Journal of Marine Science and Technology
DOI: 10.6119/JMST-012-0718-1

This article has been peer reviewed and accepted for publication in JMST but has not yet been copyediting, typesetting, pagination and proofreading process. Please note that the publication version of this article may be different from this version. This article now can be cited as doi: 10.6119/JMST-012-0718-1.

AN ASSESSMENT OF JOB PERFORMANCE OF VESSEL TRAFFIC SERVICE OPERATORS USING AN ANALYTIC HIERARCHY PROCESS AND A GREY INTERVAL MEASURE

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Key words: Job performance; Vessel traffic service (VTS); Analytic hierarchy process (AHP); Grey Interval Measure(GIM); Importance-performance analysis (IPA)

ABSTRACT

Operator training is a vital issue for vessel traffic service (VTS), since the International Maritime Organization has adopted the new version of the Guidelines for VTS 1997. Many countries have begun to alter the content of training courses, in order to comply with international standards. However, Taiwan still lacks effective method to assess individual operator's job performance, capabilities, or the effectiveness of a training program. This study collates the standard training courses to construct an Analytic Hierarchy Process (AHP) model and to investigate the relative evaluation weights for all criteria, using the group decision of the principal instructors. Grey Interval Measure (GIM) is used to evaluate the job performance for VTS operators serving in Taichung Harbor. The result shows the educational level and the duration of participation in training indeed affects the job performance. By Importance-performance analysis (IPA), those trainees who were evaluated better actually obtained higher scores on the more insignificant sub-criteria

The AHP structure and the GIM evaluation process are proved useful to authorities in the establishment of a standard for job performance of VTS.

I. INTRODUCTION

The concept of vessel traffic service (VTS) was originated from the emphasis for the vessel traffic capacity [9]. The International Maritime Organization (IMO) established a program for VTS and issued the Guidelines for Vessel Traffic Services in 1985. Many countries then established a VTS system. For example, in 1987, Europe completed its widest survey of marine traffic [6]. In Taiwan, Keelung and Kaohsiung Ports also established VTS systems in 1999 and 2001, respectively. However, recruitment conditions and training regulations for VTS operators changed when the IMO adopted a newer version of the guidelines, in 1997 [14]. In order to ensure safe and efficient navigation for individual vessels and/or vessel traffic system, the International Association of Lighthouse Authorities/Association Internationale de Signalisation Maritime (IALA/AISM) issued model courses for the training and certification of VTS personnel in 1998 [12].

VTS plays an important role in coordinating port traffic and in maintaining vessel safety [18,32]. Among them, the quality of operators is a critical factor. Some research has assessed the infrastructures of VTS [4] and its operational performance [19, 21, 28, 30]. These studies formed a basis for the establishment of the evaluation structure in this study. For example, Siersma and Mastenbroek [28] used situational awareness to quantify VTS operator performance. This study also employed the criterion as one of the evaluation sub-criteria. A few studies have dealt with training courses for VTS personnel [3, 23], but no research has considered the job performance for VTS operators and the effectiveness of a VTS training program.

Training courses can be used to teach novices to a threshold level that allows them to become a qualified member, if they could put that teaching into practice. However, VTS operators' real performance is not reflected immediately at each stage of the training process. In particular, training courses provide all of required knowledge for VTS, instead of the critical experience that may affect an operators' future performance. Therefore, an evaluation scheme or model that can address the gap between qualified training and operating performance is required.

This study aims to explore the critical factors that affect operating performance during VTS training and the relative importance between these factors. Through the collation of model courses for VTS training, an AHP is used to establish an appropriate assessment structure and to survey the relative evaluation weights for all criteria, using the group decision of the principal instructors. For verification, this model also uses a

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GIM to evaluate fifteen VTS operators currently serving in Taichung Harbor, in Taiwan.

II. VTS OPERATING AND ASSESSMENT CRITERIA

In accordance with the Standards for the Training and Certification of VTS Personnel provided by the IALA/AISM in 1998, there are model courses for training various grades of operators, such as operator basic training, supervisor advancement training, on-the-job training and on-the-job training for instructors [13]. Table 1 lists the frame-work of the operator basic training courses in IALA V103-1. It consists of eight modules with 39 subjects in total. These courses require 309 hours of instructor presentation and 240 hours of exercises or simulation for a trainee.

Although the IALA/AISM also provided a competence chart for assessing trainees, it looks more like a curriculum merely to evaluate whether a student has passed. This assessment aims to provide certification for qualified trainees. It lacks assessment from system users (such as navigators and pilots), managers of VTS authorities, or the opinions of colleagues. It hardly reflects the effectiveness of the VTS training program.

In Resolution A.857(20) Annex II [14], the IMO suggests three principles for the recruitment of VTS personnel: skills, knowledge and personal suitability characteristics. It also emphasizes and analyzes the required skills and knowledge associated with VTS functions. In particular, the Det Norske Veritas (DNV) suggests a simple formula, competence = (knowledge + skill) × attitude, to assess a crew's competence in (STCW 95) courses [11]. Obviously, knowledge, skill and attitude are the principal criteria in the assessment of a trainee's competence and they are also suitable for this study.

