THE SAFETY OF SHIP BERTHING OPERATIONS AT PORT DOCK – A GAP ASSESSMENT MODEL BASED ON FUZZY AHP

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Wen-Kai K. Hsu, Department of Shipping & Transportation Management, National Kaohsiung Marine University, and **Jui-Chung Kao**, Graduate institute of Marine Affairs & Business Administration, National Kaohsiung Marine University, Taiwan, R.O.C.

SUMMARY

The purpose of this paper is to discuss the safety of ship berthing operations at port dock. Based on the features of ship's berthing operations and the relevant literature, the safety factors (SFs) of ship berthing at port docks are first investigated. A gap assessment model based on Fuzzy AHP is then proposed to assess the perceived differences on those SFs between port marine pilots and shipmasters. Finally, the ships' berthing operations at Kaohsiung Port in Taiwan were employed to illustrate the model's practical application. The result may provide practical information for both marine pilots and shipmasters to improve the safety performance of ship berthing operations at port docks.

NOMENCLATURE

SF	Safety factor
HF	Human factor
ME	Machinery and equipment
PM	Port management
PF	Port facility
CI	Consistency index
CR	Consistency rate
MW	Marine pilot's weight on SFs
SW	Shipmaster's weight on SFs
GAM	Gap assessment model
WGI	Weight gap index
RGI	Rank gap index

1. INTRODUCTION

Recently, the ships in the world are not only becoming faster and larger, but also rapidly increasing in quantity, leading to raising maritime accidents (Hsu, 2012). A historic statistic indicated that the frequency of ship accidents during 12-20th century significantly increased from 59% in the past decade to 83% in the last 20 years (Darbra and Casal, 2004).

Generally, the most common damages caused by ship accidents include ship crash, port facility destruction, cargo damage and human casualty. In practice, those damages may affect the reputations of shipping carriers and port companies, leading to diminish their businesses. Further, more seriously, a ship accident may cause fuel oil leakage, leading to port pollution. For example, a classical case is the oil spill accident of Hebei Spirt in 2007 in Korea. The government officials called it the South Korea's worst oil spill ever. At least 30 beaches have been affected and over half of the region's sea farms are believed to have lost their stocks due to the spill. The cost of cleanup has been estimated at $330 million (Wikipedia, 2017). Since the losses from a ship accident can be so enormous, many port authorities in worldwide have paid attention to reducing the ship accidents in port (Debnath *et al*., 2011).

In practice, collision is the most frequent maritime accident (Debnath and Chin, 2010; Hsu, 2012; Alyami, 2014), and is the most commonly occur when ship berths at port dock (Hsu, 2012). Thus, to reduce ship accidents, issues related to ship berthing safety at port dock should be considered (Hsu, 2015). Further, for ship berthing operations, marine pilot and shipmaster are both of the most important key men. In practice, their close cooperation may greatly contribute to the ship berthing safety. Thus, how to reduce their perceived difference in ship berthing operations is another important issue that should be concerned. Unfortunately, in the relevant literature, there are few studies on those topics.

The purpose of this paper is to discuss the determinants of ship berthing safety at port dock. Based on the relevant literature and the features of ship's berthing operations, the safety factors (SFs) of ship berthing at port docks are first investigated. Since ship berthing safety is a highly professional issue, a fuzzy AHP model is thus constructed to weights those SFs from both perspectives of marine pilots and shipmasters. Based on those weights, a gap assessment model is finally proposed to assess their perceived differences on the SFs. Finally, the ships' berthing operations at Kaohsiung Port in Taiwan were empirically investigated to explain how to apply the model in practice. The rest of this paper is organized as follows. Section 2 reviews the literature. Section 3 explains the research method in this paper. The results are then examined in Section 4. Finally, some general conclusions and limitations for further research are given.

2. LITERATURE REVIEWS

Based on the practical operations of ship berthing, this paper reviews the determinants of ship berthing safety from ship's internal and external operational environments. The former contains ship crews and ship machinery, and the latter includes: marine pilot, tugboat operation, dock operation and port management policy.

2.1 THE INTERNAL FACTORS

2.1(a) Ship crews

In practice, the ship crew factor for ship berthing safety includes the ship crews' operational skills and their work attitudes in cooperating with the mariner pilot. The relevant literature showed the ship crews' professional skills and work attitudes have significant effects on navigation safety (Hsu, 2012). Communication and interpersonal relationships among crews significantly influence the reporting performance of shipping accidents, and so do the feedbacks from crews to the shipmaster (Oltedal and McArthur, 2011). Further, in practice, the ship crews need to work in shifts. Therefore, their physical and mental health may influence ship navigation safety (Hsu, 2012). Previous studies showed there were potentially disastrous outcomes from fatigue in terms of poor health (Hetherington, 2006).

2.1(b) Ship machinery

The previous studies indicated machinery failure (Hsu 2012) and vessel performance (Liu et al., 2005) may increases marine disasters. The type, size, age and condition of a vessel at accidents significantly affect the ship loss (Kokotos and Smirlis, 2005). The performances of machinery for ship berthing operations, including steering gear, windlass on dock, bow thruster etc., may affect the ship berthing safety (Hsu, 2015).

