Fuzzy risk assessment on safety operations for exclusive container terminals at Kaohsiung port in Taiwan

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Abstract
Because risk assessment of safety operations in exclusive container terminals at Kaohsiung port involves a host of complex considerations and uncertain information, we therefore use a fuzziness-based method to minimize the effect of such adverse factors and clarify the assessment process in this article. This article therefore uses fuzzy risk assessment steps to evaluate safety operations in exclusive container terminals at Kaohsiung port in Taiwan. This article first employs three risk assessment steps and then identifies a total of four dimensions with 16 risk factors from the literature and interviews with experts. After proposing a systematic fuzzy risk analysis and evaluation steps in order to determine risk levels, this article conducts an empirical study of Kaohsiung port by means of a survey. The empirical results reveal that (1) the leading factor influencing risk frequency is “communication misunderstanding,” (2) the leading factor influencing risk severity is “human negligence and error,” and (3) three risk factors are located in the high-risk area, while the other 13 risk factors are in the medium-risk area, and no risk factors are in the low-risk area. Furthermore, the analysis of the various risk factors suggests the adoption of three risk management strategies.

Keywords
Fuzzy risk assessment, safety operation, container terminal

Introduction
Taiwan is an island nation located in East Asia. Since most imported and exported goods and materials are shipped by sea, Taiwan’s ports play important roles in land and sea logistics chains. There are four international commercial ports in Taiwan. Kaohsiung port is the largest of these and was ranked the 12th largest international container port in the world in 2011. To accomplish the port’s policy goal of developing into a regional marine transshipment hub, the government of Taiwan plans to transform Kaohsiung port into a global logistics management center and free trade port, which will further enhance the viability of Kaohsiung port over the next decade. To ensure the realization of deregulation and internationalization at Kaohsiung port, nearly 75% of the available container berths are leased to container terminal operators operated and managed by prominent global container carriers and stevedores, referred to in this article as exclusive container terminal operators (ECTOs). Furthermore, container berths at Kaohsiung port are chiefly leased to ECTOs under contract tenancy agreements, and the remaining container berths are reserved for public use. In view of the unique position of Kaohsiung port among Taiwan’s four ports, and the predominance of exclusive container terminals (ECTs) at this port, we have chosen these ECTs as the subject of this article.

An ECT is a complicated place with highly dynamic interactions among several operating systems,¹–³ such as ship berthing, quay crane, yard moving, handling machine, and gate control systems, among others, and there is a high risk of accident associated with these multiple systems. Maintaining a safe environment is a very important means of enhancing the operational performance of an ECTO, however, and risk

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assessments of ECT safety operations therefore represents an important research task.

There are many risk factors that may influence safety operations at an ECT, and evaluation of these risk factors in terms of their impact on safety operations is beneficial to the ECTO. While the levels of risk and uncertainty associated with port operation are greater than ever before, developing an assessment model for ECT risk management is not an easy task and involves a multitude of complex considerations. As a consequence, employing a decision-making tool to perform risk assessment of safety operations is a crucial means of helping decision makers (DMs) to identify and recognize risk factors (i.e. evaluation criteria influencing safety operations). Moreover, since the risk factors are subjective or endowed with linguistic characteristics, set membership in fuzzy set theory is represented by triangular fuzzy numbers, which are in a vast majority of risk assessments of ECTs at Kaohsiung port. This study therefore employs a fuzzy-based method to perform risk assessment of ECT safety operations at Kaohsiung port.

In summary, the main purpose of this study is to investigate safety operations at ECTs in Taiwan by applying fuzzy risk assessment. The main contribution of this article lies in its definition, conversion, and treatment of vague and complex risk factors. Set membership in fuzzy set theory is employed to develop a practical model for the application of risk assessment to container terminals. We will describe the step-by-step procedures used to perform assessment in the subsequent sections. The following sections present the research methodology, fuzzy risk assessment steps, an empirical case study, and the conclusions.

**Research methodology**

In this section, some of the theoretical concepts and methods used in this article are briefly introduced. These include the triangular fuzzy numbers and algebraic operations, linguistic values, the graded mean integration representation (GMIR) method, and the similarity measure (SM) method.

**Triangular fuzzy numbers and algebraic operations**

Fuzzy set theory is designed to extract 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 that can be described employing set memberships. Once determined and defined, the sets of memberships in possibility distributions can be effectively used in logical reasoning. Because triangular fuzzy numbers are easy to use and easy to interpret, triangular fuzzy numbers are applied throughout this article.

A fuzzy number $A$ in real line $\mathbb{R}$ is a triangular fuzzy number if its membership function $f_A : \mathbb{R} \to [0, 1]$ is

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

with $-\infty < c \leq a \leq b < \infty$. A triangular fuzzy number can be denoted by $(c, a, b)$.

