# Applying Fuzzy AHP Approach to Evaluate Key Operational Safety Elements for Exclusive Container Terminals of Kaohsiung Port in Taiwan

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*Abstract:* - There are many accidents and risks occurred in many activities of operational systems at exclusive container terminals (ECTs) of Kaohsiung port in Taiwan. The container operators nowadays are facing great competitions on how reducing risks to manage those operational systems and activities at Kaohsiung port. Hence, the main purpose of this paper is to apply the fuzzy analytic hierarchy process (AHP) approach to empirically study the risk identification on key operational safety elements (OSEs) for ECTs of Kaohsiung port in Taiwan. To facilitate the main issue for obtaining the preliminary OSEs, the four dimensions and sixteen initially important elements are derived from academic literature and interviewed with senior managers working at ECTs of Kaohsiung port. Subsequently, the proposed fuzzy AHP approach is used to measure relative weights for assessing those safety elements. Finally, the systematic appraisal approach is to perform the empirical survey via AHP questionnaires. The results of this study show that: (1) the aspect of most important risk is the man dimension; and (2) the top six critical OSEs are 'operators' mistakes and faults on operations,' 'communication misunderstanding,' 'execution of the job safety rules and regulations,' 'human carelessness and omissions,' 'carrying out the standard operating procedures (SOPs),' and 'not selecting inherently safety protection of machines and equipment,' respectively. The finding of the empirical results showed that the top four risk factors all belonged to the man dimension. The safety and risk issues indicate that human error is associated with the majority of risk. It is suggested that the risk strategies on the man dimension can be focused on this aspect of safety operations of ECTs at Kaohsiung port.

*Key-Words:* - Risk; Safety; Container terminal; Fuzzy analytic hierarchy process (AHP)

## 1 Introduction

In 2011, Taiwan was referred to as the $10^{th}$ most important maritime territory in the world by UNCTAD controlling 2.63% deadweight tonnage (DWT) of the world merchant fleets [1]. There are three famous international container shipping carriers (Evergreen Line, Yang Ming Line, and Wan Hai Lines) in top 20 operators, as well as an international container port (Kaohsiung port) in top 20 ports in the world. Hence, the developments of shipping and port affairs are playing important roles in the international trade and business in Taiwan.

Regarding to the port affairs, most important port policies were proposed to set up the Kaohsiung port as a critical seaport of loading, unloading and transhipment centre, as well as the port logistics centre in the world [2]. Due to expand the existing achievements and to continue the promotion of liberalization and internationalization for Kaohsiung port, nearly 75% container berths in 2011 are leased to container terminal operators, which are operated and managed by famous global container carriers and stevedores. In this paper, those global shipping operators who operate and manage the leased container berths are the so-called exclusive container terminal operators (ECTOs). The container berths in Kaohsiung port are used of either the public or the leased to ECTOs under contract tenancy agreements.

An exclusive container terminal (ECT) is a complicated place with highly dynamic interactions among several operational systems [3-5], i.e. ship berthing system, and quay crane system in the quayside operations; yard moves system, specific handling machines system, and gate controlling system in the landside operations. There are many accidents and risks might occur in many operational activities of each system at ECTs. The recognitions and executions of risk assessments at ECTs involved different systems of operational activities could help ECTOs to effectively reduce the damage and control noticeable and unnoticeable costs, as well as eventually to affect the service quality [6] and operational effectiveness [7]. On the other hand, the seaside competition has been expanded to the landside for container carriers and related market players [8, 9]. These competitions are interrelated among the market players and the risks or uncertainties are larger than before. Hence, the ECTOs nowadays are facing great competitions on how reducing risks to manage those operational systems and activities in Taiwan.

The prevention of being occurring risks and accidents is more effective than the obstacles emerged from those out-of-order activities, e.g. stevedoring, loading, unloading, moving, hauling, transiting, etc., which are usually operated in coordination with operational safety elements (OSEs) [7]. We can refer some literature [6, 7, 10] on the risk management (RM) process; the main foundation of the entire RM process is risk identification. It is clear that if the risk can be identified, then the risk can be controlled. In this paper, the risk identification will be associated with the OSEs, which will be matched up to each cause of the accidents occurred among quayside and landside operations in ECTs of Kaohsiung port. To manage the risks for ECTOs, the evaluation of relative importance is a firstly critical issue due to the fact that this work involved as to how the priority of risk strategies can be decided, and whether or not the controls are effective in the future. However, experience showed that the evaluation of risk identification on key OSEs, which involves a multiple criteria problem, is not an easy task. The issue of assessing key OSEs faces how to evaluate the relative weights of these multiple ones. However, the Saaty's analytic hierarchy process (AHP) approach [11], proposed in 1980, is one of the commonly used techniques for this problem. The characteristic of multiple criteria problem, in which information is incomplete or imprecise or views that are subjective or endowed with linguistic characteristics creating a fuzzy environment [12-15], e.g. the phrase of 'much more important than.' Thus, the use of Zadeh's fuzzy set theory [16], proposed in 1965, would be more suitable in that situation. In light of this, a fuzziness-based AHP approach [12-14, 17, 18] is used to measure relative weights for evaluating these key OSEs.