Table 1 Outline of IALA V103-1 operator basic training course

Source: [13]

Module	Subject	Presentation (hours)	Ex. or simulation (hours)
1. Language 91/75	11 Structure of the English language as applied to voice communications	30	20
	12 Specific VTS message construction	10	15
	13 Standard phrases	45	30
	14 Collecting information	6	10
2.Traffic Management 52/54	21 Regulatory requirements	18	
	22 Roles and Responsibilities	6	3
	23 VTS Environment	6	
	24 Principles of waterway & traffic management	16	33
	25 Traffic monitoring and organization	6	18
3. Equipment 39/6	31 Telecommunications	3	
	32 Vessel Traffic Management Information Systems	2	
	33 Radar/ARPA	16	2
	34 Audio, Video and other sensors	3	
	35 VHF/Direction Finding	1	
	36 Tracking systems	12	4
	37 Equipment performance monitoring	1	
	38 Evolving technologies	1	
4. Nautical Knowledge 85/38	41 Chart-work	15	15
	42 Collision Regulations	15	15
	43 Aids to Navigation	15	
	44 Navigational Aids (Ship-borne)	6	
	45 Shipboard knowledge	30	
	46 Port operations	4	8
5. Communication Co-ordination 7/11	51 General communication skills	3	4
	52 Communications	2	6
	53 Log and record keeping	2	1
6. VHF Radio 15/42	61 Radio operator practices and procedures	5	25
	62 VHF radio systems and their use in VTS	2	
	63 Operation of radio equipment	2	11
	64 Communication procedures, including SAR	6	6
7. Personal Attributes 6/4	71 Personal interaction and human relation skills	3	2
	72 Responsibility	3	2
8. Emergency Situations 12/10	81 National and international regulations	2	
	82 Response to contingency plans	2	1

	83 Priorities and respond to situations	2	3
	84 Co-ordination with , support of , allied services	1	3
	85 Recording activities concerning emergencies	1	1
	86 Maintaining a safe waterway throughout emergency situations	1	
	87 Internal/external Emergencies	2	1
Total		309	240

Using these criteria, this study proposes 19 sub-criteria, as shown in Table 2. As in Table 1, courses with longer training hours that require reinforcement are included in the sub-criteria. Presentation courses are collected for the knowledge criterion, while those courses belonging to the skill criterion require exercises/simulation. Sub-criteria relating to personality, which are proposed by this study, are grouped into the attitude criterion.

Table 2 Proposed criteria, sub-criteria and their statements

Criteria	Sub-criteria	Statement
D1 Knowledge	C11 Structure of the English language	General/Marine English
	C12 IMO Standard phrases	IMO Standard Marine Communication Phrases (SMCP)
	C13 Regulatory requirements	International, National, Local
	C14 Equipment Principle & Limitation	Radar/ARPA, AIS
	C15 COLREG & AtoN	International Regulations for Prevention of Collision and Aids to Navigation
	C16 Shipboard knowledge	Terms, Particular, Maneuvering, COLREG & AtoN.
	C17 Port operations	Approach run and Harbor waters
	C18 Waterway/Traffic management	Monitor/organize/manage
D2 Skill	C21 Specific VTS message construction	Speak, Listen, Write, Read
	C22 Collecting information	Receive/Transmit (use SMCP)
	C23 Equipment Operation	Vessel Traffic Management Information System, (Harbor) Vessel Data Base (System), Radar, Automatic Identification System, etc.
	C24 Chart-work	Paper chart, Electronic Chart Display Information System
	C25 Radio operator practices & procedures	VHF (Very High Frequency) procedures
	C26 Emergency Situations	Planning, Exercise, Case study
D3 Attitude	C31 Personal Attributes	Special personality characteristics
	C32 Personal interaction	Interpersonal relationships
	C33 Responsibility	Vessel Traffic Regulator role
	C34 Team-work	Cooperation
	C35 Situational awareness	Punctuality and attentiveness

III. METHODOLOGIES

1. AHP

AHP is a popular method for multi-criteria decision-making. It has been successfully used in many different fields [10, 16, 17]. It can help decision-makers to address a complicated problem with multiple conflicting and subjective criteria.

The AHP procedure consists of four steps: problem modeling, weight valuation, weight aggregation and sensitivity[15]. In problem modeling, AHP permits the decision-maker to construct a hierarchical structure, using the goal, criteria, sub-criteria and alternatives, in order to be better allocate the relative weights to specific criteria and sub-criteria.

In weight evaluation, AHP uses pair-wise comparisons to assess the difference in priorities between criteria and between sub-criteria for those criteria. It generates relative weights for grouped objectives using a consistent pair-wise comparison matrix. A perfectly consistent matrix must satisfy the transitivity rule, Equation (1), for every element, p_{ij}.

$$p_{ij} = p_{ik} \times p_{kj} \quad (1)$$

Suppose that there are n objectives. Let $p_{ij} = w_i/w_j$, where w_i is the weight of the i^{th} objective, $i = 1, \ldots, n$. It is obvious that the pair-wise comparison matrix, ***P***, in Equation (2), is perfectly consistent. However, a slight inconsistency is possible for any decision-maker. The eigenvalue method is normally used to estimate the weight vector, ***w***, for n objectives, as Equation (3), where $\lambda_{\max}$ is the maximal eigenvalue. Therefore, a decision-maker can express comparative weights, p_{ij}, for elements in the upper triangle or lower triangle in the matrix, ***P***; then $p_{ji} = p_{ij}^{-1}$.

$$p = [\, p_{n\times n} \,] = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \quad (2)$$

$$Pw = \lambda_{\max} w = nw \quad (3)$$

Saaty [26] suggested four methods for estimating relative weight: (1) the average of the normalized columns (ANC); (2) the normalization of the row average (NRA); (3) the normalization of the columns and the reciprocal (NCR) and (4) the normalization of the geometric mean of the rows (NGM). This study uses ANC, which is more precise than the others, as Equation (4).

$$w'_i = \frac{1}{n}\sum_{j=1}^{n}\frac{p_{ij}}{\sum_{i=1}^{n} p_{ij}} \quad \forall i \quad (4)$$

A consistency check must be conducted using a consistency index (CI), relative to the principal eigenvalue method [27], as shown in Equation (5). When the pair-wise comparison matrix is obtained, a consistency ratio (CR) is used to assess whether the matrix is acceptably consistent. It is defined as the ratio of CI and a random index (RI), as Equation (6). Saaty [26] used 500 randomly filled matrices to obtain a series of RI's, as shown in Table 3. If CR is less than 10 percent, then the matrix can be considered as having an acceptable consistency.

$$CI = (\lambda_{max} - n)/(n - 1) \quad (5)$$

$$CR = CI/RI \quad (6)$$

Table 3 Random indices proposed by Saaty

n	3	4	5	6	7	8	9
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: [26]

Since this study uses the AHP method for the group decision, the weight aggregation and sensitivity use another methodology, a GIM.