Zadeh’s extension principle and Chen’s function principle are usually employed to perform algebraic operations on fuzzy numbers. Because Zadeh’s extension principle is used extensively, we use this extension principle in this article. Let $A_1 = (c_1, a_1, b_1)$ and $A_2 = (c_2, a_2, b_2)$ be fuzzy numbers, the algebraic operations of any two fuzzy numbers $A_1$ and $A_2$ can be expressed as

1. Fuzzy addition, $\oplus$: $A_1 \oplus A_2 = (c_1 + c_2, a_1 + a_2, b_1 + b_2)$
2. Fuzzy subtraction, $\ominus$: $A_1 \ominus A_2 = (c_1 - b_2, a_1 - a_2, b_1 - c_2)$
3. Fuzzy multiplication, $\otimes$: $A_1 \otimes A_2 = (kc_2, ka_2, kb_2)$, $k \in \mathbb{R}$, $k \geq 0$
4. Fuzzy division, $\oslash$: $A_1 \oslash A_2 = (c_1 / b_2, a_1 / a_2, b_1 / c_2)$, $c_1 > 0$, $c_2 > 0$

**Linguistic values**

Risk frequency refers to a specific risk within a certain period of time, while risk severity refers to the severity of loss caused by a specific risk occurring within a certain period of time. Measures of risk frequency and risk severity usually consist of 5- or 7-point Likert scale, in which the frequency or severity is divided into five or seven levels. However, frequency and severity sometimes do not fit neatly into this type of classification system. For example, we can create a risk matrix with five frequency levels and seven severity levels, resulting in a risk matrix with 35 cells, or we can divide both the frequency and severity into five levels, resulting in a risk matrix with 25 cells.

Linguistic expressions are converted into and represented by triangular fuzzy numbers, which are in turn employed in the preference rating system. However, in a fuzzy decision environment, two preference ratings consisting of fuzzy numbers and linguistic values characterized by fuzzy numbers can be used. Based on practical needs and the need to...
match the algorithms of the fuzzy risk assessment model, DMs may apply one or both of the preference ratings. In this article, the linguistic risk frequency, linguistic risk severity, and linguistic levels of risk values (RVs) are obtained by means of a review of the literature and consultation with seven senior port experts—three senior ECT managers, two senior officers working at Kaohsiung Port Bureau, and two scholars specializing in port and shipping research. In order to obtain sufficient views from ECT circles, three (rather than two) senior ECT managers were selected. Finally, we relied on a committee of seven port-related experts to help us with the preliminary determination of standards for linguistic risk frequency, linguistic risk severity, and linguistic levels of RVs.

In this article, the linguistic sets of risk frequency and risk severity are defined as $RF = \{VR, R, M, O, V\}$ and $RS = \{ES, NS, M, S, VS\}$, where $VR = \text{very rare}$, $R = \text{rare}$, $M = \text{moderate}$, $O = \text{often}$, $VO = \text{very often}$, $ES = \text{extremely slight}$, $NS = \text{not serious}$, $M = \text{moderate}$, $S = \text{severe}$, and $VS = \text{very severe}$. Here, the membership functions of the linguistic values in both frequency and severity sets are subjectively defined as $VR = ES = (0, 0.1, 0.25, 0.4)$, $R = NS = (0.1, 0.25, 0.4)$, $M = (0.3, 0.5, 0.7)$, $O = S = (0.6, 0.75, 0.9)$, and $VO = VS = (0.9, 1, 1)$, respectively. These linguistic values are used to express the linguistic terms of both frequency and severity in the questionnaire. In addition, the linguistic values can be presented in a similar form to the mathematical expression of equation (1) in section “Triangular fuzzy numbers and algebraic operations.” For example, the membership function of linguistic value $R = NS = (0.1, 0.25, 0.4)$ can be expressed as

$$f_R(x) = f_{NS}(x) = \begin{cases} (x - 0.1)/0.15, & 0.1 \leq x \leq 0.25 \\ (0.4 - x)/0.15, & 0.25 \leq x \leq 0.4 \\ 0, & \text{otherwise} \end{cases}$$

To save space, the membership functions of the other linguistic values are omitted since they are analogous to the above-mentioned expression.

In this article, we define RVs as the values resulting from the multiplication of risk frequency and risk severity. Since the risk rating matrix must be classified based on different frequencies and severities, the RVs are subjectively divided into three risk areas (RAs) according to references in the literature and experts’ opinions. The set of linguistic levels of RAs in this study is defined as $RA = \{LR, MR, HR\}$, where $LR = \text{low-risk area}$, $MR = \text{medium-risk area}$, and $HR = \text{high-risk area}$. Here, the membership functions of the linguistic levels of RAs are aggregated from the seven experts’ opinions, and these are subjectively defined as $LR = (0, 0.01, 0.15)$, $MR = (0.04, 0.15, 0.45)$, and $HR = (0.30, 0.45, 1)$, respectively. Furthermore, after referring to linguistic risk level concepts in the study of Lavasani et al., we employed the extension of fuzzy risk assessment to both quantitative and qualitative data in proposing a fuzzy aggregate risk assessment model.

**GMIR method**

Various methods can be used to perform defuzzification of triangular fuzzy numbers. A simple and powerful method, the GMIR method, which was proposed by Chen and Hsieh, is employed to defuzzify triangular fuzzy numbers in this article.

Let $A_i = (a_i, b_i, c_i), \ i = 1, 2, \ldots, n$, be $n$ triangular fuzzy numbers. Employing the GMIR method, the GMIR value $P(A_i)$ of $A_i$ is

$$P(A_i) = \frac{c_i + 4a_i + b_i}{6}$$

Suppose $P(A_i)$ and $P(A_j)$ are the GMIR values of the triangular fuzzy numbers $A_i$ and $A_j$, respectively. We define

(i) $A_i > A_j \iff P(A_i) > P(A_j)$
(ii) $A_i < A_j \iff P(A_i) < P(A_j)$
(iii) $A_i = A_j \iff P(A_i) = P(A_j)$

**SM method**

In the real world, there may be differences of opinion among experts or DMs. Integrating the linguistic RVs of all DMs’ opinions is an important issue in a fuzzy environment, and the SM approach can be used to resolve this problem. An easy-to-use variant of the SM method, proposed by Yang et al. in 2005, is used to justify the linguistic level of RA of each risk factor in this article.