2.2 THE EXTERNAL FACTORS

2.2 (a) Marine pilot

In practice, marine pilot is the main commander in ship berthing operations. Thus, their professional skills should be a significant determinant of ship berthing safety. Practically, during ship berthing operations, the marine pilot needs to give steering orders to the ship crews who may come from different areas and speak different languages. Thus, poor communication may lead to crews' misunderstanding and, as a result, increase ship's berthing accidents. Therefore, in addition to professional skills, the marine pilot's language and communication abilities may also be an important determinant of ship berthing safety. Relevant studies indicated that poor communications between crews and marine pilot significantly affect the safety of ship navigation in ports (Hetherington *et al*., 2006; Darbra *et al*., 2007; Hsu, 2012). The language and cultural differences of seafarers may affect the shipping safety (Hetherington. *et al*., 2006; Knudsen and Hassler, 2011).

2.2 (b) Tugboat operation

In practice, tugboats could assist a ship in berthing alongside and departing from docks by pushing and towing the ship. Relevant studies showed that tugboat failure is one of the determinants of marine accidents in ports (Darbra et al., 2007). Further, the factors affecting the tugboat performances include the number of tugboats, the horse powers of the tugboats, and the operating skills of the tugboat drivers (Hsu, 2012).

2.2 (c) Dock operational environment

For ship berthing operations, the dock operational environment includes two parts: the line handling operation and the dock facility. The former contains linemen, line handling boat and the windlass on the dock. Previous studies showed that the operating skills and work attitudes of linemen have significant effects on ship navigation safety in port (Hsu, 2012). The operating location of the line handling boat and the number of windlass on the dock may affect ship berthing safety (Paulauskas; 2006). As for the dock facility, the berth's length usually is the most important determinant of ship berthing safety. In practice, for providing enough space for ship mooring operations, the berth's length should be at least 1.2 times longer than the berthing vessel (Liu et al., 2006). However, due to the trend of large-sized ship development, the space may frequently be squeezed, leading to increase collisions between neighboring ships.

2.2 (d) Port regulations

To improve port safety, port authorities may develop rules to regulate the ships' operations in port. For example, in Kaohsiung port, the regulations for ship's berthing operations include: *Ship navigation regulations in port*, *Marine pilot laws, Tugboat operator regulations* and *Line handling operator regulations*. Relevant studies showed that safety management system in port is an important determinant of operational safety offshore (Wang, 2002). However, in practice, the operators may not comply with the regulations completely, and further those regulations may not be developed perfectly.

2.2 (e) Port policy

For improving businesses, port authorities may allow excessive ships to enter port simultaneously. This may lead to rush ship berthing operations, increasing ship collisions. Relevant studies showed that the risks of ship collision increase with the density of ships at a particular water area (Hsu, 2015). Further, another policy for improving port's businesses is to speed up the logistical operations of terminals. This may lead to haste the berthing operations, also increasing ship accidents (Hsu, 2012).

3. RESEARCH METHOD

3.1 RESEARCH FRAMEWORK

The research framework of this paper is shown in Figure 1. The safety factors (SFs) for ship's berthing operations are first investigated. A fuzzy AHP model is then proposed to weight the SFs from both marine pilots and shipmasters. Based on those two weights, a gap assessment model is finally constructed. Finally, the ships berthed at Kaohsiung port in Taiwan were empirically investigated to illustrate the practical application of the model.

3.2 MEASUREMENT OF SAFETY FACTORS

3.2 (a) The definitions of safety factors

Based on the relevant literature and interviews with several practical marine pilots and shipments, we reorganized the determinants mentioned in Section 2 and identified the safety factors (SFs) as four dimensions, in which the weather and geography is not considered for it is a natural factor,

(1) Human factor (HF)

For ship berthing operations, the operators include marine pilot, ship crews, turbot drivers and linemen on dock. Thus, the human factor is defined as those operators' capabilities, such as professional skill, communication, emergency handling and working concentration, etc. (Hetherington *et al*., 2006; Darbra *et al*., 2007; Knudsen and Hassler, 2011; Hsu, 2012; Ding and Tseng, 2013; Hsu 2015).

(2) Machinery and equipment (ME)

This factor is defined as the conditions of machines and equipment onboard ship and on dock for the ship's berthing operations, such as the main engine, steering engine and deck machines (windlasses) onboard ship, and the turbots and mooring lines on dock. (Paulauskas; 2006; Darbra *et al*., 2007; Liu *et al*., 2006; Hsu, 2012; Hsu, 2015).

(3) Port management (PM)

This factor contains both port regulation and pot policy. It is defined as the completeness and performance of the regulations about ship's berthing operations in port, and the policy for improving the port's businesses, such as speeding up the logistical operations of the port, allowing excessive ships to stay in port, etc. (Paulauskas; 2006; Debnath *et al*., 2011; Hsu, 2012; Hsu 2015).

(4) Port facility (PF)

This factor is defined as the infrastructures and equipment of the dock for ship's berthing operations, such as the berth length, the situation of bollard and pads on dock, etc. (Paulauskas ; 2006; Liu *et al*., 2006; Tai and Yang, 2016).

Based on the above definitions, a two-layer hierarchy structure of SFs for ship berthing safety was first created. For improving the practical validity of the SFs, two experts (one marine pilot and one shipmaster) were then asked to revise those SFs and check if any important SFs were missed. Further, they also were asked to check the independences among the SFs. After several rounds of discussions and modifications, the final hierarchy structure of the SFs, shown in Table 1, contains four dimensions of SFs for the first layer and 14 SFs for the second layer.