In summary, the main purpose of this paper is to apply the fuzzy AHP approach to empirically study the risk identification on key OSEs for ECTs of Kaohsiung port in Taiwan. The preliminary OSEs are adopted in Section 2. The method of fuzzy AHP approach is introduced in Section 3. An empirical survey is studied in Section 4. Finally, conclusions are drawn in the last section.

## 2 Adoption of Preliminary OSEs

As mentioned in the above section, an ECT usually includes quayside and landside operations with five operational systems, which the operational functions can be consisted of storage, loading, unloading, and gate controls [3-5]. When a ship is docked at a berth, the import containers as well as export ones are loading and unloading of the ship using the cranes. Then, these containers are moved to the marshalling yard for short term storage, or to the container yard for longer storage, or to the container freight station for being assemble or disassemble using different types of handling equipment. The non-standard containers, e.g. reefer containers, dangerous (DG) containers, etc., would be arranged to the special stack areas for storage. Finally, the trucks or container trailers hauled these containers away through the gate of an ECT.

A series of operational activities can be associated with four OSEs (i.e. 'four Ms.') In the meanwhile, a '5W1H' method can be another useful tool for identifying hazards [19]. The method involved with (1) where, i.e. identifying the working place, e.g. the frontline of ship operation area, or the backline of yard storage area; (2) who, i.e. identifying the object or target, e.g. stevedores, gantry crane operators, truckers, tally man, and so on; (3) what, i.e. identifying the covering scope, e.g. human factors, operational model, machine and equipment factor, and environment factor, etc.; (4) when, i.e. identifying the evaluation time, e.g. pre-operation, on-operation, or after-operation; (5) why, i.e. the identifying reason; and (6) how, i.e. identifying measures, e.g. checklist, questionnaire, experience, common sense, interviews, job safety analysis, etc.

Risk identification is the first procedure to RM process. Risks could not be managed without prior identification before occurrence [20]. In other words, only a comprehensive understanding to the various risks of the corporation may predict the possible risks involved and further choose the effective approach for risk processing. The main purpose of risk identification lies on the identification of all predictable risks. The risk identification proposed in this study is generated from [20] history review, situational analysis and decision-making meetings of creative thinking. Here, the '5W1H' method is a supporting role to assist with the 'four Ms' to identify the hazards at ECTs of Kaohsiung port in this paper.

Based on the above concepts, the preliminary OSEs were conducted based on a review of the literature [3-7, 10, 21-24] and comprehensive interviews conducted by the authors with senior managers working at Kaohsiung port ECTs. Finally, the 'four Ms' dimensions with sixteen initially important factors are suggested; and their codes are shown in parentheses. Those dimensions and initially factors are categorized and explained as below.

**(1). Man ($M_1$).** This dimension related participated people working in the ECTs, e.g. stevedores, gantry crane operators, truckers, tally man, and so on. It is referred that most of accidents are caused by human negligence [10]. Fan [25] had surveyed the disturbance caused of the accidents at Keelung Port in Taiwan; the human negligence is accounted for 60% of all disturbances. More emphases on this dimension will reduce the risk and influence the operational service quality [6] and safety performance [23]. Four initially important factors are summed to measure this dimension, as follows:

- Operators' mistakes and faults on operations ($C_{11}$). Many accidents occurred in different operational activities is a universal phenomenon. Identifying these operators' mistakes and faults on different operations may help with risks monitor. However, it should be affirmed as what the operational activities in what situations are appeared.
- Communication misunderstanding ($C_{12}$). The communication problems arise both from misapprehension and from cases when message or information in a team was not explicitly shared. When communication problems occur, the risk of accidents might be increased. It also might be reduced accuracy and efficiency and brought about the mental workload of these participants.
- Human carelessness and omissions ($C_{13}$). Majority of the cases of ECTs accidents occur due to human carelessness, orientation education and on the job training are good solutions for avoiding these risk factors emerged. Setting up a good and usual practice in the operations, the errors occurred on this factor might be reduced.
- Execution of the job safety rules and regulations ($C_{14}$). Actually, there are many measures dominated on the job safety rules and regulations. The accidents occurred due to the participants do not strictly perform these rules and regulations. If the understandings of those measures are built up, then the risk could be reduced in the future.