2. Grey Interval Measure

A grey number is an uncertain number with fixed lower and upper bounds, but unknown distribution [25]. A grey number, $a(\otimes)$, with a lower limit, a^-, and an upper limit, a^+, is defined as an interval grey number, denoted as $a(\otimes) \in [a^-, a^+]$, $a^- < a^+$. Its whitenization values, $a(\tilde{\otimes})$, are represented as Equation (7).

$$a(\tilde{\otimes}) = \alpha a^- + (1 - \alpha)a^+,\ \alpha \in [0, 1] \quad (7)$$

Given two grey numbers, $a_1(\otimes) \in [a_1^-, a_1^+]$ and $a_2(\otimes) \in [a_2^-, a_2^+]$, the basic sum, difference, reciprocal, product and quotient operations are defined in Equations (8) to (13).

$$a_1(\otimes) + a_2(\otimes) \in [a_1^- + a_2^-, a_1^+ + a_2^+] \quad (8)$$

$$a_1(\otimes) - a_2(\otimes) \in [a_1^- - a_2^-, a_1^+ - a_2^+] \quad (9)$$

$$a_1(\otimes)^{-1} \in [1/a_1^+, 1/a_1^-] \quad (10)$$

$$a_1(\otimes) \times a_2(\otimes) \in [\min\{a_1^-a_2^-, a_1^-a_2^+, a_1^+a_2^-, a_1^+a_2^+\}, \max\{a_1^-a_2^-, a_1^-a_2^+, a_1^+a_2^-, a_1^+a_2^+\}] \quad (11)$$

$$a_1(\otimes) \div a_2(\otimes) \in [\min\{a_1^-/a_2^-, a_1^-/a_2^+, a_1^+/a_2^-, a_1^+/a_2^+\}, \max\{a_1^-/a_2^-, a_1^-/a_2^+, a_1^+/a_2^-, a_1^+/a_2^+\}] \quad (12)$$

$$ka_1(\otimes) \in [ka_1^-, ka_1^+] \quad (13)$$

According to Equations (2) and (6), a Grey (arithmetic) mean for n grey interval numbers, $a_j(\otimes) \in [a_j^-, a_j^+]$, $j = 1, \ldots, n$, is denoted as $\text{avg}_n(\otimes)$. The Grey mean is also a grey interval number and can be represented as Equation (14). It is used to summarize the evaluation of all of the reviewers for the operator candidates. The final judgment is specified using the Whitenization function of the Grey mean, as in Equation (15).

$$\text{avg}_n(\otimes) = [\frac{1}{n}\sum_{j=1}^{n} a_j^-,\ \frac{1}{n}\sum_{j=1}^{n} a_j^+] \quad (14)$$

$$\text{avg}_n(\tilde{\otimes}) = \frac{\alpha}{n}\sum_{j=1}^{n} a_j^- + \frac{(1-\alpha)}{n}\sum_{j=1}^{n} a_j^+,\ \alpha \in [0, 1] \quad (15)$$

IV. INVESTIGATION AND RELATIVE WEIGHTS

This study uses a group decision to construct the AHP model, in order to investigate the evaluation weights and then to assess the job performance of VTS operators serving at Taichung Harbor (TCHB). Thirteen experienced instructors, in the first (AHP structure judgment) phase including three professors from the university, in the second (reviewer for comparison) phase including four professors and four VTS section chiefs from each ports in Taiwan, in the third (umpire) phase including two professors, one VTS section chief, two VTS station managers and three pilots (those serving at TCHB), were invited to conduct this survey.

1. Problem Modeling and Questionnaire Design

In the first phase, the evaluated structure in Table 2 was shown to the experts, in order to judge whether the criteria and sub-criteria were suitable for the evaluation of the job performance for VTS operators. The experts suggested that five sub-criteria: C14, C15, C17, C21 and C31, be deleted. The final AHP structure thus comprised three criteria and fourteen sub-criteria, in total, as shown in Figure 1. It should be noted that the sequences of the sub-criteria were renewed.

The criteria and their individual sub-criteria were used to design a questionnaire for investigate the results of the reviewers' pair-wise comparisons. Every reviewer was asked to assign a comparative importance to every pair of two objectives, according to the scales shown in Table 4. However, their results had to pass the consistency hypothesis, as mentioned in the methodology description. Because the number of invited reviewers was small, each one's opinions were valuable to this study. They were asked to slightly amend their selection, until the comparative results were consistent.