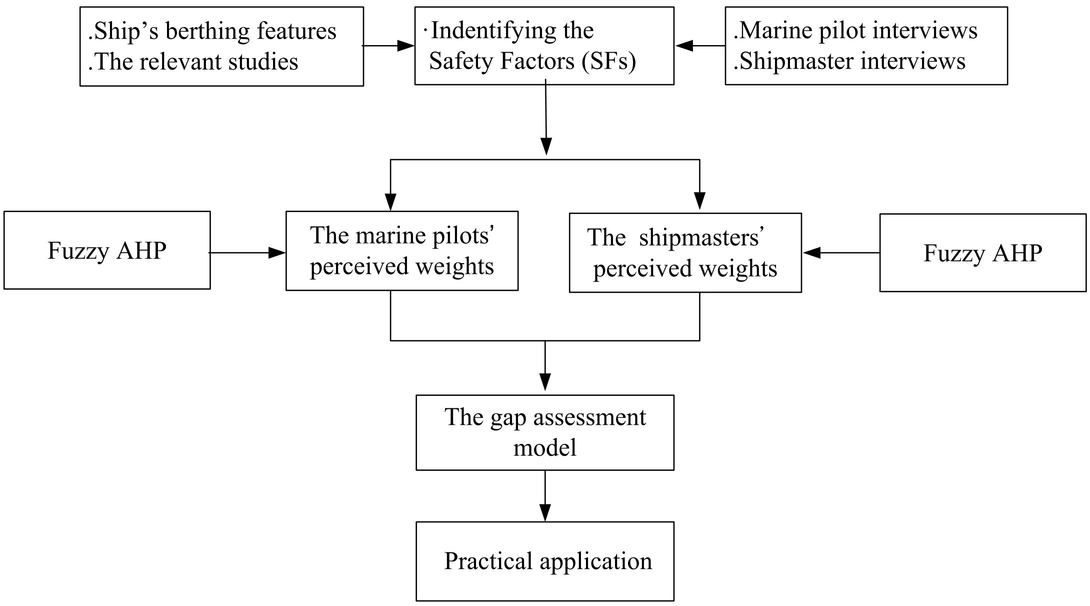

Figure 1. Research framework.

Table 1. Hierarchical structure of safety factors (SFs) for ship berthing operations

Layer 1: Construct		Layer 2: Safety factors (SFs)
Human factors (HF)	HF1	Professional skills.
	HF2	Communications.
	HF3	Emergency response.
	HF4	Working concentration.
Machinery (ME)	ME1	The conditions of the main engine and steering engine.
	ME2	The number and condition of the tugboats.
	ME3	The number and condition of the windlasses.
	ME4	The condition of the mooring lines.
Port management (PM)	PM1	The completeness of the port's rule and regulations.
	PM2	The performance of the port's rule and regulations.
	PM3	The port policy for improving business.
Port facility (PF)	PF1	The width and depth of the main channel.
	PF2	The berth's length
	PF3	The shore equipment, such as bollard and pads.

Table 2: Profile of the respondents

Characteristics	Range	Marin pilot		Shipmaster	
		Frequency	%	Frequency	%
Experience	5-10	2	14.29	5	26.32
	10-15	2	14.29	3	15.78
	16-20	3	21.42	5	26.32
	Above 20	7	50.00	6	31.58
Age (years)	40-50	1	7.14	5	26.32
	51-55	4	28.57	6	31.58
	56-60	5	35.72	6	31.58
	Above 60	4	28.57	2	10.52
Education level	Master	1	7.14	2	10.52
	University	5	35.72	15	78.95
	College	8	57.14	2	10.53

3.2 (b) Questionnaire design

In this paper, an AHP survey with a nine point rating scale was designed to measure subject's perceived importance on SFs. Based on the hierarchical structure of SFs in Table 1, an AHP survey, shown in Appendix, with five criteria and 14 sub-criteria was created. To validate the scale, the survey was then pre-tested by two experts, who revised the SFs previously, to check if the statements in the survey were understandable.

3.2 (c) Research sample

Since both of marine pilot and shipmaster are the main characters in ship's berthing operations, the marine pilots of Kaohsiung Port and the shipmasters berthing ships at Kaohsiung Port were surveyed in this paper. To enhance the validity of the survey, an assistant was dispatched to help each subject fill out the survey. In this paper, the research sample contains 20 marine pilots and 20 shipmasters.

For each of the sample, the consistency index (CI) was first calculated to test the consistency of its pairwise comparison matrix. The results indicated seven samples with CI > 0.1 were highly inconsistent (Saaty, 1980), including 6 marine pilot samples and 1 shipmaster sample. Therefore, those questionnaires were discarded, and thus only 33 valid surveys were remained in this paper. The profiles of the validated respondents' characteristics are shown in Table 2. It shows that, for marine pilot samples, all of the subjects have at least 10 years of experience with over 80% respondents having over 20 years. For shipmasters, all of the respondents have at least 10 years of experience with over 40% respondents having over 20 years. Note, the remarkable qualifications of the respondents could endorse the reliability of the survey.

