818)
\]

\[ \lambda_{\text{max}} \] = 3

(2) From layer-C to layer-B:

\[
\{w_1\}^T = (0.4, 0.4, 0.2)
\]

\[ \lambda_{\text{max}} = 3 \]

\[
\{w_2\}^T = (0.25, 0.75)
\]

\[ \lambda_{\text{max}} = 2 \]

\[
\{w_3\}^T = (0.75, 0.25)
\]

\[ \lambda_{\text{max}} = 2 \]

2.4 Check the consistency

Due to the complexity of influence factors and diversity of knowledge and experience the evaluation will be different and the comparison matrices might be not consistent. Consistency can be checked using the consistency index (CI):
When all values of CI are small than 0.1, every comparison matrix has satisfactory consistency, the calculated eigenvectors are the weights for the corresponding influence factors.

Furthermore, the consistency ratio (CR) can also be checked using

\[
CR = \frac{CI}{RI} < 0.1 \quad (3)
\]

The calculated results are:

\begin{align*}
(1) \text{ From layer-B to layer-A:} \\
CI_0 &= 0 \\
CR_0 &= 0 \\
(2) \text{ From layer-C to layer-B:} \\
CI_1 &= 0 \\
CR_1 &= 0 \\
CI_2 &= 0 \\
CR_2 &= 0 \\
CI_3 &= 0, \\
CR_3 &= 0.
\end{align*}

We find that all the layers satisfy the consistency requirement.

2.5 Evaluate the final assessed risk index

The final results include two parts:

(1) Calculate the relative risk impact (RRI) of each influence factors on the overall risk:

\[
\{RRI\} = [M] \bullet \{w\} \quad (4)
\]

Where \{RRI\} is a 7×1 vector, [M] is a 7×3 matrix and \{w\} is a 3×1 vector.

The calculated results are:

\[
\begin{bmatrix}
0.4 & 0 & 0 \\
0.4 & 0 & 0 \\
0.2 & 0.25 & 0 \\
0.75 & 0 & 0 \\
0 & 0.25 & 0 \\
0 & 0 & 0.75 \\
0 & 0 & 0
\end{bmatrix} \bullet \begin{bmatrix}
0.5455 \\
0.1818 \\
0.2727 \\
0.1091 \\
0.0682 \\
0.2045 \\
0.0455
\end{bmatrix} = \begin{bmatrix}
0.2182 \\
0.2182 \\
0.1091 \\
0.1364 \\
0.0682 \\
0.2045 \\
0.0455
\end{bmatrix}
\]

The total summation of the impact factors are exactly equal to one. The RRI are plotted in Figure 2 in which we can find that the sequence of importance of influence factor and its percentage of relative impact value are: (1) climate factors (A11)(CL) 21.82%; (2) geomorphology factors (A12) (GE), 21.82%; (3) external factors of human factors (B12) (HE), 20.45%; (3) acute mountain sickness (C11)(AMS), 13.64%; and (4) Animal and Plants factors (A13)(AP), 10.91%, (5) internal human factors (B11)(HI), 6.82%, and (7) downhill delay (C12)(DD), 4.55%, respectively.

Figure 3 Diagram for relative risk impact (RRI) for influence factors of mountain accidents

(2) Calculate the overall risk index (RI):

\[
RI = \{RRI\}^T \bullet \{E\} = \sum_{i=1}^{7} RRI_i \bullet E_i \quad (5)
\]

Where \{E\} is a 7×1 vector denoting the evaluation value of each influence factor (sub-criteria) as shown in Table III. The value of RI can predict the real mountain accident occurrence.
The five grades of risk of mountain accidents based on the obtained risk index can be divided into five levels as follows:

1. $0 \leq RI < 2$: Very safe;
2. $2 \leq RI < 4$: Safe;
3. $4 \leq RI < 6$: Intermediate;
4. $6 \leq RI < 8$: Dangerous;
5. $8 \leq RI < 10$: Very dangerous.