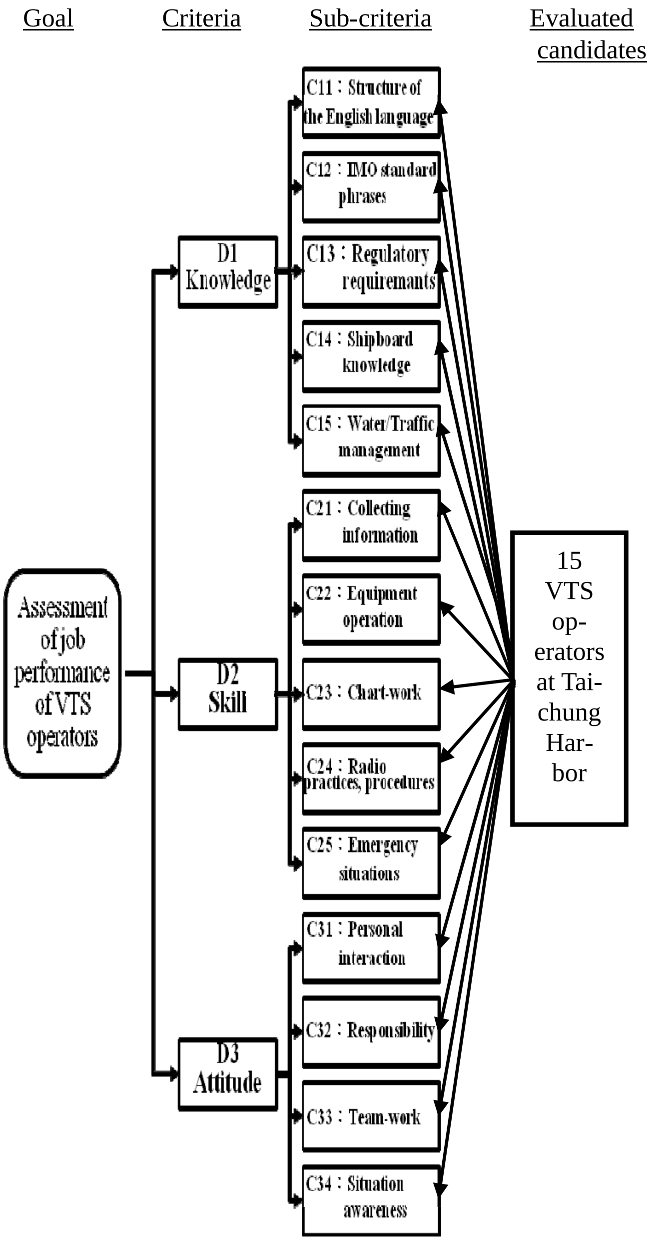


Fig. 1. AHP model for assessment of job performance of VTS operators

Table 4 Comparative importance scale for the questionnaire investigation

Scale	Definition	Description
1	Equally important	The importance of both comparative objectives is equal
3	Weakly important	Experience and judgment weakly tend to prefer one objective
5	Strongly important	Experience and judgment strongly tend to prefer one objective
7	Demonstrably important	Experience and judgment demonstrably tend to prefer one objective
9	Absolutely important	Experience and judgment absolutely tend to prefer one objective
2, 4, 6, 8	Intermediate values	Need to compromise

2. Group Decision for Weight Valuation

For all questionnaires, the relative weights for each can be calculated using Equation (4). Then, the geometric mean of each objective is calculated, using expert opinions, and applied to normalize the relative weights.

As listed in Table 5, three criteria have weights of 0.395892 for knowledge, 0.329236 for skill and 0.274872 for attitude, respectively. C14, C24, C34 are the most important sub-criteria for each individual criterion. They are also the three most important items of all of the sub-criteria.

Table 5 Relative weight of each criterion and sub-criterion

Criterion (Weight)	Sub-criteria	Geometric mean	Final weight	Rank in criterion	Rank for all sub-criteria
D1 Knowledge (0.395892)	C11 Structure of the English language	.09702	.04836	5	11
	C12 IMO standard phrases	.14588	.07271	3	6
	C13 Regulatory requirements	.18126	.09034	2	5
	C14 Shipboard knowledge	.23282	.11603	1	1
	C15 Waterway/traffic management	.13736	.06846	4	8
D2 Skill (0.329236)	C21 Collecting information	.11263	.04630	4	12
	C22 Equipment operation	.10422	.04285	5	13
	C23 Chart-work	.15559	.06397	3	9
	C24 Radio operator practices & procedures	.26186	.10765	1	2
	C25 Emergency situations	.16654	.06847	2	7
D3 Attitude (0.274872)	C31 Personal interaction	.09541	.03151	4	14
	C32 Responsibility	.28726	.09485	2	4
	C33 Team-work	.15574	.05143	3	10
	C34 Situational awareness	.29402	.09709	1	3

These results show that knowledge is the most important criterion, especially for marine navigation. VTS operators must have sufficient knowledge of seamanship. Skill, another personal condition for learning, is the second most important criteria. Standard and professional radio communication ranks as the most important course of all of the VTS skills courses. This skill is indeed required in the working life of VTS operators. Although personal attitude is weighted at the third position, situational awareness and responsibility are ranked third and fourth of all of the sub-criteria. It is noted that personal interaction (C31) is listed as the last important, so the training program may not provide any opportunity to develop this skill. The routine working skills, including collecting information (C21) and equipment operation (C22), are easily acquired on the job rather than on the training programming.

V. EVALUATION RESULTS

Eight umpires evaluated 15 trainees who are working at TCHB VTS. The panel of umpires, consisted of senior experts with various positions and experience at the same organization and some academicians. Every umpire had instructed the candidates or seen their performance on the job. The personal information for the trainees is shown in Table 6.

Table 6 Personnel information for evaluated trainees

TCHB VTS	Grade	1st	2nd	3rd	4th	Sum
Age	>=50 y	2	3	2	1	8
	>=40 y	1	1	1	0	3
	<40 y	1	0	1	2	4
	Average Age	47.0	53.0	45.5	34.0	45.6
Experience in VTS	>=10 y	3	3	1	0	7
	>=5 y	1	0	1	1	3
	<5 y		1	2	2	5
	Average Ex-	11.5	13.5	7.5	3.0	9.3
Educational level	Master(3)	2	0	1	1	4
	Bachelors (2)	2	0	2	1	5
	Vocational	0	4	1	1	6
	Average Edu-	2.5	1.0	2.0	2.0	1.9
Profession	Navigation (4)	1	1	2	1	5
	Communication	1	2	0	0	3
	Shipping (2)	1	0	1	1	3
	others(1)	1	1	1	1	4
	Average pro-	2.5	2.8	2.8	2.3	2.6
Participation in training	>=7 y	3	0	0	0	3
	>=3 y	1	4	3	1	9
	<3 y	0	0	1	2	3
	Average train-	6.8	4.8	2.8	1.7	4.1
	Total Trainees	4	4	4	3	15

1. Grey Interval Measures

When evaluating, the judgment might be a range of values rather than a specific number. Grey numbers can represent a judgment range without any pattern for this evaluation. This study proposed a Grey measurement form to allow each umpire to assess each trainee. Umpires could give numerical ranges marks or reference verbal scales for every sub-criterion. Actually, it is also applicable if umpires can precisely ensure to evaluate by a specific mark. The upper and lower bounds in the Grey measurement will be regarded as the same one in this case.