3.3 THE WEIGHTS OF SAFETY FACTORS

From the sample data, 33 pairwise comparison matrices (14 marine pilot and 19 shipmasters) were obtained. In the traditional AHP, an arithmetic mean is used to integrate the multiple subjects' opinions. However, the arithmetic mean is usually sensitive to extreme values. Thus, we adopt fuzzy AHP to integrate the subjects' perceptions. In this paper, we first used the geometric mean to measure the consensus of the subjects (Buckley 1985; Saaty 1980). Then, a triangular fuzzy number characterized by minimum, geometric mean and maximum of the measuring scores was constructed to integrate the 33 pairwise comparison matrices into two fuzzy positive reciprocal matrix, one for marine pilot samples and one for shipmaster samples. Finally, based on those fuzzy reciprocal matrices, a fuzzy AHP approach was conducted to weight the SFs, including both of the measurements of marine pilots and shipmasters (Hsu *et al*., 2015).

3.3 (a) The fuzzy positive reciprocal matrix

Suppose $\tilde{A}=[\tilde{a}_{ij}]_{n\times n}$ be a fuzzy positive reciprocal matrix with n SFs, where $\tilde{a}_{ij}=[l_{ij},\ m_{ij},\ u_{ij}]$ is a triangular fuzzy number with

$$[l_{ij},\ m_{ij},\ u_{ij}]=\begin{cases}[1,\ 1,\ 1], & \text{if } i=j\\ [1/u_{ji},\ 1/m_{ji},\ 1/l_{ji}], & \text{if } i\neq j\end{cases}.$$

Let $A^{(k)}=\left[a_{ij}^{(k)}\right]_{n\times n}$, $k=1,2,...,m$, denote the pair-wise comparison matrix of m subjects. Then, according to the abovementioned integration procedure, those m matrices can be integrated into the following fuzzy matrix:

$$\tilde{A}=\left[\tilde{a}_{ij}\right]_{n\times n} \tag{1}$$

where $\tilde{a}_{ij}=\left[\min_{1\le k\le m}\left\{a_{ij}^{(k)}\right\},\left(\prod_{k=1}^{m}a_{ij}^{(k)}\right)^{1/m},\max_{1\le k\le m}\left\{a_{ij}^{(k)}\right\}\right]$ is a triangular fuzzy number, $i=1,2,...,n$, $j=1,2,...,n$ and $k=1,2,...,m$.

3.3 (b) The consistency tests

Since the $\tilde{A}$ is a fuzzy numbers, its consistency cannot be tested directly as traditional AHP. In this paper, the geometric means is first employed to defuzzify the criteria in $\tilde{A}$ (i.e. the $\tilde{a}_{ij}$ $i=1,2,...,n$, $j=1,2,...,n$) by the form of trapezoid fuzzy number, and thus convert the $\tilde{A}$ into a crisp matrix. Then, the consistency test is undertaken to the test the crisp matrix as traditional AHP (Buckley, 1985). Since $\tilde{A}$ is a triangular fuzzy number with parameter $\tilde{a}_{ij}=[l_{ij},\ m_{ij},\ u_{ij}]$, its trapezoid fuzzy number form is $a_{ij}=[l_{ij},\ m_{ij},\ m_{ij},\ u_{ij}]$. Thus, those a_{ij} can be defuzzified as:

$$a_{ij}=(l_{ij}\cdot m_{ij}\cdot m_{ij}\cdot u_{ij})^{1/4},\ i=1,2,...,n,\ j=1,2,...,n \tag{2}$$

In traditional AHP, both of indexes CI (Consistency Index) and CR (Consistency Ratio) are usually used to test the consistency of its positive reciprocal matrix:

$$\mathrm{CI}=\frac{\lambda_{\max}-n}{n-1} \tag{3}$$

and

$$\mathrm{CR}=\frac{\mathrm{CI}}{\mathrm{RI}} \tag{4}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the positive reciprocal matrix and n is the number of criteria in the matrix. The RI represents a randomized index, whose values are shown in Table 3 (Hsu *et al*, 2015). Saaty (1980) suggested that a value for $\mathrm{CR}\le 0.1$ is an acceptable range for the consistency test of the matrix.

The results of consistency tests for both the pairwise comparison matrices, marine pilot sample and shipmaster sample, are listed in Table 4. Since all of the C.R. indexes in Table 4 are less than 0.1, all of the positive reciprocal matrixes in the sample data are consistent.

Table 3. The randomized index (RI)

n	3	4	5	6	7	8	9	10	11	12
R.I.	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

Table 4. The results of the consistency tests.

pairwise comparison matrices	Layer	C.I.	R.I.	C.R. (C.I./R.I.)
Marine pilot	Layer 1	0.076	1.115	0.068
	Layer2: HF	0.085	0.882	0.096
	Layer2: ME	0.071	0.882	0.080
	Layer2: PM	0.028	0.525	0.053
	Layer2: PF	0.053	0.882	0.060
Shipmaster	Layer 1	0.034	1.115	0.030
	Layer2: HF	0.074	0.882	0.084
	Layer2: ME	0.031	0.882	0.035
	Layer2: PM	0.075	0.882	0.085
	Layer2: PF	0.049	0.882	0.056

3.3 (c) The local weights of SFs

For determining the weights of the SFs in fuzzy positive reciprocal matrix $\tilde{A}$, we need to find the eigenvectors of the $\tilde{A}$. Due to the special structure of $\tilde{A}$ (positive reciprocal matrix), Saaty (1980) suggested four methods to find the eigenvectors: Average of Normalized Columns (ANC), Normalization of the Row Average (NRA), Normalization of the Reciprocal of Columns Sum (NRCS) and Normalization of the Geometric Mean of the Rows (NGMR). Since the NGMR method was applied most popularly in previous studies, this paper adopts it to determine the local weights of the SFs $\tilde{A}$.