**(2). Machine ($M_2$).** This dimension related machines and equipment in the ECTs, e.g. vehicles, transfer cranes, straddle carriers, stackers, container fork lift, yard tractor, trucks, chassis, fire-fighting equipment, and so on. Fan [25] had surveyed the breakdown of machinery is accounted for 15% of all disturbances. Many perils hided from the operational areas are exposed in the ECTs, when the related machines and equipment are operated. The operational environment is in hiding limitless dangerous, and hence, it should be careful and discreet. Four initially important factors are summed to measure this dimension, as follows:

- Not selecting inherently safety protection of machines and equipment ($C_{21}$). Experience show safety of innate character is the most important factor influencing machines and equipment to achieve operational safety performance. It can be reduced the risk of machines and equipment by using some design-basis devices. Even failures on human operations are emerged, the inherently safety of machines and equipment can be maintained and kept the fail-safe. Machines and equipment comes first at safety protection due to the fact that these machines might be out-of-order in the operations. The safety protection should be provided for the operational work force. Safety protective equipment provides a buffer or a cushion along with restraining from the risks incidence.
- Following with normalized operating procedure ($C_{22}$). The decreased operational risks, highly reliability on operational performance, and hence increasing productivity will be depended on degree of normalization of operations. The operating problems can be easily found out by following with the normalized operating procedure. It is a way to keep operating quality more efficiently and to uphold the safety more effectively.
- A series of checks maintenance ($C_{23}$). It can be divided the checks into inspection, periodical check, irregular check, frequent check, temporary check, an emphasis check, and so on. The checks are in advance to take precautions against the hazards. If the hazards are beforehand

checked to reform the improvements, it would be eliminated from the calamity. Besides, a safety environment can be created by the series of checks and maintenance.

- Requisite safety facilities and equipment tallied with standards ($C_{24}$). The executions of tallying with standards and safety facilities and equipment are important. The clear regulations are stipulated on the national laws that the business owners should understand the norms as the lowest standard and should take effect in the safety practice. If this safety factor could be reduced, the loss of operational performance might be effectively controlled.

**(3). Media ($M_3$).** This dimension related operational space and environments in the ECTs, e.g. dynamic routes of berth and yard, illumination, pothole, and so on. Fan [25] had surveyed the traffic accident, DG cargoes, and others media are accounted for 8% of all disturbances. External and largely environmental forces, e.g. climatic, operational, vehicular or pedestrian might be the factors influencing the media [7]. Four initially important factors are summed to measure this dimension, as follows:

- Drawing up faultlessly dynamic routes in ECTs ($C_{31}$). We analyze the causes of the accidents of ECTs in Taiwan; many hazards are occurred due to the fact that the dynamic routes of the operational areas are ill-advised. Hence, providing a good route plan might reduce the risk emerged.
- Motion countermeasures of special environments ($C_{32}$). This criterion indicates the special countermeasures should be made in the special environments, e.g. typhoons, storms and violent wind, receiving DG cargoes or special containers etc. When the bad weather is forecasted, the countermeasures in ECTs should be deployed the work ahead of time. In addition, when the special container or DG cargoes are received to handle in the ECTs, the view and survey of all treating processes should be identified to avoid the accidents.
- Illuminative improvements ($C_{33}$). The operational areas in ECTs need better illumination, especially when related participated people are working during the night. The line of vision as well as the vehicles travel safety might be affected by the unfavourable illumination on-the-scene operations. The improvements of the replacements on the illuminative facilities could promote the safety performance at night working.
- Automation of operations ($C_{34}$). To quest for accuracy and safety in the container operations, automation among different operational areas would be essential to greatly increase the productivity. Constructing the environment of automation would increase the efficiency and effectiveness of different operations, as well as reduce the operational risks. Hence, automation of operations would improve the safety performance.

**(4). Management ($M_4$).** This dimension related operational management system, e.g. standard operating procedures (SOPs), on job training and orientation education, explanation of workplace safety, and so on. Fan [25] had surveyed the management dereliction is accounted for 17% of all disturbances. Standards, procedures, and controls might be the factors influencing the management [7]. Four initially important factors are summed to measure this dimension, as follows:

- Carrying out the SOPs ($C_{41}$). It is written documents or instructions covering all steps and activities of different operations, which can improve or ensure quality against accidents. A company with faultless management system should formulate the rationality of operational procedures, and would take effects when there is a halt with fast turnover of staff, or when the irreconcilable conflict between enterprise departments is indecisive. Hence, carrying out the SOPs might reduce machine dimension and fraction defective. Finally, a quality assurance policy might be established in the function of control.
- On job training and orientation education ($C_{42}$). Strictly guiding the safety and risk management is an important operational procedure on the job training and orientation education. All steps of SOPs should be notified to the participated workers. More importantly, when all kinds of accidents are occurred in the simulated situations and cases study, how the risk for a minimum loss could be controlled in that positions. These would be essential to instruct them in the training and education.
- Not performing a safety auditing and safety inspection ($C_{43}$). Strictly auditing and inspecting the safety and risk factors emerged on the above three dimensions, especially the human carelessness and omissions, is an important function of control. Increasing the investigation into the accidents of machinery maintenance, human errors, and environmental forces would be advantageous in the machinery operations, personal security and stevedoring quality. Hence, safety auditing and safety inspection can be guided to strengthen the human safety behaviour