The evaluation value for mountain accidents occurred in Taiwan is proposed based on the following consideration:

(A1) Natural Factors:

(A11) Climate Conditions (CL): Including wind, rain, snow, frost, dew, hail, sleet, drizzle, glaze, etc. In Taiwan the frequently encountered climate situations are storm (strong wind and heavy rain) carried by typhoons from March to November as well as snow in high mountains. The temperature in high mountains changes rapidly and significantly from day to night. The risk of mountain accidents thus highly depends on this factor.

(A12) Geomorphology Conditions (GE): Including steepest slope, cliff, disintegrated wall, deep lake, rip current, dense frost, etc. High risk exists when mountaineers enter these regions.

(A13) Injury caused from Animals and/or Plants (AP): Wild animals include bears, wild cats and dogs, snakes, bees, ants, etc. Plants with poison also would cause death or injury of mountaineers.

(B1) Human Factors:

(B11) Internal Factors (HI): Healthy conditions and psychological situations.

(B12) External Factors (HE): Experience, capacity, equipment, preparation, planning, judgment and team workability, etc.

(C1) Hybrid Factors

(C11) Acute Mountain Sickness (AMS): This sickness occurs in some mountaineers when they climb high mountains. One of serious situation is we cannot expect the occurrence of this situation before it happens. And when serious AMS occurs for any one of mountaineers the risk of accidents increases immediately.

(C12) Downhill Delay (DD): The basic consideration of time delay of downhill is the based on the preparation of climbing. Each project of mountain climbing will prepared enough food and water for the proposed dates, but if some unexpected situations encountered the date of downhill is postponed.

This will force the mountaineers stayed in the mountains under conditions of lack of food and/or water. Experienced leader might help mountaineers survived from natural plants but sometimes there are no helpers for mountaineers.

### TABLE III

| Criteria and Sub-Criteria for Risk Assessment of Mountain Accidents Occurred in Taiwan |
|---------------------------------|---------------------------------|
| Qualitative Ranking Levels | Quantitative Ranking Levels (1-9) |
| **A** | **B** | **C** |
| **RI** | **RI** | **RI** |
| Very safe | Clear climate | 1 |
| Safe | Rainy | 3 |
| Intermediate | Windy and Rainy | 5 |
| Dangerous | Strong wind, heavy rain | 7 |
| Very Dangerous | Stormy, Typhoon, Snowy | 9 |
| Very small dangerous | Only a little bad GE | 1 |
| Slight dangerous | Some small GE exist | 3 |
| Intermediate | Many GE exist | 5 |
| Dangerous | Serious GE exist | 7 |
| Very dangerous | Very serious GE exist | 9 |
| Slight Injury | Skin injury, can walk | 1 |
| injury | Need simple curing | 3 |
| emergent | Need curing, Cannot walk | 5 |
| Serious | Need urgent curing, stretcher | 7 |
| Very serious | Dangerous, near to death | 9 |
| Very small | Both health and psy are good | 1 |
| Small | Only health is good | 3 |
| Big | Health and psy. are fair | 5 |
| Intermediate | Health and psy. are unstable | 7 |
| Very Big | Both Health and psy. are bad | 9 |
| Very small | All the HE are well | 1 |
| Small | One of the HE is not good | 3 |
| Big | Two of the HE are not good | 5 |
| Intermediate | Half of the HE are not good | 7 |
| Very Big | All of the HE are not good | 9 |
| Very slight | Slight (Tired) | 1 |
| Slight | Slight (Headache) | 3 |
| Intermediate | Slight (Insomnia, vomit) | 5 |
| Serious | (Unstable step, unclear recognition, illusion) | 7 |
| Very serious | Severe (Stupor, pulmonary edema) | 9 |
| Very short | DD < 6 hr | 1 |
| Short | 6hr < DD < 24 hr | 3 |
| Intermediate | 24 hr < DD < 48 hr | 5 |
| Long | 48 hr < DD < 96 hr | 7 |
| Very Long | 96 hr < DD | 9 |

III. Case Study of Risk Assessment of Mountain Accidents

We then check the validity of the risk assessment model proposed and explained previously by applying it to mountain accidents occurred in Taiwan.
3.1 Description of Four Mountain Accidents Occurred in Taiwan

The four occurred mountain accidents are summarized as follows:

(1) Case 1: Mountain Accident at Round Peak of Yushan (Jade Mountain), Kaohsiung:

In the morning of January 8, 2010, a man of mountaineering team helped to clean the snow embedded on the road and when he led the people downhill he accidentally fell down valley behind 300 meters. Rescue party found and helicopter took his body to the hospital.