For the $\tilde{A}$, the geometric means of the triangular fuzzy numbers for the ith SF ($i = 1,2,...,n$) can be found as:

$$\tilde{w}_i = \left(\prod_{j=1}^{n} \tilde{a}_{ij}\right)^{1/n} = \left[\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}, \left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}, \left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}\right], \quad i = 1,2,...,n \tag{5}$$

Based on Equation (5), we have:

$$\sum_{i=1}^{n} \tilde{w}_i = \left[\sum_{i=1}^{n}\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}, \ \sum_{i=1}^{n}\left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}, \ \sum_{i=1}^{n}\left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}\right] \tag{6}$$

Also, based on Equations (5)-(6), the fuzzy weight of the ith SF ($i = 1,2,...,n$) can then be obtained as:

$$\tilde{W}_i = \frac{\tilde{w}_i}{\sum_{i=1}^{n} \tilde{w}_i} = \left[\left(\frac{\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}}\right), \left(\frac{\left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}}\right), \left(\frac{\left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}}\right)\right], \quad i = 1,2,...,n \tag{7}$$

3.3 (d) The defuzzification process

Since the local weight, $\tilde{W}_i$, of the ith SF ($i = 1,2,...,n$) is fuzzy, this paper uses Yager's index (1981) to defuzzify the $\tilde{W}_i$ into a crisp number W_i, $i = 1,2,...,n$ (Hsu *et al*, 2016). For convenience of explanation, let $\tilde{W}_i = [l_i^W, m_i^W, u_i^W]$, where

$$[l_i^W, m_i^W, u_i^W] = \left[\left(\frac{\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}}\right), \left(\frac{\left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} m_{ij}\right)^{1/n}}\right), \left(\frac{\left(\prod_{j=1}^{n} u_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} l_{ij}\right)^{1/n}}\right)\right], \quad i = 1,2,...,n$$

Then, the $\tilde{W}_i$, $i = 1,2,...,n$ can be defuzzified as:

$$W_i = (l_i^W + 2\, m_i^W + u_i^W)/4, \quad i = 1,2,...,n. \tag{8}$$

Finally, normalizing the W_i ($i = 1,2..,n$), the crisp local weight of the ith SFs can be obtained as:

$$\omega_i = W_i / \sum_{i=1}^{n} W_i, \quad i = 1,2,...,n \tag{9}$$

3.3 (e) The global weights of the SFs

By the above steps in Sections 3.3.1~3.3.4, all the local weights of the SFs in Table 1 can be found. The global weights of the SFs can then be found by multiplying their low level of local weights by their corresponding high level of global weights. Table 5 shows the results of all global weights of the SFs for the marine pilot sample. The global weights (and ranks) of the SFs in layer 1 are shown in the second field, and the ones of the SFs in layer 2 are shown in the fifth and last fields. Likewise, the global weights of SFs for the shipmaster sample are shown in Table 6.

Table 5. The marine pilot weights (MWs) of safety factors.

Layer1 SFs	The global weights of Layer 1 SFs (%)	Layer2S Fs	The local weights of Layer 2 SFs (%)	The global weights of Layer 2 SFs (%)	Rank
HF	38.55 (1)	HF1	45.934	17.71	1
		HF2	13.607	5.25	9
		HF3	24.565	9.47	3
		HF4	15.895	6.13	6
ME	28.55 (2)	ME1	42.94	12.26	2
		ME2	29.182	8.33	5
		ME3	17.414	4.97	10
		ME4	10.465	2.99	14
PM	20.03 (3)	PM1	45.016	9.02	4
		PM2	24.755	4.96	11
		PM3	30.23	6.06	7
PF	12.87 (4)	PF1	45.331	5.83	8
		PF2	29.482	3.79	12
		PF3	25.187	3.24	13

Table 6. The shipmaster weights (SWs) of safety factors.

Layer1 SFs	The global weights of Layer 1 SFs (%)	Layer2SFs	The local weights of Layer 2 SFs (%)	The global weights of Layer 2 SFs (%)	Rank
HF	39.62 (1)	HF1	36.53	14.47	1
		HF2	12.62	5.00	10
		HF3	31.59	12.52	3
		HF4	19.27	7.63	5
ME	27.29 (2)	ME1	46.1	12.58	2
		ME2	24.27	6.62	7
		ME3	20.67	5.64	8
		ME4	8.96	2.45	14
PM	11.2 (4)	PM1	47.94	5.37	9
		PM2	25.48	2.85	13
		PM3	26.57	2.98	12
PF	21.9 (3)	PF1	46.44	10.17	4
		PF2	32.67	7.15	6
		PF3	20.89	4.57	11

3.4. THE GAP ASSESSMENT MODEL

For assessing the subjects' perceived differences on SFs, a Gap Assessment Model (GAM) is proposed in this paper. The GAM contains two steps: indentifying the SFs' gaps and determining the degrees of the SFs' gaps.