and weaken the unsafe activities occurred. Top manager support to strengthen the safety climate ($C_{44}$). The promise and support of top manager is the most effective in carrying out the safety policy. When the safety climate in an enterprise is performed among all departments, there is a positive effect on the safety performance. Shang and Lu [24] had shown this effect in container terminal operations. Hence, the safety climate should be strengthened by top manager's support and promise, and then the core value of risk and safety management can be internalized in every staff, thereby reducing the hazards and accidents.

# 3 Fuzzy AHP Approach

Some of the theoretical concepts and evaluating steps of the fuzzy AHP approach are described below.

## 3.1 Fuzzy set theory

The fuzzy set theory [16] is designed to deal with the extraction of the primary possible outcome from a multiplicity of information that is expressed in vague and imprecise terms. Fuzzy set theory treats vague data as possibility distributions in terms of set memberships. Once determined and defined, the sets of memberships in possibility distributions can be effectively used in logical reasoning.

### 3.1.1 Triangular fuzzy numbers

A fuzzy number $A$ [26] in real line $\Re$ is a triangular fuzzy number if its membership function $f_A : \Re \to [0,1]$ is

$$f_A(x) = \begin{cases} (x-c)/(a-c), & c \le x \le a \\ (x-b)/(a-b), & a \le x \le b \\ 0, & otherwise \end{cases}$$

with $-\infty < c \le a \le b < \infty$. The triangular fuzzy number can be denoted by $(c, a, b)$. Due to the fact that the triangular fuzzy numbers are easy to use and easy to interpret, therefore, we will use them to represent the survey data in this paper.

### 3.1.2 The algebraic operations of fuzzy numbers

Let $A_1 = (c_1, a_1, b_1)$ and $A_2 = (c_2, a_2, b_2)$ be fuzzy numbers. According to the extension principle [16], the algebraic operations of any two fuzzy numbers $A_1$ and $A_2$ can be expressed as

- Fuzzy addition:
  $A_1 \oplus A_2 = (c_1 + c_2, a_1 + a_2, b_1 + b_2)$,
- Fuzzy subtraction:
  $A_1 \ominus A_2 = (c_1 - b_2, a_1 - a_2, b_1 - c_2)$,
- Fuzzy multiplication:
  (i) $k \otimes A_2 = (kc_2, ka_2, kb_2), k \in \Re, \ k \ge 0$;
  (ii) $A_1 \otimes A_2 \cong (c_1c_2, a_1a_2, b_1b_2)$,
  $c_1 \ge 0, \ c_2 \ge 0$,
- Fuzzy division:
  (i) $(A_1)^{-1} = (c_1, a_1, b_1)^{-1}$
  $\cong (1/b_1, 1/a_1, 1/c_1), c_1 > 0$;
  (ii) $A_1 \oslash A_2 \cong (c_1/b_2, a_1/a_2, b_1/c_2)$,
  $c_1 \ge 0, c_2 > 0$.

## 3.2 Evaluating steps of fuzzy AHP approach

The systematic steps of fuzzy AHP approach is described below.

**Step 1. Develop a hierarchical structure**

A hierarchy structure is the framework of system structure. We can skeletonise a hierarchy to evaluate research problems and benefit the context. The hierarchy structure can be constructed as Figure 1, which is covered with $k$ dimensions and $p + \cdots + q + \cdots + r$ factors, respectively.

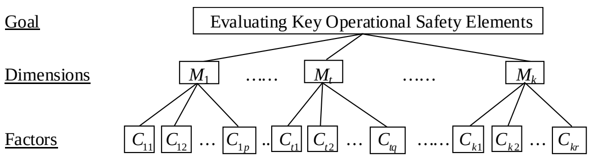


Figure 1. Hierarchy structure

**Step 2. Collect pair-wise comparison matrices of decision attributes**

We choose experts to collect pair-wise comparison matrices of decision factors, which is represented the relative importance of each pair-wise factor.

(1) Let $x_{ij}^h$, $h = 1, 2, \ldots, n$, be the relative importance given to dimension $i$ to dimension $j$ by expert $h$ on the Dimensions layer. Then, the pair-wise comparison matrix is defined as $[x_{ij}^h]_{k \times k}$.