Let $A_1 = (c_1, a_1, b_1)$ and $A_2 = (c_2, a_2, b_2)$ be triangular fuzzy numbers, the SM of fuzzy numbers $A_1$ and $A_2$ can thus be expressed as

$$S(A_1, A_2) = \begin{cases} 1, & \text{if } A_1 = A_2 \\ \exp(-d^2(A_1, A_2)/\sigma), & \text{if } A_1 \neq A_2 \end{cases}$$

where

$$d^2(A_1, A_2) = (a_1 - a_2)^2 + \frac{(c_1 + a_1) - (c_2 + a_2))^2}{4}$$

$$+ \frac{(b_1 + a_1) - (b_2 + a_2))^2}{4}$$

$$\sigma = \frac{(D_1 + D_2)}{2} + \frac{|c_1 - c_2| + |b_1 - b_2|}{8}$$

$$D_1 = \frac{1}{2}|(a_1 + c_1) - (a_2 + c_2)|$$

$$D_2 = \frac{1}{2}|(a_1 + b_1) - (a_2 + b_2)|$$
Fuzzy risk assessment steps

Three risk assessment steps, namely, (1) risk identification, (2) risk analysis and evaluation, and (3) formulation of risk strategies, are usually employed in conventional risk research. However, because the risk factors in MCDM evaluation problems are usually subjective, uncertain, ambiguous, and fuzzy due to incomplete information, the linguistic values of fuzzy set theory are employed in the second step (i.e. risk analysis and evaluation) of risk assessment. The following is a description of the method used to perform fuzzy risk assessment of safety operations in ECTs at Kaohsiung port.

Risk identification

Canale et al. stated that experience, common sense, and specific risk management tools can be used to aid risk identification employing the “five Ms” model: man, machine, media, management, and mission. This model also involves (1) relevant people working in an ECT, such as stevedores and gantry crane operators; (2) relevant machines and equipment, such as straddle carriers and container fork lifts; (3) operating spaces and environments, such as dynamic routes between berths and yards and illumination; (4) relevant operational management systems, such as standard operating procedures (SOPs) and on-the-job training and orientation education; and (5) the desired outcome, that is, the results of the first three Ms’ interactions. Canale et al. pointed out that the first three Ms (i.e. man, machine, and media) interact to produce a successful mission; moreover, management facilitates interaction between the other four Ms (i.e. man, machine, media, and mission). The management dimension is a critical element in this model because the controlling functions affect the risk performance associated with high danger or high safety. This study therefore includes the first four Ms. Furthermore, risk identification in this study was conducted based on a review of the literature and comprehensive interviews were conducted by the authors with senior managers working at Kaohsiung port ECTs. Four dimensions and 16 preliminarily risk factors related to safety operations are considered (see Table 1).

Fuzzy risk analysis and evaluation

A number of studies have employed the “risk matrix model” (RMM) (e.g. the Australian/New Zealand Standard, that is, AS/NZS 4360) to assess placement of risk levels in terms of risk analysis and evaluation. The RMM can help risk managers to develop highly efficient risk management strategies across multiple risk levels in accordance with various risk factors, lessening loss occurrence rates and thereby reducing corporate financial impact.

Markowski and Mannan discuss the traditional RMM when constructing a risk matrix in four steps, namely, (1) categorization and scaling of risk frequency and risk severity, (2) categorization and scaling of output risk index, (3) accumulation of risk-based rules knowledge, and (4) graphical presentation of the risk matrix. Due to the fuzzy and vague characteristics of many risk factors, the traditional RMM can be extended to a fuzzy risk matrix to perform risk assessment in a fuzzy environment. A number of studies, such as the work of Bodea and Dascalu, Dikmen et al., Markowski and Mannan, Nieto-Morote and Ruiz-Vila, and Yilmaz and Ayan, have applied a fuzzy logic model—a very popular risk modeling method—to deal with fuzzy risk inferences. In this study, we provide feasible and practicable directions concerning how to combine the traditional RMM and linguistic values to verify which risk factor belongs in a respective risk area. We employ a straightforward similarity approach—the SM method—to compare the RVs of all risk factors and risk levels, such that each risk factor is assigned to one RA. The systematic steps involved in the fuzzy risk analysis and evaluation are described below.

Step 1. Assess the fuzzy risk frequency (FRF) and fuzzy risk severity (FRS) of each risk factor. Let FRF and FRS, i = 1, 2, ..., m, p = 1, 2, ..., n, be the FRF and FRS, measured by the linguistic values of Likert 5-point scale, given to each risk factor by DM p, respectively.

Step 2. Calculate the fuzzy RV (FRV) of each risk factor i. The FRV can be defined as the values after the multiplication of FRF and FRS.