The Grey mean of the evaluated results from all umpires was calculated by using Equation (14). Table 7 shows the results of the calculation for fifteen trainees. The maximal Grey interval is 10.6, on P8's C33, while the minimal Grey interval is 4.4, on P7's C25. The total average Grey interval is 5.81, with a variance of 0.85.

2. Whitenization Aggregation and Sensitivity Analysis

The whitenization function was applied to calculate the whitenized values for an umpire's evaluation and then to produce the aggregated results for all trainees. Table 8 shows the final evaluation results, for $\alpha = 0.5$. Trainee P4 has the highest performance of 87.71, while trainee P15 is the last, with 70.18.

A sensitivity analysis was conducted, to tune the value of α by per 0.1. No change occurs in the rankings, as shown by the range of 0.1 and 0.9 for α. The largest variation is 4.95 and the smallest is 4.42. These results show that the final evaluation for all trainees is stable.

By making a comparison with the personal data for every trainee, we divide four grades for all trainees based on their whitenized values. First grade are trainees P4, P5, P11, and P14. Second grade are trainees P2, P3, P9, and P12. Third grade are trainees P1, P6, P8, and P10. Fourth grade are trainees p7, p13, and p15.

As a conclusion from personnel information shows in table 6, the educational level and the participation in training indeed affects the job performance. Interestingly, the trainees in the second grade are the oldest, most experienced, but the lowest educational level. It shows that the whitenized value is the runner-up. The influential factors may include the participation duration in training program and the promotion opportunities in their career. In this study case, three trainees in first grade were promoted from operator to supervisor positions, before this survey was conducted, due to their qualified job performance.

3. Importance-Performance Analysis (IPA)

The criterion with the highest average score is Chart-work (C24) and second is Shipboard knowledge (C14). Table 9 lists the average scores for the four grades' evaluation and rankings for all of the sub-criteria. Figure 2 shows an importance-performance analysis (IPA) of the rankings for all of the sub-criteria in four grades. The lower left sector represents more importance and better performance, while the lower right sector represents less importance but better performance. The upper left sector represents more importance but worse performance, while the upper right sector is the area of little importance and worse performance. In the first grade, it has nine criteria matching the rankings of importance. It shows that trainees in the first grade know well the importance of criteria and have good performance. In the second grade, it has three criteria matching the rankings of importance. On the other hand, trainees in the third and fourth grade do not get a good hold of their job. Furthermore, those trainees who were evaluated better actually obtained higher scores on the more insignificant sub-criteria, as shown in Table 8.

Table 7 Results of the summation of the Grey means for all umpires

Sub-criteria	Trainee							
	P1	P2	P3	P4	P5	P6	P7	P8
C11	[71.1 76.1]	[74.4 79.4]	[69.4 74.4]	[83.9 89.4]	[78.9 85.0]	[75.0 80.0]	[73.9 78.9]	[67.8 73.3]
C12	[67.8 73.3]	[74.4 79.4]	[68.9 73.9]	[85.0 90.6]	[80.0 86.1]	[70.0 75.0]	[62.7 72.8]	[64.4 69.4]
C13	[69.4 75.6]	[70.0 75.6]	[77.2 82.2]	[83.9 91.7]	[79.4 85.6]	[66.1 71.7]	[65.6 71.1]	[72.8 78.9]
C14	[81.7 86.7]	[81.1 86.1]	[66.7 72.2]	[92.8 98.3]	[85.6 91.1]	[80.0 85.0]	[79.4 85.0]	[64.4 70.0]
C15	[68.9 73.9]	[72.2 77.8]	[78.9 83.9]	[83.3 89.0]	[75.6 80.6]	[65.0 70.0]	[63.3 68.9]	[75.0 80.6]
C21	[72.2 77.2]	[75.0 80.0]	[79.4 84.4]	[75.0 80.0]	[70.6 75.6]	[66.7 72.8]	[64.4 70.0]	[76.1 81.1]
C22	[70.6 75.6]	[73.3 79.4]	[76.7 83.3]	[83.9 91.1]	[79.4 85.6]	[64.4 70.0]	[63.9 69.4]	[72.8 78.3]
C23	[83.9 88.9]	[84.4 89.4]	[65.6 71.7]	[73.9 80.0]	[70.0 75.6]	[83.3 88.9]	[81.1 86.1]	[63.9 68.9]
C24	[67.2 73.3]	[71.7 77.2]	[76.7 82.8]	[87.2 92.8]	[82.8 88.3]	[67.2 72.8]	[65.6 70.6]	[74.4 79.4]
C25	[69.4 74.4]	[68.9 75.6]	[70.0 75.6]	[83.9 89.4]	[77.2 82.2]	[62.2 67.8]	[60.0 64.4]	[65.0 72.2]
C31	[62.2 67.8]	[70.0 76.1]	[67.2 76.1]	[83.9 90.6]	[78.3 86.1]	[67.2 73.9]	[64.4 71.1]	[72.8 78.9]
C32	[63.9 70.6]	[68.3 75.0]	[71.1 78.9]	[85.6 90.6]	[81.1 86.7]	[62.8 68.9]	[61.1 67.8]	[70.0 76.1]
C33	[65.0 70.0]	[69.4 76.1]	[71.1 78.3]	[84.4 89.4]	[78.9 85.0]	[67.8 73.9]	[65.0 71.7]	[68.3 78.9]
C34	[66.1 72.2]	[70.6 77.8]	[70.0 78.3]	[86.7 93.9]	[82.8 89.4]	[65.6 72.2]	[63.9 70.6]	[68.3 76.7]