(2) Let $x_{uv}^h$, $h = 1, 2, \ldots, n$, be the relative importance given to factor $u$ to factor $v$ by expert $h$ on the Factors layer. Then, the pair-wise comparison matrix with respect to each dimension is defined as $[x_{uv}^h]_{p \times p}, \cdots,$ $[x_{uv}^h]_{q \times q}, \cdots, [x_{uv}^h]_{r \times r}$.

**Step 3. Transform relative importance into triangular fuzzy number**

The generalized means is a typical representation of many well-known averaging operations [27], e.g., min, max, geometric mean, arithmetic mean, harmonic mean, etc. The min and max are the lower bound and upper bound of generalized means, respectively. Besides, the geometric mean is more effective in representing the multiple decision makers' consensus opinions [11]. To aggregate all information generated by different averaging operations, we use the grade of membership to demonstrate their strength after considering all approaches. For the above-mentioned reasons, the triangular fuzzy numbers characterized by using the min, max and geometric mean operations is used to convey the opinions of all experts.

Let $x_{ij}^{h} \in \{1/9, 1/8, \ldots, 1/2, 1\} \cup \{1, 2, \ldots, 8, 9\}$, $h = 1, 2, \ldots, n,\ \forall i,\ j = 1, 2, \ldots, k$, be the relative importance given to dimension $i$ to dimension $j$ by expert $h$ on the Dimensions layer. After integrating the opinions of all $n$ experts, the triangular fuzzy numbers can be denoted by

$$\tilde{B}_{ij}^{D} = (c_{ij}, a_{ij}, b_{ij}),$$

where

$$c_{ij} = \min\{x_{ij}^{1}, x_{ij}^{2}, \ldots, x_{ij}^{n}\},$$

$$a_{ij} = \left(\prod_{h=1}^{n} x_{ij}^{h}\right)^{1/n},$$

$$b_{ij} = \max\{x_{ij}^{1}, x_{ij}^{2}, \ldots, x_{ij}^{n}\}.$$

By the same concept, we can integrate the opinions of all $n$ experts on the Factors layer, i.e. the triangular fuzzy numbers can be denoted by

$$\tilde{B}_{uv}^{F} = (c_{uv}, a_{uv}, b_{uv}),\ \forall u, v = 1, \ldots, p;\ \cdots;\ \forall u, v = 1, \ldots, q;\ \cdots;\ \forall u, v = 1, \ldots, r,$$

where

$$c_{uv} = \min\{x_{uv}^{1}, x_{uv}^{2}, \ldots, x_{uv}^{n}\},$$

$$a_{uv} = \left(\prod_{h=1}^{n} x_{uv}^{h}\right)^{1/n},$$

$$b_{uv} = \max\{x_{uv}^{1}, x_{uv}^{2}, \ldots, x_{uv}^{n}\}.$$

**Step 4. Build fuzzy positive reciprocal matrices**

We use the integrated triangular fuzzy numbers to build fuzzy positive reciprocal matrices. For the Dimensions layer, the fuzzy positive reciprocal matrix can be denoted by

$$B_{k}^{D} = \left[\tilde{B}_{ij}^{D}\right]_{k\times k} = \begin{bmatrix} \tilde{1} & \tilde{B}_{12}^{D} & \cdots & \tilde{B}_{1k}^{D} \\ 1/\tilde{B}_{12}^{D} & \tilde{1} & \cdots & \tilde{B}_{2k}^{D} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{B}_{1k}^{D} & 1/\tilde{B}_{2k}^{D} & \cdots & \tilde{1} \end{bmatrix},$$

where

$$\tilde{B}_{ij}^{D} \otimes \tilde{B}_{ji}^{D} \cong \tilde{1}, \quad \forall i,\ j = 1, 2, \ldots, k.$$

For saving space, by using the same concept, the equations of fuzzy positive reciprocal matrices are omitted to reason by analogy on the Factors layer.

**Step 5. Calculate the fuzzy weights of the fuzzy positive reciprocal matrices**

Let $\tilde{Z}_{i}^{D} = \left(\tilde{B}_{i1}^{D} \otimes \tilde{B}_{i2}^{D} \otimes \cdots \otimes \tilde{B}_{ik}^{D}\right)^{1/k}$, $\forall i = 1, 2, \ldots, k$, be the geometric mean of triangular fuzzy number of $i^{th}$ dimension on the Dimensions layer. Then, the fuzzy weight of $i^{th}$ dimension can be denoted by

$$\tilde{W}_{i}^{D} = \tilde{Z}_{i}^{D} \otimes \left(\tilde{Z}_{1}^{D} \oplus \tilde{Z}_{2}^{D} \oplus \cdots \oplus \tilde{Z}_{k}^{D}\right)^{-1}.$$

For being convenient, the fuzzy weight is denoted by

$$\tilde{W}_{i}^{D} \cong (w_{ic}^{D}, w_{ia}^{D}, w_{ib}^{D}).$$

For saving space, the equations of fuzzy weights are omitted to reason by analogy on the Factors layer.