FRV = FRF ⊗ FRS, i = 1, 2, ..., m,

p = 1, 2, ..., n

Let FRF = (cF, dF, bF) and FRS = (cS, aS, bS), then the FRV of each risk factor i can be represented as

FRV = (cF, aF, bF, aF, bF) = (aV, bV, rV)

Step 3. Calculate the average FRV (AFRV) of each risk factor i. For being easy to represent the equation,
Table 1. Risk factors of safety operations at ECTs of Kaohsiung port.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Risk factors</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man</td>
<td>Operators’ mistakes and faults on operations (R_1)</td>
<td>Identifying these operators’ mistakes and faults on different operations may help with risks monitor.</td>
</tr>
<tr>
<td></td>
<td>Communication misunderstanding (R_2)</td>
<td>When communication problems occur, the risk of accidents might be increased.</td>
</tr>
<tr>
<td></td>
<td>Human carelessness and omissions (R_3)</td>
<td>Majority of the cases of ECTs accidents occur due to human carelessness.</td>
</tr>
<tr>
<td></td>
<td>Execution of the job safety rules and regulations (R_4)</td>
<td>Setting up a good and usual practice in the operations, the errors occurred on this factor might be reduced.</td>
</tr>
<tr>
<td>Machine</td>
<td>Not selecting inherently safety protection of machines and equipment (R_5)</td>
<td>The accidents occurred because the participants do not strictly adhere to these rules and regulations. If the understandings of those measures are built up, then the risk could be reduced in the future.</td>
</tr>
<tr>
<td></td>
<td>Following with normalized operating procedure (R_6)</td>
<td>Safety protective equipment provides a buffer or a cushion along with restraining from the risks incidence.</td>
</tr>
<tr>
<td></td>
<td>A series of checks maintenance (R_7)</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>Requisite safety facilities and equipment tallied with standards (R_8)</td>
<td>The checks are in advance to take precautions against the hazards. Besides, a safety environment can be created by the series of checks and maintenance.</td>
</tr>
<tr>
<td>Media</td>
<td>Drawing up faultlessly dynamic routes in ECTs (R_9)</td>
<td>Many hazards occurred due to the fact that the dynamic routes of the operational areas are ill-advised. Providing a good route plan might reduce the risk emerged.</td>
</tr>
<tr>
<td></td>
<td>Motion countermeasures of special environments (R_{10})</td>
<td>This indicates that the special countermeasures should be made in the special environments, for example, typhoons, storms, and violent wind, and receiving DG cargoes or special containers.</td>
</tr>
<tr>
<td></td>
<td>Illuminative improvements (R_{11})</td>
<td>The improvements of the replacements on the illuminative facilities could promote the safety performance at night working.</td>
</tr>
<tr>
<td></td>
<td>Automation of operations (R_{12})</td>
<td>Constructing the environment of automation would increase the efficiency and effectiveness of different operations, as well as reduce the operational risks.</td>
</tr>
<tr>
<td>Management</td>
<td>Carrying out the SOPs (R_{13})</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>On-the-job training and orientation education (R_{14})</td>
<td>All steps of SOPs should be notified to the participated workers during the job training and orientation education. 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.</td>
</tr>
<tr>
<td></td>
<td>Not performing a safety auditing and safety inspection (R_{15})</td>
<td>Safety auditing and safety inspection can be guided to strengthen the human safety behavior and weaken the unsafe activities occurred.</td>
</tr>
<tr>
<td></td>
<td>Top manager support to strengthen the safety climate (R_{16})</td>
<td>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.</td>
</tr>
</tbody>
</table>

ECT: exclusive container terminal; DG: dangerous; SOP: standard operating procedure.

We suppose the experts’ weights are equal. Then, the AFRV of each risk factor \(i\) can be denoted as

\[
AFRV_i = \frac{1}{n} \otimes \sum_{p=1}^{n} FRV_{ip}^p
\]

Let \(FRV_{ip}^p = (q_{ip}^p, o_{ip}^p, r_{ip}^p), i = 1, 2, \ldots, m, p = 1, 2, \ldots, n\), be the FRV of each risk factor \(i\), then the AFRV of each risk factor \(i\) can be denoted as

\[
AFRV_i = \frac{1}{n} \otimes (FRV_{i1}^1 \oplus FRV_{i2}^2 \oplus \cdots \oplus FRV_{in}^n) = (Y_i, Q_i, Z_i)
\]

where \(Y_i = \frac{1}{n} \sum_{p=1}^{n} q_{ip}^p, Q_i = \frac{1}{n} \sum_{p=1}^{n} o_{ip}^p\) and \(Z_i = \frac{1}{n} \sum_{p=1}^{n} r_{ip}^p\)

**Step 4.** Compare the AFRV\(_i\) and three linguistic risk levels. Using the linguistic values and the SM method, the RA of each risk factor can be effectively determined.

### Risk strategies

Risk management strategies are often divided into categories of risk control and risk financing.\(^{36–38}\) The former refers to the strategies or measures intended to reduce the risk occurrence rate and loss frequency and thereby preventing and reducing losses. Common risk control strategies or measures include risk avoidance, risk transfer, loss prevention, and loss reduction. The
latter refers to financial planning to ensure the availability of funds to quickly restore the situation prior to risk occurrences. Common risks financing strategies or measures include reserve contributions, credit financing, and insurance. In this article, some risk strategies are suggested after risk analysis and evaluation.