Sub-criteria	Trainee						
	P9	P10	P11	P12	P13	P14	P15
C11	[75.0 80.0]	[65.0 70.0]	[78.3 84.4]	[65.6 70.6]	[67.8 72.8]	[78.3 85.6]	[75.6 81.1]
C12	[72.2 77.8]	[63.3 68.3]	[81.7 86.7]	[64.4 69.4]	[62.8 68.3]	[80.0 87.2]	[66.1 71.7]
C13	[76.1 81.1]	[74.0 78.9]	[80.0 86.1]	[74.4 80.0]	[75.0 80.0]	[80.6 86.1]	[70.0 75.0]
C14	[66.1 71.7]	[65.0 70.0]	[83.3 90.0]	[65.6 70.6]	[62.8 68.3]	[89.4 94.4]	[63.3 68.3]
C15	[78.3 83.3]	[76.7 81.7]	[77.2 82.2]	[77.8 82.8]	[77.2 82.2]	[78.3 84.4]	[70.0 75.0]
C21	[81.1 86.1]	[77.8 82.8]	[70.0 75.0]	[80.0 85.0]	[79.4 84.4]	[74.4 80.0]	[68.9 74.4]
C22	[77.8 83.9]	[76.7 82.2]	[80.0 85.0]	[75.6 80.6]	[75.0 81.7]	[80.0 85.0]	[65.6 70.6]
C23	[65.6 71.1]	[63.3 69.4]	[68.3 73.3]	[65.0 70.0]	[61.7 67.2]	[73.9 80.0]	[63.9 68.9]
C24	[77.2 83.9]	[75.0 80.6]	[82.8 88.3]	[77.2 83.9]	[73.3 79.4]	[85.0 91.7]	[68.9 73.9]
C25	[71.7 77.2]	[70.0 75.0]	[77.8 83.3]	[71.1 76.7]	[67.8 73.3]	[78.9 83.9]	[65.0 70.6]
C31	[73.3 80.6]	[70.6 77.8]	[80.0 85.0]	[71.7 77.8]	[66.7 73.3]	[78.9 85.6]	[70.0 77.8]
C32	[74.4 80.0]	[70.6 76.7]	[80.6 88.9]	[71.1 78.3]	[65.0 71.1]	[84.4 89.4]	[66.7 73.3]
C33	[74.4 81.7]	[71.1 78.3]	[78.9 84.4]	[72.2 78.3]	[66.7 74.4]	[78.3 85.6]	[68.9 74.4]
C34	[74.4 81.1]	[70.0 77.8]	[83.3 88.3]	[71.7 78.9]	[66.1 72.8]	[86.1 91.1]	[66.1 73.3]

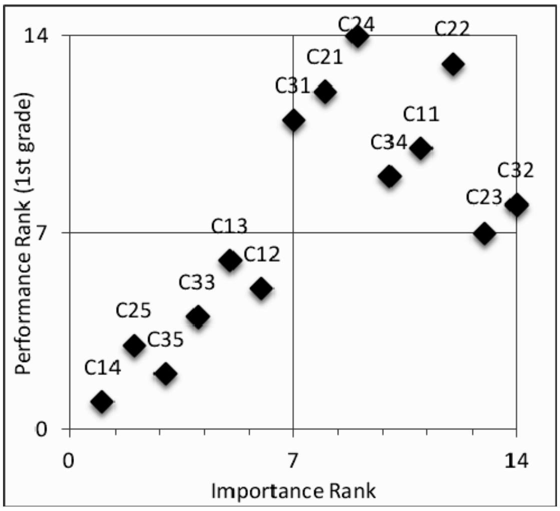
Table 8 Whitenization aggregation results for α = 0.5

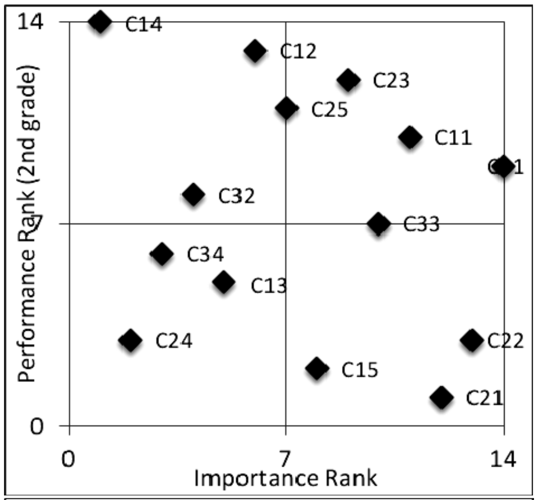
Sub-criteria	Trainees								
	P1	P2	P3	P4	P5	P6	P7	P8	P9
C11	73.6	76.9	71.9	86.7	81.9	77.5	76.4	70.6	77.5
C12	70.6	76.9	71.4	87.8	83.1	72.5	70.0	66.9	75.0
C13	72.5	72.8	79.7	87.8	82.5	68.9	68.3	75.8	78.6
C14	84.2	83.6	69.4	95.6	88.3	82.5	82.2	67.2	68.9
C15	71.4	75.0	81.4	86.2	78.1	67.5	66.1	77.8	80.8
C21	74.7	77.5	81.9	77.5	73.1	69.7	67.2	78.6	83.6
C22	73.1	76.4	80.0	87.5	82.5	67.2	66.7	75.6	80.8
C23	86.4	86.8	68.6	76.9	72.8	86.1	83.6	66.4	68.3
C24	70.3	74.4	79.7	90.0	85.6	70.0	68.1	76.9	80.6
C25	71.9	72.2	72.8	86.7	79.7	65.0	62.2	68.6	74.4
C31	65.0	73.1	71.7	87.2	82.2	70.6	67.8	75.8	76.9
C32	67.2	71.7	75.0	88.1	83.9	65.8	64.4	73.1	77.2
C33	67.5	72.5	74.7	86.9	81.9	70.8	68.3	73.6	78.1
C34	69.2	74.2	74.2	90.3	86.1	68.9	67.2	72.5	77.8
Aggregation	73.1	76.2	75.1	87.7	82.4	71.8	70.2	72.5	76.6
Rank	10	6	7	1	3	12	14	11	5