**Step 6. Defuzzify the fuzzy weights to crisp weights**

For solving the problem of defuzzification powerfully, the graded mean integration representation (GMIR) method, proposed by Chen and Hsieh [28] in 2000, is used to defuzzify the fuzzy weights.

Let $\tilde{W}_{i}^{D} = (w_{ic}^{D}, w_{ia}^{D}, w_{ib}^{D})$, $\forall i = 1, 2, \ldots, k,$ be $k$ fuzzy weights. By the powerful method, the GMIR of $\tilde{W}_{i}^{D}$ can be denoted by

$$W_{i}^{D} = (w_{ic}^{D} + 4w_{ia}^{D} + w_{ib}^{D})/6,\ \forall i = 1, 2, \ldots, k.$$

For saving space, the defuzzifications of fuzzy weights are omitted to reason by analogy on the Factors layer.

**Step 7. Standardize the crisp weights**

For being convenient to compare the relative importance between each layer, these crisp weights are standardized and denoted by

$$SW_{i}^{D} = W_{i}^{D} \Big/ \sum_{i=1}^{k} W_{i}^{D}.$$

**Step 8. Calculate the integrated weights for each layer**

Let $SW_i^D$ and $SW_u^F$ be the standardized crisp weights on the Dimensions and Factors layers, respectively. Then,

(i) The integrated weights of each aspect on the Dimensions layer is

$$IW_i^D = SW_i^D, \ \forall i = 1, 2, \ldots, k.$$

(ii) The integrated weights of each factor on the Factors layer is

$$IW_u^F = SW_i^D \times SW_u^F,$$

$\forall i = 1, 2, \ldots, k$; $\forall u = 1, \ldots, p$; $\cdots$; $\forall u = 1, \ldots, q$; $\cdots$; $\forall u = 1, \ldots, r$.

# 4 Empirical Survey

In this section, an empirical survey of risk identification on key OSEs for ECTs of Kaohsiung port in Taiwan is studied and implemented, as follows.

## 4.1 Questionnaire and data collection

In this section, four dimensions and sixteen initially important factors, as mentioned above in Section 2, were used to design the Saaty's AHP questionnaire, and to collect pair-wise comparison matrices of each layer to represent the relative importance. For this research, most global shipping operators and stevedores in ECTs at Kaohsiung port are requested to fill in the AHP questionnaires. The questionnaire survey was carried out from October 2011 to February 2012. The surveys were completed through e-mails, phone calls, and in-person interviews conducted by the authors. Most respondents were middle or senior managers who had been working in the field for over 16 years. Due to the fact that the AHP problem is involved with the group decision-making, where Robbins [29] suggested that five to seven decision-makers are sufficient when dealing with group decision-making problems; and as risk evaluation can be generated by a group of professional experts [29]. As a result, nineteen questionnaires were checked for validity, the number of responses was deemed acceptable.

## 4.2 Results and discussions

In our case, with four dimensions and sixteen initially important factors, there are five (1+4) pair-wise comparison matrices to collect. The authors use the four dimensions ($M_1$ – $M_4$) of the nineteen valid questionnaires as an example for illustrating the computational process of the fuzzy AHP approach. As regards to the others four pair-wise comparison matrices, these are omitted by reasoning by analogy. The computing process and empirical results are shown as follows.

**Step 1. Build fuzzy fuzzy positive reciprocal matrix.** The authors used the data of the relative importance of nineteen valid questionnaires to collect pair-wise comparison matrix and then transformed these data into triangular fuzzy numbers using the geometric mean approach. We use the integrated triangular fuzzy numbers to build fuzzy positive reciprocal matrix. The result of the fuzzy positive reciprocal matrix for the Dimensions layer ($M_1$ – $M_4$) is shown as Table 1.

Table 1. The fuzzy positive reciprocal matrix of four dimensions

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ |
|---|---|---|---|---|
| $M_1$ | (1, 1, 1) | (0.250, 3.877, 9) | (0.167, 3.148, 9) | (0.167, 1.509, 9) |
| $M_2$ | (0.111, 0.258, 4) | (1, 1, 1) | (0.333, 2.178, 9) | (0.167, 1.002, 7) |
| $M_3$ | (0.111, 0.318, 6) | (0.111, 0.459, 3) | (1, 1, 1) | (0.167, 0.569, 6) |
| $M_4$ | (0.111, 0.663, 6) | (0.143, 0.998, 6) | (0.167, 1.758, 6) | (1, 1, 1) |

**Step 2. Calculate the fuzzy weights of fuzzy positive reciprocal matrix.** Using the Step 5 of fuzzy AHP approach, the geometric mean of triangular fuzzy number ( $\tilde{Z}_i^D$ ) and the fuzzy weights ($\tilde{W}_i^D$) of four dimensions can be shown as Table 2 .