Case study

Questionnaire and data collection

Data concerning the four dimensions and 16 risk factors were collected via a questionnaire (see the Appendix), which was divided into three parts: Part I introduced the risk factors, Part II collected basic information data concerning the participants, and Part III measured risk frequency and severity using Likert 5-point scales concerning the 16 risk factors. The Likert 5-point scales ranged from “1” for “very rare” to “5” for “very often” in the case of risk frequency and from “1” for “extremely slight” to “5” for “very severe” in the case of risk severity.

A pretest was conducted in the process of designing the questionnaire items: Five senior experts working at ECTs, five senior officers working at the Kaohsiung Port Bureau, and five academic scholars specializing in port and shipping research were asked to evaluate the questionnaire pretest. A few items’ wording or explanations were modified to reflect the pretest results.

With regard to reliability analysis, Cronbach’s α was used to measure the consistency of all risk factors in each dimension. Our reliability analysis revealed that coefficients for risk frequency and risk severity were 0.874 and 0.862, respectively; the fact that both of these coefficients for risk frequency and risk severity were in each dimension. Our reliability analysis revealed that coefficients for risk frequency and risk severity were 0.874 and 0.862, respectively; the fact that both of these coefficients were used to measure the consistency of all risk factors.

The questionnaire was completed by employees working at Kaohsiung port ECTs. Most ECT operators were invited to complete the questionnaires. To increase the response rate, questionnaire could be completed and returned by mail or e-mail, over the phone, or were completed during interviews conducted by the authors. We used an effective follow-up method to increase the response rate—for example, mail and e-mail messages were sent to respondents three times over a period of 3 months during the data collection period. Regarding the data collected through phone calls and in-person interviews, we discussed the research issues and collected the responses. To prevent sampling bias, invalid questionnaires were discarded. Although each data collection technique employed was associated with many types of bias, sufficient guidance was provided to prevent sampling bias. A total of 63 valid samples were collected out of the 100 questionnaires distributed.

Results and discussions

The preliminary results of the GMIR values and ranks are shown in Table 2: the analysis of accident risk factors associated with safety operations are summarized as follows.

The GMIR values of the top three risk factors in terms of frequency were in the order of “communication misunderstandings (R7),” “human negligence and error (R3),” and “operators’ mistakes and faults (R1),” respectively. It is worth noting that these three risk factors are all derived from the “man” dimension. This dimension is usually the “area of greatest variability and thus the majority of risk.” It has been asserted that more than 53% of marine and port accidents result from human error. Shiu et al. also indicated that most accidents are caused by human negligence. As a consequence, implementing human safety management within the operating process is an important issue for ECTOs and should be investigated further.

Conversely, the GMIR values of the lowest three risk factors were in the order of “carrying out SOPs (R13),” “a series of maintenance checks (R7),” “requisite safety facilities and equipment meeting standards (R8),” respectively. The empirical results showed that the SOPs are actually implemented by ECTOs, where these SOPs refer to unique procedures helping to eliminate accidents. If all SOPs are followed during operations, the frequency of accidents may decrease. Incidents connected with the other two risk factors have a lower risk probability than the others. In the case of the two risk factors from the “machine” dimension, better compliance with SOPs is needed to help diminish the risk frequency.

The GMIR values of the top three risks of factor severity were in the order of “human negligence and error (R3),” “not selecting safeguards for machines and equipment (R8),” and “implementation of on-the-job safety rules and regulations (R4),” respectively. These are all risk factors that can cause extensive damage. Specifically, “human negligence and error (R3)” was associated with both the risk frequency and risk severity categories, which suggests that a clear understanding of job safety rules and regulations is critical for ECTOs. The empirical results show that operators may face increased costs if they do not adhere to job safety rules and regulations. It would be prudent for ECTOs
to stress these rules and regulations as part of their terminal operations training programs.

Conversely, the GMIR values of the lowest three factors of risk severity were “drawing up faultless dynamic routes in ECTs (R9),” “improved illumination (R11),” and “automation of operations (R12),” respectively. The empirical results also show that these three risk factors were all derived from the “media” dimension. It is important to recognize, however, that losses and damages associated with operating spaces and environments may be lower than those associated with other risk factors. Nevertheless, this cannot lead to the assumption that these three factors are not important in safety work, since they occur frequently in terminal operations.

We subsequently used the steps in section “Fuzzy risk analysis and evaluation” to evaluate the risk levels of each risk factor. The SM method was used to determine the RA. The similarity values were calculated by comparing the AFRV of each risk factor and linguistic risk level. Finally, the risk position of each risk factor was identified. The results of fuzzy risk analysis and evaluation are shown in Table 3. In summary, three risk factors are located in the HR. They are “operators’ mistakes and faults (R1),” “communication misunderstandings (R2),” and “human negligence and error (R3).” The other 13 risk factors are located in the MR. No risk factors are located in the LR.

As mentioned previously, when considering the actual occurrence of different risk factors within the operational process at Kaohsiung port ECTs, the risk strategies for the various risk factors were obtained from relevant literature1–3,23,25,26,29 and interviews with ECT experts and scholars. We conclude that when the severity of loss is high, risk retention is unrealistic. On the other hand, when there is a high probability of loss associated with a specific incident, the cost of insurance will also be high. Some risk solution techniques will consequently be necessary.