(2) Case 2: Mountain Accident at Forest Roads in Stone Mountain, Kaohsiung:

A leader of 51 years old with his member visited the mountains in southern Taiwan. In themorning of February 10, 2011, the leader dropped from the hill and down to bottom of wall caused injury of chest and broken of ribs. He then transported by helicopter to hospital for rescue.

(3) Case 3: Mountain Accident at Trident Peak of Yushan (Jade Mountain), Kaohsiung:

At 22:30, September 4, 2013, a man of 58 years old followed a leader but dropped a valley. The leader then called for rescue but the man was dead until next morning and his body was taken by helicopter to hospital.

(4) Case 4: Mountain Accident at Great Sword Mountain, Taichung:

During December of 2013 a male mountain climber disappeared in the area of Great Sword Mountain, Taichung, Taiwan. Due to the serious and difficult atmosphere and geomorphology situations around the mountain, the snow-frozen corpse was found by rescue party two months later.

3.2 Evaluation for Four Cases of Mountain Accidents

The evaluation data for four mountain accidents occurred in Taiwan can be observed in Table IV.

The evaluation points obtained from expert and fuzzy inference system (FIS) executed by MATLAB toolbox are listed in parallel for comparison. Both columns of evaluation points will be employed for risk assessment based on the present AHP model.

### TABLE IV

<table>
<thead>
<tr>
<th>Evaluation Points</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case 1</td>
</tr>
<tr>
<td></td>
<td>Expert</td>
</tr>
<tr>
<td>A11 CL</td>
<td>9</td>
</tr>
<tr>
<td>A12 GE</td>
<td>7</td>
</tr>
<tr>
<td>A13 AP</td>
<td>3</td>
</tr>
<tr>
<td>B11 HI</td>
<td>4</td>
</tr>
<tr>
<td>B12 HE</td>
<td>5</td>
</tr>
<tr>
<td>C11 AMS</td>
<td>3</td>
</tr>
<tr>
<td>C12 BD</td>
<td>2</td>
</tr>
</tbody>
</table>

3.3 Risk Assessment Result

From the data in Table IV and Eq. (5), we can calculate the overall risk index for each case of mountain accident. The results are shown in Table V and Figure 4.

### TABLE V

<table>
<thead>
<tr>
<th>Risk Assessment</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>From Expert</td>
<td>5.6136</td>
<td>4.5182</td>
<td>5.4227</td>
<td>6.5318</td>
</tr>
<tr>
<td>From FIS</td>
<td>6.3905</td>
<td>4.3336</td>
<td>5.3750</td>
<td>6.6030</td>
</tr>
</tbody>
</table>

It can be found that the risk indices for each, respectively, case obtained from expert judgment is similar to that obtained by the FIS results. Except for case 2, the assessed risk indices obtained from expert judgment are smaller (non-conservative) than those obtained from FIS. Compared among these four case we found that the risk of mountain accident is: Case 4 > Case 1 > Case 3 > Case 2, this result is accurate as checked by the real situation in practice.
IV. CONCLUDING REMARKS

A simple and convenient technique for risk assessment of mountain accidents based on analytical hierarchy process (AHP) has been proposed and successfully tested for applying to assess the risk of the occurrence of totally four mountain accidents occurred in Taiwan. The AHP model consists three layers and seven major influence factors can be checked for more real cases so as to expect to be applicable for prediction and assessment of potential area where mountain accidents prone to occur. The framework and structure of the proposed AHP can also be adjusted and modified to fit different situations in another regions and countries.

Risk assessment of four cases show that:
(a) The sequence of risk level is Case 4 > Case 1 > Case 3 > Case 2, which is reasonable in practice;
(b) The sequence of importance in natural factors are: climate, geology and animals and plants;
(c) The sequence of importance in human factors are: external, internal;
(d) The sequence of importance in hybrid factors are: AMS, downhill delay.

This risk assessment model based on AHP can also be employed for planning and action of executing rescues of mountain accidents.

REFERENCES