3.4 (a) The identification of the SFs' gaps

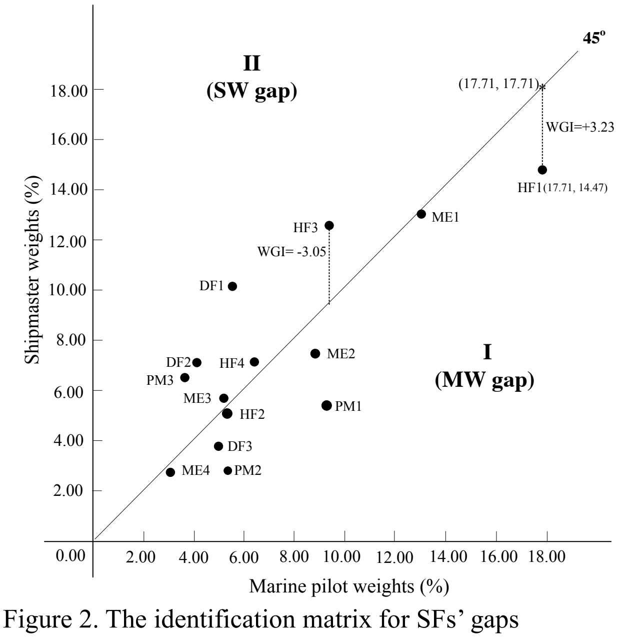

Figure 2. The identification matrix for SFs' gaps

The basic concept of GAM is that an SF with higher (or lower) marine pilots' perceived importance (marine pilot weight, MW) and lower (or higher) shipmasters' perceived importance (shipmaster weight, SW) should be a gap. Based on the above concept, a two-dimensional of identification matrix with both weights (MWs and SWs) is constructed to assess the gaps of SFs. The matrix is shown as Figure 2, in which the MW is depicted on the x-axis, the SW on the y-axes, and a 45° line divides the matrix into two quadrants. The SFs in Quadrant I imply that their MWs are higher than their SWs. In this paper, those SFs are termed as MW gaps. Likewise, the SFs in Quadrant II imply that their SWs weights are higher than their MWs. Thus, those SFs are named as SWs gaps. Further, the SFs on the 45° line is called NO gap for their MWs being equal to their SWs. The results of Figure 2 indicate there are 8 SFs locate in the Quadrant I zone (i.e. MW gaps) and 6 SFs located in the Quadrant II zone (i.e. SW gap).

3.4 (b) The degree of the SFs' gaps

Although the identification matrix can verified the SFs' gaps (MW gap , SW gap or NO gap), it does not show the degree for those gaps. Two gap index, Rank Gap Index (RGI) and Weight Gap Index (WGI), were proposed to determine the degrees of the SFs' gaps in each Quadrant.

(1) Weight Gap Index (WGI)

Let ω_i^M and ω_i^S denote the MW and the SW of the ith SF ($i = 1,2,...,n$), which can be obtained from the fifth fields of Table 5 and Table 6, respectively. Then, the WGI is defined by the difference of ω_i^M and ω_i^S :

$$WGI_i = \omega_i^M - \omega_i^S, \quad i = 1,2,...,n \tag{10}$$

(2) Rank Gap Index (RGI)

Let r_i^M and r_i^S denote the ranks of MW and SW of the ith SF ($i = 1,2,...,n$), Then, the RGI is defined by the difference of r_i^M and r_i^S:

$$RGI_i = r_i^M - r_i^S, \quad i = 1,2,...,n \tag{11}$$

Table 7. The safety factor' RGI (Rank Gap Index) and WGI (Weight Gap Index)

Layer 1 RFs	Layer 1 RFs RGI (%)	Layer 1 RFs WGI (%)	Layer 2 RFs	Layer 2 RFs RGI (%)	Layer 2 RFs WGI (%)
HF	0	-1.07	HF1	0	**3.23**
			HF2	-1	0.25
			HF3	0	**-3.05**
			HF4	1	-1.51
ME	0	+1.26	ME1	0	-0.32
			ME2	-2	1.71
			ME3	2	-0.67
			ME4	0	0.54
PM	**-1**	**+8.83**	PM1	**-5**	**3.65**
			PM2	-2	2.11
			PM3	**-5**	**3.08**
PF	**+1**	**-9.03**	PF1	**4**	**-4.34**
			PF2	**6**	**-3.36**
			PF3	2	-1.33

Note: The boldfaced numbers represent the SFs with higher gaps.

Equation (9) and (10) implies that a SF with a positive WGI or a negative RGI has a MW gap, and a SF with a negative WGI or a negative RGI has a SW gap. The results of the SFs' WGIs and RGIs for the empirical study are listed in Table 7.

4. RESULTS AND IMPLICATIONS

4.1 THE IMPORTANCE WEIGHYS OF SFs

The results of Table 5 and Table 6 indicate, in the first layer of SF constructs, both of the marine pilots and shipmasters consider the HF (MW = 38.551% and SW = 39.62%) is the most important construct to affect ship berthing safety, and followed by ME (MW = 28.55% and SW = 27.29%). Further, in the second layer of SFs, for marine pilots, the SFs with higher weights are: HF1 (17.71%), ME1(12.26%), HF3(9.47%) and PM1(9.02%); for shipmasters, the SFs with higher weights are: HF1 (14.47%), ME1(12.58%), HF3(12.52%) and PF1(10.17%). These results imply that the most important SFs to affect ship berthing safety should be HF1(*Professional skills*), and followed by ME1 (*The conditions of main engine and steering engine* and HF3 (*Emergency response*). Further, from Figure 2, we can also have a result that the larger the distance from SFs to the origin O, the higher the SFs' weights. In Figure 2, it is clear the largest distance from SFs to O is HF1, and followed by ME1 and HF3.