Risk strategies15,19,23,29,36–38,41–44 can be divided into three categories: risk prevention, risk reduction, and risk transfers. Incidents characterized by high frequency and low severity are most appropriately dealt with through risk prevention, which lowers the probability of an incident. Incidents with low frequency and high severity call for risk reduction, to minimize the aggregate amount of losses that must be borne. In addition,

| Table 2. The preliminary results of risk frequency and risk severity. |
|-----------------|------------------|-----------------|-----------------|------------------|-----------------|
| **Risk factors** | **Frequency** | **Severity** |
|                 | Average fuzzy   | GMIR values     | Rank | Average fuzzy   | GMIR values     | Rank |
| **GMIR**        | **risk frequency** | GMIR values     | Rank | **risk frequency** | GMIR values     | Rank |
| R1              | (0.294, 0.456, 0.622) | 0.457 3 | (0.513, 0.667, 0.806) | 0.664 4 |
| R2              | (0.348, 0.512, 0.675) | 0.512 1 | (0.451, 0.615, 0.771) | 0.614 9 |
| R3              | (0.325, 0.472, 0.624) | 0.473 2 | (0.554, 0.706, 0.835) | 0.702 1 |
| R4              | (0.251, 0.397, 0.548) | 0.398 5 | (0.532, 0.683, 0.817) | 0.680 3 |
| R5              | (0.198, 0.325, 0.468) | 0.328 10 | (0.570, 0.706, 0.816) | 0.702 1 |
| R6              | (0.241, 0.365, 0.505) | 0.368 6 | (0.50, 0.65, 0.798) | 0.653 6 |
| R7              | (0.171, 0.282, 0.419) | 0.286 15 | (0.484, 0.631, 0.760) | 0.628 7 |
| R8              | (0.135, 0.226, 0.360) | 0.233 16 | (0.537, 0.663, 0.762) | 0.658 5 |
| R9              | (0.263, 0.405, 0.548) | 0.405 4 | (0.429, 0.571, 0.703) | 0.570 14 |
| R10             | (0.217, 0.345, 0.489) | 0.348 7 | (0.475, 0.619, 0.751) | 0.617 8 |
| R11             | (0.183, 0.294, 0.435) | 0.299 12 | (0.378, 0.528, 0.673) | 0.527 15 |
| R12             | (0.214, 0.337, 0.486) | 0.342 9 | (0.349, 0.492, 0.641) | 0.493 16 |
| R13             | (0.183, 0.282, 0.413) | 0.287 14 | (0.452, 0.587, 0.717) | 0.587 12 |
| R14             | (0.178, 0.294, 0.435) | 0.298 13 | (0.457, 0.595, 0.724) | 0.594 11 |
| R15             | (0.225, 0.341, 0.476) | 0.344 8 | (0.456, 0.599, 0.735) | 0.598 10 |
| R16             | (0.206, 0.310, 0.446) | 0.315 11 | (0.435, 0.575, 0.706) | 0.574 13 |

ECT: exclusive container terminal; SOP: standard operating procedure; GMIR: graded mean integration representation.
some situations may call for risk transfer to shift the risk to a third party by way of an insurance contract or disclaimer agreement. These three strategies are discussed in greater detail below.

1. **Risk prevention.** Risk countermeasures can be taken before the occurrence of an incident to reduce the possibility of loss. Such countermeasures may include the strengthening of on-the-job training, the thorough implementation of SOPs, the restriction of the driving speed of container trailers within container terminal areas, and the requirement that trailers drive on fixed routes.

2. **Risk reduction.** Risk strategies seeking to reduce the impact of an incident may be taken before or after the incident occurs. Such measures may include the maintenance of operating equipment, the replacement of obsolete and run-down equipment and tools, and the strengthening emergency and contingency system exercises.

### Table 3. Results of fuzzy risk analysis and evaluation.

<table>
<thead>
<tr>
<th>Factors</th>
<th>$AFRV_i$</th>
<th>Linguistic risk levels</th>
<th>$S(A_i, A_j)$</th>
<th>Risk position</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>(0.2189, 0.3829, 0.5616)</td>
<td>L</td>
<td>0.4067</td>
<td>HR</td>
</tr>
<tr>
<td>$R_2$</td>
<td>(0.1768, 0.3355, 0.5405)</td>
<td>L</td>
<td>0.4532</td>
<td>HR</td>
</tr>
<tr>
<td>$R_3$</td>
<td>(0.3195, 0.4934, 0.6716)</td>
<td>L</td>
<td>0.3129</td>
<td>HR</td>
</tr>
<tr>
<td>$R_4$</td>
<td>(0.1505, 0.3059, 0.5079)</td>
<td>L</td>
<td>0.4861</td>
<td>MR</td>
</tr>
<tr>
<td>$R_5$</td>
<td>(0.1302, 0.250, 0.4017)</td>
<td>L</td>
<td>0.5607</td>
<td>MR</td>
</tr>
<tr>
<td>$R_6$</td>
<td>(0.1373, 0.2510, 0.4111)</td>
<td>L</td>
<td>0.5592</td>
<td>MR</td>
</tr>
<tr>
<td>$R_7$</td>
<td>(0.0959, 0.1925, 0.3329)</td>
<td>L</td>
<td>0.6444</td>
<td>MR</td>
</tr>
<tr>
<td>$R_8$</td>
<td>(0.0824, 0.1637, 0.2927)</td>
<td>L</td>
<td>0.6914</td>
<td>MR</td>
</tr>
<tr>
<td>$R_9$</td>
<td>(0.1414, 0.2659, 0.4151)</td>
<td>L</td>
<td>0.5410</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{10}$</td>
<td>(0.1186, 0.2321, 0.3862)</td>
<td>L</td>
<td>0.5850</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{11}$</td>
<td>(0.0821, 0.1706, 0.3103)</td>
<td>L</td>
<td>0.6790</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{12}$</td>
<td>(0.0979, 0.2004, 0.3502)</td>
<td>L</td>
<td>0.6314</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{13}$</td>
<td>(0.0978, 0.1875, 0.3192)</td>
<td>L</td>
<td>0.6530</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{14}$</td>
<td>(0.0975, 0.1954, 0.3363)</td>
<td>L</td>
<td>0.6398</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{15}$</td>
<td>(0.1162, 0.2212, 0.3687)</td>
<td>L</td>
<td>0.6012</td>
<td>MR</td>
</tr>
<tr>
<td>$R_{16}$</td>
<td>(0.1095, 0.2024, 0.3427)</td>
<td>L</td>
<td>0.6298</td>
<td>MR</td>
</tr>
</tbody>
</table>