Table 2. The geometric mean of triangular fuzzy number and the fuzzy weights

| | $i$=1 | $i$=2 | $i$=3 | $i$=4 |
|---|---|---|---|---|
| $\tilde{Z}_i^D$ | (0.2890, 2.0715, 5.1962) | (0.2803, 0.8662, 3.9843) | (0.2130, 0.5368, 3.2237) | (0.2269, 1.0385, 3.8337) |
| $\tilde{W}_i^D$ | (0.0178, 0.4590, 5.1490) | (0.0173, 0.1919, 3.9482) | (0.0131, 0.1189, 3.1945) | (0.0140, 0.2301, 3.7989) |

**Step 3. Defuzzify the fuzzy weights and normalize the crisp weights.** Using the Step 6 of fuzzy AHP approach, the fuzzy weights can be defuzzified by the GMIR method to obtain the crisp weights ($W_i^D$). Then using the Step 7 of fuzzy AHP approach, we can obtain the standardized weights ($SW_i^D$). The results can be shown as Table 3.

Table 3. The defuzzified and standardized weights of four dimensions

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ |
|---|---|---|---|---|
| Defuzzified weights | 1.1671 | 0.7887 | 0.6139 | 0.7889 |
| Standardized weights | 0.3475 | 0.2348 | 0.1828 | 0.2349 |

**Step 4. Calculate the integrated weights.** For saving space, the authors used the same computational process of fuzzy AHP for each factor to obtain the standardized weights. And then, the results of the integrated weights can be shown as Table 4.

Table 4. The standardized weights and integrated weights for the proposed hierarchy

| D | (A) | F | (B) | (C) |
|---|---|---|---|---|
| $M_1$ | 0.3475 (1) | $C_{11}$ | 0.2703(1) | 0.09393 (1) |
| | | $C_{12}$ | 0.2488 (2) | 0.08646 (2) |
| | | $C_{13}$ | 0.2367 (4) | 0.08225 (4) |
| | | $C_{14}$ | 0.2442 (3) | 0.08486 (3) |
| $M_2$ | 0.2348 (3) | $C_{21}$ | 0.3098 (1) | 0.07274 (6) |
| | | $C_{22}$ | 0.2818 (2) | 0.06617 (7) |
| | | $C_{23}$ | 0.1572 (4) | 0.03691 (15) |
| | | $C_{24}$ | 0.2512 (3) | 0.05898 (9) |
| $M_3$ | 0.1828 (4) | $C_{31}$ | 0.2993 (1) | 0.05471 (10) |
| | | $C_{32}$ | 0.2863 (2) | 0.05234 (12) |
| | | $C_{33}$ | 0.1618 (4) | 0.02958 (16) |
| | | $C_{34}$ | 0.2526 (3) | 0.04617 (14) |
| $M_4$ | 0.2349 (2) | $C_{41}$ | 0.3124 (1) | 0.07338 (5) |
| | | $C_{42}$ | 0.2541 (2) | 0.05969 (8) |
| | | $C_{43}$ | 0.2302 (3) | 0.05407 (11) |
| | | $C_{44}$ | 0.2033 (4) | 0.04776 (13) |

Note: Numbers in parentheses are ranks.
D: Dimensions; F: Factors.
(A): Standardized / Integrated weights;
(B): Standardized weights;
(C)=(A)*(B): Integrated weights.

The results of empirical study in Table 4 are shown as follows:

(1) Man ($M_1$), ranking 1, is the most important risk dimension influencing the ECT of Kaohsiung port from the operators' perspective in Taiwan. The dimensions of management ($M_4$) and machine ($M_2$) are ranked in the second and third places. These two dimensions are very close with the values of importance weights of 0.2349 and 0.2348, respectively. This indicated that management and machine dimensions are almost equally important in this study. Media ($M_3$) is the lowest ranked. Nevertheless, these values of importance weights could be widely different among various container terminals in the world.

(2) For man dimension ($M_1$), 'operators' mistakes and faults on operations ($C_{11}$)' is the critical safety element. For machine dimension ($M_2$), 'not selecting inherently safety protection of machines and equipment ($C_{21}$)' is the critical safety element. For media dimension ($M_3$), 'drawing up faultlessly dynamic routes in ECTs ($C_{31}$)' is the critical safety element. For management dimension ($M_4$), 'carrying out the SOPs ($C_{41}$)' is the critical safety element.