The above results conclude that human factor is the most important determinant of ship berthing safety, especially the capabilities of staffs' professional skills and emergency response. Practically, the main operators in ship's berthing operations include marine pilot, shipmaster, ship crews, tugboat drivers and linemen. Thus, for improving ship's berthing safety, port authority may focus on strengthening those operators' professional literacy. Further, in practice, most ship accidents occur in an instant. Thus, the response capability for emergencies is particularly important for those staffs. For enhancing those staffs' capabilities, this paper suggests the port authority may make policy to encourage or even mandatory require staffs to attend related training activities regularly, such as experience sharing, computer simulation for berthing operations, analysis of the causes of collisions, and how to prevent accidents etc. Further, the port authority may also make a license system to force the staffs to participate in those trainings.

4.2. THE RESULTS OF GAP ASSESSMENTS

Both of the RGI (Rank Gap Index) and WGI (Weight Gap Index) in Table 7 indicate that the main diverged viewpoints on the SF constructs between marine pilots and shipmasters are: PM (Port management) (RGI=-1 and WGI= +8.83%) and PF (Port facility) (RGI=+1 and WGI=-9.03%). The marine pilots pays more attention to port management (PM), especially to PM1 (port's rules and regulations) and PM3 (port policy for improving business). Whereas, the shipmasters perceive more importance on port facility (PF), especial on PF1(main channel's width and depth) and PF3 (shore equipment). Furthermore, the results of Table 7 also indicate that the other two constructs, HF and ME, have no gap in RGI and lower gap WGI (-1.07 and +1.26). However, for the SFs in the layer 2, even if both HF1 and HF3 have no gap in RGI, but have significant gap in WGI (+3.23 and -3.05). This result implies that the marine pilots perceive more importance on professional skills (HF1), whereas, shipmasters pay more attention on emergency response (HF3). The above results may provide information for both marine pilots and shipmasters to improve their cooperation in ship berthing operations.

In practice, the marine pilot and shipmaster are the most important roles in ship's berthing operations. The former realizes the port environments, such as tide, dock facility, tugboats etc. The later knows the ship conditions, including main engine, steering engine, operating crews etc. Their close cooperation is the best guarantee for ship berthing operations. In practice, both the key men understand their diverged opinions is helpful to improve the cooperation.

5. CONCLUSION

The purpose of this paper is to assess the determinants of ship berthing safety at port dock. Specifically, this paper investigates the differences of perspectives between marine pilots and shipmasters who are the key men in ship berthing operations. In this paper, a gap assessment model based on a fuzzy AHP was proposed to assess the their perceived difference on the determinants of ship berthing safety. The proposed model is easy to use that can extend its practical applications. Further it can also provide theoretical references for relevant research on methodology and ship navigation safety.

For demonstrating the practical application of the proposed model, the ship berthing operations at Kaohsiung Port in Taiwan were empirically investigated. The results indicated operating human factor is the most important determinant of ship berthing safety. In practice, the main operating staffs in ship berthing operations include the marine pilot, ship crews, turbot drivers and linemen. Thus, those staffs' personal literacy should be enhanced, especially in professional skills and emergency response. Further, the main diverged viewpoints between marine pilots and shipmasters are the SFs of port management and port facility. The former emphasizes more the port management; and the latter cares more about the port facility. This result may provide practical information for both marine pilots and shipmasters to improve their cooperation, enhancing the safety performance of ship berthing operations.

For AHP approach, one of the main assumptions is the independences among the safety factors. In this paper, the assumption is only verified by practical experts. In theoretically, this is not rigorous enough. Thus, it should be further confirmed in future research. Furthermore, in this paper, 14 marine pilots and 19 shipmasters at Kaohsiung Port in Taiwan were empirically surveyed to validate the proposed model. For enhancing the validity of the questionnaire investigation, this paper adopted an interview survey instead of a mailed survey. Thus, the validity and reliability of the findings in this paper could be endorsed. However, for better confirming the empirical results, more representative samples may be necessary in future research.