ECT: exclusive container terminal; SOP: standard operating procedure; HR: high-risk area; MR: medium-risk area.

$L = (0, 0.01, 0.15); M = (0.04, 0.15, 0.45); H = (0.30, 0.45, 1).$
3. **Risk transfer.** Risk transfer strategies seek to transfer risk to others through insurance contracts or other means before an incident. Such strategies may include risk transfer through insurance contracts, the addition of disclaimer agreements in transport contracts, and the outsourcing of the high-risk operations to stevedoring operators.

The philosophy behind risk management is to seek a cost/benefit equilibrium point. The best risk strategy calls for efficient and effective risk reduction performance at the lowest cost. According to our empirical results, the top three risk factors were located in the HR, and the other 13 risk factors were located in the MR. The top three risk factors all belonged to the “man” dimension. The majority of reports in the literature on safety and risk issues indicate that human error is associated with the majority of risk. The following discussion consequently focuses on these three high-risk factors.

First, because operators’ mistakes and operational faults (R1) ranked third and fourth in terms of risk frequency and risk severity among safety operation attributes, respectively, this factor was classified as high risk. This indicates that many accidents occur due to different operating activities. As various operational activities are embedded in SOPs, identifying operator mistakes and faults associated with different operating activities may help to monitor inherent risks. Proposed risk prevention countermeasures include (1) ECTOs can strengthen on-the-job training to reduce potential losses due to human error and (2) ECTOs can reinforce safety standards in the working environment in order to lessen the impact of potential problems. Moreover, ECTOs should also clarify which operating activities should take place under various conditions and consider transferring risk to insurance companies when appropriate, such as by taking out policies covering machines and equipment, accident insurance, or liability insurance.

Second, the safety operation attribute “communication misunderstandings (R2)” ranks first and ninth in terms of risk frequency and risk severity, respectively, and is therefore classified as high risk. Poor communication between operating personnel often results in misunderstandings; the development of risk prevention SOPs should help to decrease the number of accidents associated with poor communication. Action procedures and informational messages pertaining to safety operations can be announced during morning meetings or posted on bulletin boards.

Third, the safety operation attribute “human negligence and error (R3)” ranks second and first in terms of risk frequency and risk severity, respectively, and is therefore located in the HR. This indicates that this risk factor most frequently appears as part of the terminal operations process. Operating personnel carelessness and/or omissions in container terminals often result in costly damage. Risk prevention countermeasures that can be used to avoid such accidents include employing qualified operating personnel who possess professional licenses, strengthening on-the-job training and orientation education, and ensuring that all SOPs are strictly followed. Meanwhile, the adoption of a loss reduction strategy can minimize damages—such as by establishing an emergency organization or holding contingency drills in order to mitigate the impact of accidents caused by human carelessness and/or omissions. A risk transfer strategy can also be employed to reduce human errors; this may include personnel security inspections and the occasional audit of operating personnel behavior. Penalties such as salary deductions for operating personnel who disregard posted regulations may also help limit accidents.

In summary, the principles of risk management can be adopted to address different risk factors, as shown in Table 4. It is suggested that these risk strategies can be applied to the safety operations of ECTs at Kaohsiung port, and these risk strategies can also be widely applied by various industries.

**Conclusions**

There are many risk factors that influence the safety operations of ECTs at Kaohsiung port, and an evaluation of these risk factors in terms of their impact on ECT safety operations is consequently urgent and beneficial to the ECTOs. However, the evaluation of risk management among ECTs usually involves a MCDM problem and imprecise information with subjective and linguistic characteristics. A fuzzy-based method was therefore used in this article to perform risk assessment of the safety operations of ECTs at Kaohsiung port, and the main purpose of this study was to investigate the safety operations of ECTs at Kaohsiung port by applying fuzzy risk assessment.

We used the following three risk assessment steps to evaluate this issue. First, four dimensions with 16 preliminary risk factors were identified from the literature and expert interviews. Subsequently, fuzzy risk analysis and evaluation steps were performed in order to locate the fuzzy risk levels, and the RA of each risk factor was determined using the SM method. Finally, an empirical study was performed. The results showed the following:

1. The top three risk frequency factors are “communication misunderstanding,” “human negligence and error,” and “operators’ mistakes and faults.”
2. The top three risk severity factors are “human negligence and error,” “not selecting safeguards for machines and equipment,” and “implementation of on-the-job safety rules and regulations.”
3. In summary, three risk factors are located in the HR. They are “operators’ mistakes and faults,” “communication misunderstandings,” and “human negligence and error.” The other 13 risk factors are...
located in the MR. There are no risk factors located in the LR in this study.