(3) The top six critical safety elements are 'operators' mistakes and faults on operations ($C_{11}$),' 'communication misunderstanding ($C_{12}$),' 'execution of the job safety rules and regulations ($C_{14}$),' 'human carelessness and omissions ($C_{13}$),' 'carrying out the SOPs ($C_{41}$),' and 'not selecting inherently safety protection of machines and equipment ($C_{21}$),' respectively. The weights of these six critical safety elements are all above 7%, and the sum of six weights is 49.36% (about 1/2). However, if we consider that the weights are all above 5.5%, and the sum of the nine weights is 67.85% (about 2/3), then we must add the other three quasi-critical safety elements, i.e. 'following with normalized operating procedure ($C_{22}$),' 'on job training and orientation education ($C_{42}$),' and 'requisite safety facilities and equipment tallied with standards ($C_{24}$),' respectively. At the same time, the lowest weights of four safety elements are, below 5% (the sum of four weights is 16.04%), 'top manager support to strengthen the safety climate ($C_{44}$),' 'automation of operations ($C_{34}$),' 'a series of checks maintenance ($C_{23}$),' and 'illuminative improvements ($C_{33}$),' respectively.

According to our empirical results, the top four risk factors all belonged to the 'Man' aspect. The majority of reports in the literature [4, 6, 7, 10, 22-24] on safety and risk issues indicate that human error is associated with the majority of risk. Overall speaking, the terminal managers should pay more attention on the factor of human errors firstly. This survey indicates four critical OSEs are contributed to the man dimension. They are 'operators' mistakes and faults on the operations,' 'communication misunderstanding,' 'execution of the job safety rules and regulations,' and 'human carelessness and omissions,' respectively. We can see these four critical OSEs in the first dimension indicate the managers should carefully affirmed different operational activities in what situations might be appeared. Next critical safety element presents the messages should be correct to share the accurate information among the operational teams. Then, the job safety rules and regulations must be strictly observed. The human carelessness and omissions might be reduced to arise by using the on job training and education. It is suggested that safety supervision and management system should be made and developed for the participated workers in this dimension.

As for the other two critical OSEs, i.e. ‘carrying out the SOPs,’ and ‘not selecting inherently safety protection of machines and equipment.’ The former element is contributed to the management dimension; the latter is to the machine dimension. It indicates that operational workers comply with all the SOPs in the operational activities might reduce the human errors, as well as might develop a good management system of quality assurance policy. Regarding the ‘inherently safety protection of machines and equipment,’ it is the basic apparatus to avoid the risk to appear. Although the other important OSEs influencing the operational risk are not stated detail, however, they have evident impacts on the safety climate. Hence, it is suggest that more descriptions should be worthy to note with a lot of attention in the future. It is just because these factors are hinted at initially important factors.

## 5 Conclsions

This paper aims to indentify risk on key OSEs for ECTs of Kaohsiung port in Taiwan by using the fuzzy AHP approach. Firstly, to facilitate the main issue for obtaining the preliminary OSEs, a series of operational activities are associated with the ‘four Ms’ and ‘5W1H’ method to derive the preliminary OSEs at ECTs of Kaohsiung port. These initially important OSEs have been discussed and publicized in academic and management fields and can be summarized as four dimensions and sixteen initially important OSEs. Subsequently, the next issue faced how to evaluate the relative weights of the multiple criteria problem. The proposed fuzzy AHP approach is used to measure relative weights for evaluating these key OSEs. Finally, an empirical survey was conducted, using the fuzzy AHP approach, to demonstrate the systematic appraisal process for prioritizing importance weights of risk factors on OSEs. The AHP expert questionnaire was designed to help illustrate of the operational process of the proposed fuzzy AHP model.

The results of empirical study were as follows:

(1) The aspect of most important risk is ‘man’ dimension.

(2) The top six critical OSEs are ‘operators’ mistakes and faults on operations,’ ‘communication misunderstanding,’ ‘execution of the job safety rules and regulations,’ ‘human carelessness and omissions,’ ‘carrying out the SOPs,’ and ‘not selecting inherently safety protection of machines and equipment,’ respectively.

Actually, this paper only focused on the fuzzy AHP approach to the empirical study. Of course this is not a new and innovative method. However, we applied this method to study the existing problems just like this title of our paper. We think one of the main contributions of this paper is to apply this method of risk identification for business application in the Taiwanese ports.

Moreover, the results of this study pertain to ECTs in Kaohsiung port, and the results are not necessarily generalizable to other ports. We believe our paper can contribute to the safe operations of ECTs at Kaohsiung port. The ECTOs located there can use our empirical results to formulate and implement safety policies. Researchers interested in investigating similar aspects of loading and discharging operations or cargo damage connected to transit operations can employ analogous procedures in the future. Furthermore, the entire evaluation of RM procedure [6, 30-34] included three steps—namely ‘risk identification,’ ‘risk analysis and evaluation,’ and ‘formulation of risk strategies,’ respectively. However, this paper only studied the first step of RM procedure; follow-up studies can focus on the other two RM procedures using various risk management methods in the future.

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