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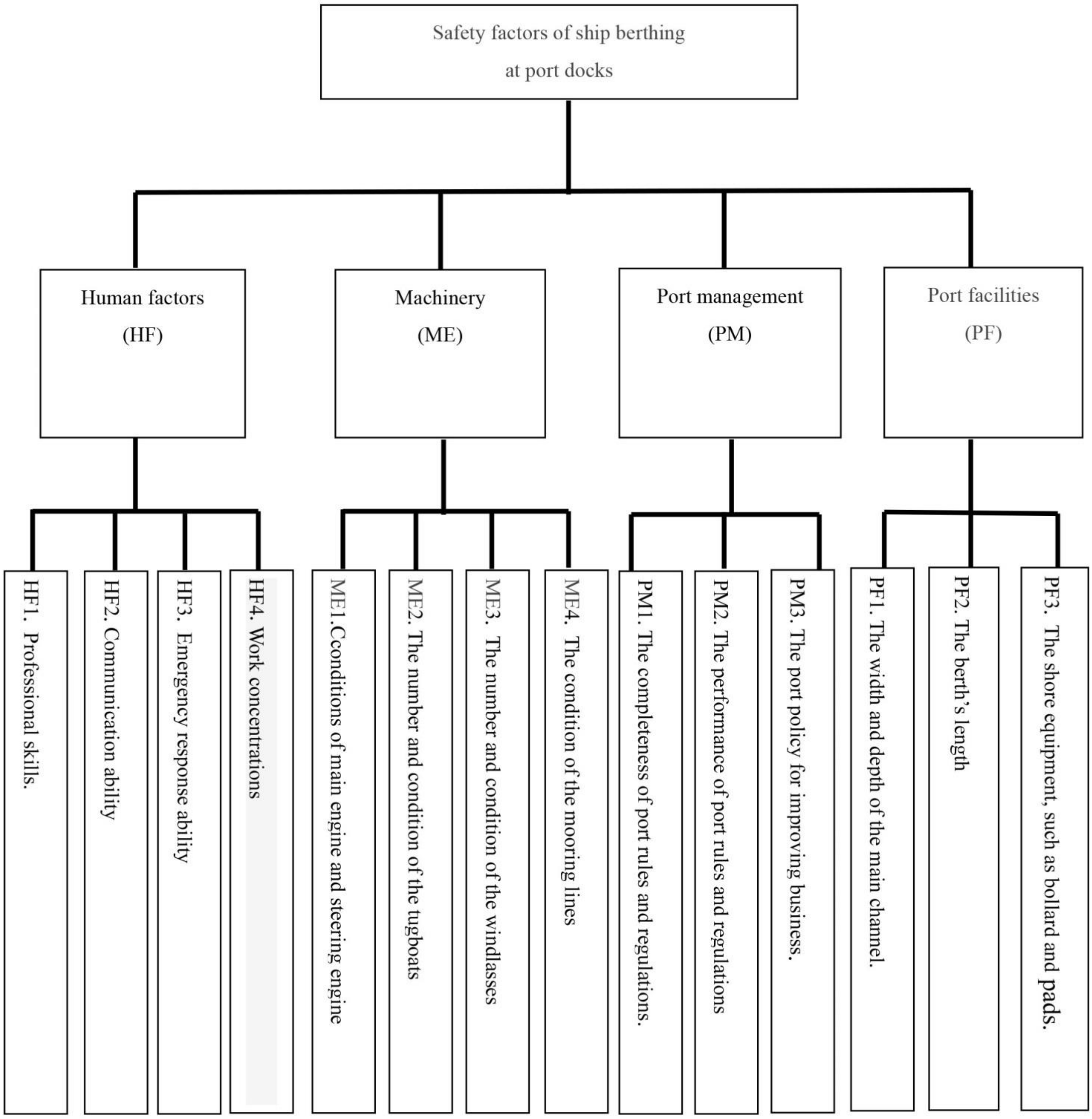
APPENDICES

The AHP questionnaire



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※Please make ranking for 4 safety factors (HF, ME, PM and PF) to help following respondents in consistency:

≧___≧___≧

	Most important								Equally								Most important	
HF Human factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME** Machinery
HF Human factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PM** Port management
HF Human factors	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF** Port facilities
ME Machinery	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PM** Port management
ME Machinery	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF** Port facilities
PM Port facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF** Port facilities

Continue to next page

Safety factors：Human factors; HF

※Please make ranking for safety factors to help following respondents in consistency, please ranking with the code (HF1, HF2, HF3 and HF4)：

____≧_____≧_____≧_____

	Most important								Equally								Most important	
HF1. Professional skill	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF2.** Conmunication
HF1. Professional skill	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF3.** Emergency response
HF1. Professional skill	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF4.** Work concentration
HF2. Conmunication	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF3.** Emergency response
HF2. Conmunication	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF4.** Work concentration
HF3. Emergency response	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**HF4.** Work concentration

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Safety factors：Machinery and equipment; ME

※Please make ranking for safety factors to help following respondents in consistency, please ranking with the code(ME1, ME2, ME3 and ME4)：

_____≧_____≧_____≧_____

	Most important								Equally								Most important	
ME1. Situation of marine engines	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME2.** Situation of tug-boats
ME1. Situation of marine engine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME3.** Situation of windlasses
ME1. Situation of marine engine	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME4.** Situation of mooring lines
ME2. Situation of tug-boats	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME3.** Situation of windlasses
ME2. Situation of tug-boats	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME4.** Situation of mooring lines
ME3. Situation of windlasses	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**ME4.** Situation of mooring lines

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Safety factors：Port management policies: PM

※Please make ranking for safety factors to help following respondents in consistency, please ranking with the code(PM1, PM2 and PM3)：

_____≧_____≧_____

	Most important								Equally								Most important	
PM1. Completeness of rule regulations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PM2.** Performance of rule regulations
PM1. Completeness of rule regulations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PM3.** Port policy for business
PM2. Performance of rule regulations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PM3.** Port policy for business

Safety factors**:** Port facilities; PF

※Please make ranking for safety factors to help following respondents in consistency, please ranking with the code(PF1, PF2 and PF3)：

_____≧_____≧____

	Most important								Equally								Most important	
PF1. Depth/width of main channel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF2.** Berth lengths
PF1. Depth/width of main channel	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF3.** Situations of shore equipments
PF2. Berth lengths	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**PF3.** Situations of shore equipments