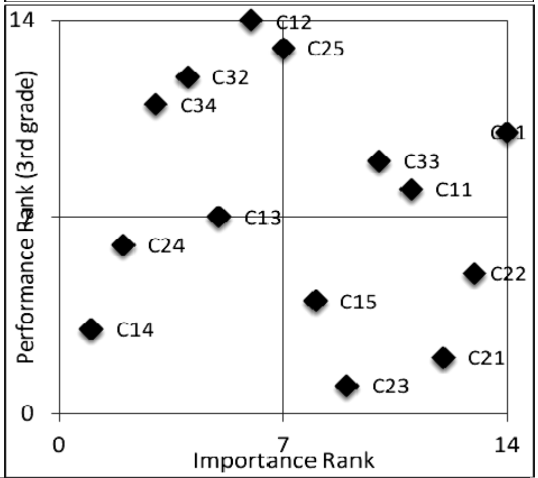
Sub-criteria	Trainees						Average	Rank
	P10	P11	P12	P13	P14	P15		
C11	67.5	81.4	68.1	70.3	81.9	78.3	76.0	8
C12	65.8	84.2	66.9	65.6	83.6	68.9	73.9	12
C13	76.4	83.1	77.2	77.5	83.3	72.5	77.1	5
C14	67.5	86.7	68.1	65.6	91.9	65.8	77.8	2
C15	79.2	79.7	80.3	79.7	81.4	72.5	77.1	4
C21	80.3	72.5	82.5	81.9	77.2	71.7	76.7	6
C22	79.4	82.5	78.1	78.3	82.5	68.1	77.2	3
C23	66.4	70.8	67.5	64.4	76.9	66.4	73.9	13
C24	77.8	85.6	80.6	76.4	88.3	71.4	78.4	1
C25	72.5	80.6	73.9	70.6	81.4	67.8	73.4	14
C31	74.2	82.5	74.7	70.0	82.2	73.9	75.12	10
C32	73.6	84.7	74.7	68.1	86.9	70.0	75.0	11
C33	74.7	81.7	75.3	70.6	81.9	71.7	75.4	9
C34	73.9	85.8	75.3	69.4	88.6	69.7	76.2	7
Aggregation	73.3	82.4	74.4	71.6	84.6	70.2		
Rank	9	4	8	13	2	15		

Table 9 Scores for the four grades' evaluation and rankings for all of the sub-criteria

Sub-criteria		C11	C12	C13	C14	C15	C21	C22	C23
rank		11	6	5	1	8	12	13	9
1st grade	score	82.99	84.65	84.17	90.63	81.33	75.07	83.75	74.38
	rank	10	5	6	1	12	13	7	14
2nd grade	score	73.61	72.57	77.08	72.50	79.38	81.39	78.82	72.81
	rank	10	13	5	14	2	1	3	12
3rd grade	score	72.29	68.96	73.42	75.35	73.96	75.83	73.82	76.32
	rank	8	14	7	3	4	2	5	1
4th grade	score	75.00	68.15	72.78	71.20	72.78	73.61	71.02	71.48
	rank	1	12	3	7	3	2	8	6
Sub-criteria		C24	C25	C31	C32	C33	C34	Average	
rank		2	7	14	4	10	3		
1st grade	score	87.36	82.08	83.54	85.90	83.13	87.71	83.33	
	rank	3	11	8	4	9	2		
2nd grade	score	78.82	73.33	74.10	74.65	75.14	75.35	75.56	
	rank	3	11	9	8	7	6		
3rd grade	score	73.75	69.51	71.39	69.93	71.67	71.11	72.68	
	rank	6	13	10	12	9	11		
4th grade	score	71.95	66.85	70.56	67.50	70.19	68.79	70.66	
	rank	5	14	9	13	10	11		







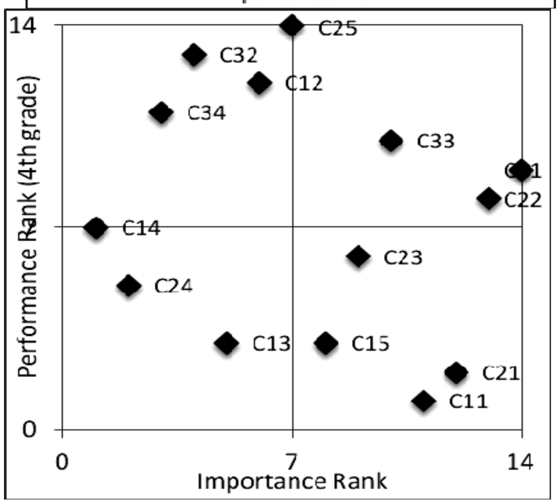


Figure 2. IPA of the rankings for all of the sub-criteria in four grades

VI. CONCLUSIONS AND SUGGESTIONS

The IMO and the IALA provided the necessary modules and subjects for VTS training courses and even suggested a scheme for certification. However, there did not propose an evaluation method to assess VTS trainees. This study constructed an AHP model to assess a variety of criteria for job performance, i.e. knowledge, skill and attitude, and the pertinent sub-criteria. Knowledge is the most important of these three criteria, while skill is second most important. Each sub-criterion of these three criteria had its weight in the aggregation using expert decision. Shipboard knowledge, radio operator practices & procedures and situational awareness are the most critical conditions that will affect personal performance after accepting VTS training.

For the case study, the AHP model and a GIM were used to evaluate fifteen VTS operators serving at Taichung Harbor, in Taiwan. The assessment results are verified to be effective and can reflect a VTS operator's performance on the job. It is found that the educational level significantly affects the job performance. The duration of participation in the training program also influences the job performance. However, the importance -performance analysis shows that trainees in the first grade can still reach a satisfied level for operating performance, as evidenced by the average scores for the evaluation.

The case study for Taichung Harbor shows that the modules of the training courses could be adjusted to suit the operator's educational level and background and the properties of the traffic environment, particularly for the international standard format of external communication, teamwork and resource management, situational awareness and VTS responsibility. The evaluation method used in this study can also be used to determine an individual operator's job performance and capability and the effectiveness of the training program.