Risk management strategies are provided in this study based on the frequency of occurrence of various risk factors. However, as an evaluation of risk management costs and benefits is not included, follow-up studies can focus on cost-effective risk reduction using various risk management methods. 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 article 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.

**Funding**

This article is partially based upon the result of the research sponsored by National Science Council of the Republic of China, under the project number of NSC 101-2410-H-309-015.

**Acknowledgement**

The authors gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

**References**


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Appendix

Questionnaire

Main questions. The main questions of this questionnaire are divided into three parts. The descriptions of risk factors and the Likert 5-point scales are first introduced in Part I. Second, the basic data of participants are shown in Part II. Meanwhile, the risk frequency and risk severity by using the Likert 5-point scales are shown in Part III. Please mark a “✓” in the appropriate box if you agree with one of the answers.

Part I: (1) The descriptions of 16 risk factors.

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Operators’ mistakes and faults on operations</td>
<td>Identifying these operators’ mistakes and faults on different operations may help with risks monitor. When communication problems occur, the risk of accidents might be increased.</td>
</tr>
<tr>
<td>2. Communication misunderstanding</td>
<td>Majority of the cases of ECTs accidents occur due to human carelessness. Setting up a good and usual practice in the operations, the errors occurred on this factor might be reduced.</td>
</tr>
</tbody>
</table>

(continued)
Risk factors Descriptions

4. Execution of the job safety rules and regulations
The accidents occurred because the participants do not strictly adhere to these rules and regulations. If the understandings of those measures are built up, then the risk could be reduced in the future.

5. Not selecting inherently safety protection of machines and equipment
Safety protective equipment provides a buffer or a cushion along with restraining from the risks incidence.

6. Following with normalized operating procedure
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.

7. A series of checks maintenance
The checks are in advance to take precautions against the hazards. Besides, a safety environment can be created by the series of checks and maintenance.

8. Requisite safety facilities and equipment tailored with standards
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.

9. Drawing up faultlessly dynamic routes in ECTs
Many hazards occurred due to the fact that the dynamic routes of the operational areas are ill-advised. Providing a good route plan might reduce the risk emerged.

10. Motion countermeasures of special environments
This indicates the special countermeasures should be made in the special environments, for example, typhoons, storms and violent wind, and receiving DG cargoes or special containers.

11. Illuminative improvements
The improvements of the replacements on the illuminative facilities could promote the safety performance at night working.

12. Automation of operations
Constructing the environment of automation would increase the efficiency and effectiveness of different operations, as well as reduce the operational risks.

13. Carrying out the SOPs
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.

14. On-the-job training and orientation education
All steps of SOPs should be notified to the participated workers during the job training and orientation education. 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.

15. Not performing a safety auditing and safety inspection
Safety auditing and safety inspection can be guided to strengthen the human safety behavior and weaken the unsafe activities occurred.

16. Top manager support to strengthen the safety climate
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.

Part I: (2) The Likert 5-point scales of risk frequency and risk severity.

<table>
<thead>
<tr>
<th>Definition of risk frequency</th>
<th>Scale</th>
<th>Definition of risk severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very rare</td>
<td>1</td>
<td>Extremely slight</td>
</tr>
<tr>
<td>Seldom</td>
<td>2</td>
<td>Slight</td>
</tr>
<tr>
<td>Passable</td>
<td>3</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Sometimes</td>
<td>4</td>
<td>Severe</td>
</tr>
<tr>
<td>Very often</td>
<td>5</td>
<td>Very severe</td>
</tr>
</tbody>
</table>

Part II: Your basic data.

(1) Your Company Name and Your Department Name are: ———and———.

(2) Your Job Title is: ☐ general manager or deputy general manager ☐ director or deputy director ☐ manager ☐ staff or sales representative

(3) Your age (years old) is: ☐ 25 or less ☐ 26–30 ☐ 31–40 ☐ 41–50 ☐ 51–60 ☐ 61 and above

(4) The years of your working experience at this company is: ☐ 5 or less ☐ 6–10 ☐ 11–15 ☐ 16–20 ☐ 21–25 ☐ 26 and above
Part III: Impact survey of risk frequency and risk severity.

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Risk frequency</th>
<th>Risk severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Operators’ mistakes and faults on operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Communication misunderstanding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Human carelessness and omissions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Execution of the job safety rules and regulations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Not selecting inherently safety protection of machines and equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Following with normalized operating procedure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. A series of checks maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Requisite safety facilities and equipment tallied with standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Drawing up faultlessly dynamic routes in ECTs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Motion countermeasures of special environments</td>
<td></td>
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</tr>
<tr>
<td>11. Illuminative improvements</td>
<td></td>
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</tr>
<tr>
<td>12. Automation of operations</td>
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</tr>
<tr>
<td>13. Carrying out the SOPs</td>
<td></td>
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<td>14. On-the-job training and orientation education</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Not performing a safety auditing and safety inspection</td>
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<td></td>
</tr>
<tr>
<td>16. Top manager support to strengthen the safety climate</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>