REFERENCES

1. Becker, J.L., Denise, L.B. and Amanda K.R., "Applying AHP to the prioritization of maritime booking confirmation," *Proceedings of the 10th International Symposium on the Analytic Hierarchy/Network Process*, pp.11701-11714 (2009).
2. Cai L., Guo S.S. and Tang H.M., "An Enterprise performance Evaluating System Using Fuzzy-AHP," *Institute of Electrical and Electronics Engineers (IEEE) International Conference*, pp.1071-1075 (2006).
3. Chen, H.C. and Chen, Z.Z., "A Study in knowledge acquisition approaches and contents for VTS operators in Taiwan (using AHP)," *The 3rd Session of Ten School Alliance Shipping Academic Seminar*, pp.155-164 (2005).
4. Chen, H.C. and Lee, H.H., "The information of AIS applied to the operation of VTS," *The Pacific Congress on Marine Science and Technology (PACON) International Conference,* pp.1301-1310 (2005).
5. Chen, Y.F., "Applying ANP to Develop the Strategy of Sustainable Competitive Advantage in Taiwan's Photovoltaic Industry." *International Journal of Decision Support Systems Technologies,* Vol.3, No.3 pp.42-57 (2011)
6. Cutland, M.J., Degre, T., Deutsch,C., and The Commission of the European Community, *COST 301 Final Report—Shore-based marine navigation aid systems, Main Report,* TRID Accession No.00656713 Transportation Research Board, St. NW, Washington D.C. (1987).
7. Ding, J. F., "Applying fuzzy AHP approach to assess key value activities for ocean freight forwarders in Taiwan," *Journal of Interdisciplinary Mathematics*, Vol.14, No.3, pp.331-346 (2011).
8. Fang, J., Peide L., and Xin Z., "The Evaluation Study of Knowledge Management Performance Based on Grey-AHP Method," *International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD),*Vol.3, pp.444-449, 2007.
9. Fujii, Y. and Tanaka, K., "Traffic capacity," *The Journal of Navigation,* Vol. 24, pp. 542-543 (1971).
10. Ho, W., "Integrated analytic hierarchy process and its applications-a literature review," *European Journal of Operational Research*, Vol. 186, No. 1, pp. 211-228 (2008).
11. Huang, S., *Core competence,* 2011 Annual Forum PPS003, Center for teaching and learning development, Taiwan University, (2011).
12. IALA/AISM, IALA Recommendation V-103, *Standard for Training and Certification of VTS Personnel*, London, UK, (1998).
13. IALA/AISM, Model Course V-103/1, *VTS Operator Basic Training*, London, UK, (1999).
14. IMO, Res. A.857(20),*Guidelines for Vessel Traffic Services*, (1997).
15. Ishizaka, A. and Labib, A., "Analytic hierarchy process and expert choice: benefits and limitations," *OR Insight*, Vol. 22, No. 4, pp. 201-220 (2009).
16. Kumar, S. and Vaidya, O., "Analytic hierarchy process: an overview of applications," *European Journal of Operational Research*, Vol. 169, No. 1, pp. 1-29 (2006).
17. Liberatore, M. and Nydick, R., "The analytic hierarchy process in medical and health care decision making: a literature review," *European Journal of Operational Research*, Vol. 189, No. 1, pp. 194-207 (2008).
18. Lin, B. and Chen, H. C., "A design on ship's routing for navigational safety within Kaohsiung approaches," *The International Seminar on Global Transportation Network*, National Taiwan Ocean University, pp55-66 (2001).
19. Lin, B. and Huang, C. H., "Comparison between ARPA radar and AIS characteristics for vessel traffic service," *Journal of Marine Science and Technology*, Vol. 14, No. 3, pp. 182-189 (2006).
20. Lin, C.T., "Using Fuzzy AHP to Evaluate Service Performance of a Travel Intermediary," *The Service Industries Journal*, Vol.29, No.3. pp.281-296 (2009)
21. Lin, X. P., *A Study on The Comparison of VTS Between Keelung And Kaohsiung Ports in Taiwan and The Main Container Ports in The Asia (Using AHP),* Master thesis, Department of Merchant Marine, National Taiwan Ocean University, Keelung, Taiwan (2009).
22. Liu, S. and Lin, Y., *Grey Information: Theory and Practical Applications, Springer*, London, pp. 30-46 (2006).
23. Miller, C. and Chen, H. C., *VTS manual of operating procedure & VTR training,* Canada-Taiwan Maritime System Technology Program Final Report, COMART International Corporation, MOTC (2004).
24. Rafikul I. and Shuib B. M. R., "Employee Performance Evaluation by the AHP," *Asia Pacific Management Review*, Vol. 11(3), pp.163-176 (2006).
25. Rosenberg, D. E., "Shades of grey: a critical review of grey-number optimization," *Engineering Optimization*, Vol. 41, No. 6, pp. 573-592 (2009).
26. Saaty, T. L., "A scaling method for priorities in hierarchical structures," *Journal of Mathematical Psychology*, Vol. 15, pp. 234-281 (1977).
27. Saaty, T. L., "Decision-making with the AHP: why is the principal eigenvector necessary," *European Journal of Operational Research*, Vol. 145, No. 1, pp. 85-91 (2003).
28. Siersma, E. and Mastenbroek, N., "Measurement of vessel traffic service operator performance," *AI & SOCIETY*, Vol. 12, pp. 78-86 (1998).
29. Triantaphyllou, E., Lootsma, F. A., Pardalos, P. M., and Mann, S. H., "On the evaluation and application of different scales for quantifying pair-wise comparisons in fuzzy sets," *Journal of Multi-Criteria Decision Analysis,* Vol. 3, pp. 133-155 (1994).
30. Ung, S.T., Williams, V., and Chen, H. C., "Human error assessment and management in port operation using fuzzy AHP," *Marine Technology Society Journal*, Vol. 40, No. 1, pp. 68-81 (2006).
31. Wu, C.R., Lin, C.T. and Lin, Y.C., , "The Best Prophylaxis of Medical Disputes via the AHP-GRA Model," *Journal of Statistics and Management Systems*, Vol. 12. No. 1, pp. 47-58 (2009)
32. Zhou, H.P., *Maritime Traffic Management*, Marine Transportation Research Center, National Taiwan Ocean University, Keelung, Taiwan, (2003).