FAHP FOR SELECTING TRANSPORT MODES OF TAIWAN OFF-SHORE ISLANDS' MILITARY LOGISTICS

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SUMMARY

Three off-shore islands of Taiwan: Penghu, Kinmen and Matsu are critical in tactical position for Taiwan military, but lack of scarcity resource. Therefore, logistics is very important especially for the off-shore islands. Practically, most of the goods and materials are transported to the islands in the way of shipping and air transportation by Taiwan. However, the severe weather of the islands makes the transportation difficult or even to delay, which is a serious problem for the military logistics of the islands. To raise transportation performance, a proper evaluation method is necessary for military logistics to select the best transport mode based on reducing cost and emphasizing efficiency. Generally, analytic hierarchy process (AHP) may be a method in the selection of transport modes for Taiwan off-shore islands' military logistics. However, some computation procedures in AHP are hard or complicated especially for processing numerous interviewees' messages. To resolve the above tie, we utilize fuzzy analytic hierarchy process(FAHP) in selecting transport modes for Taiwan off-shore islands' military logistics in this paper. After integrating interviewees'(i.e., querying soldiers') opinions into fuzzy pair-wise comparison matrices, FAHP, being different from AHP, simply and efficiently yields priorities of the fuzzy pair-wise comparison matrices to find the best transport mode of Taiwan off-shore islands' military logistics.

1. INTRODUCTION

Taiwan is a country in East Asia and governs some islands which makes up over 99% of its territory, as well as Penghu, Kinmen, Matsu, and other minor islands. Practically, Penghu, Kinmen and Matsu in critical tactical positions are three important off-shore islands of Taiwan. However, their resources are few and even lack of water. Due to scarcity resources, the three islands' development is heavily limited. The three off-shore islands' necessary goods and materials come from Taiwan by shipping or air transportation. Severe weather including northeast monsoon, dense fog, and billows which occur in winter and spring make the transportation between the three off-shore islands and Taiwan delayed heavily. Since the three islands' tactical positions are critical, armies consisting of numerous soldiers are stationed in the three islands. To achieve tactical tasks, armies need lots of goods and materials, and therefore military logistics are necessary. Based on emphasizing efficiency and reducing cost, military logistics has to find the best transport mode for the three islands to raise transportation performance.

Through a questionnaire, we query soldiers in the three off-shore islands about transportation selection of military logistics, and then use fuzzy analytic hierarchy process(FAHP) to find the optimal transport mode from candidate modes. FAHP is cognized as the fuzzy extension of analytic hierarchy process (AHP). AHP proposed by Saaty (1980) [14] is a well-known multi-criteria decision-making(MCDM) method. Additionally, a decision-making problem with several evaluation criteria belongs to MCDM problems (Hwang, 1981)[7]. MCDM under fuzzy (i.e. imprecision, subjectiveness and vagueness) environment is commonly called fuzzy multi-criteria decision-making (FMCDM) (Akdag et al., 2014[1]; Büyüközkan, Çifçi, 2012[2]; Celik, Deha Er, Ozok, 2009[3]; Patil, Kant, 2014; Wang, 2014a[16]; Wang, 2015[17]; Wang, 2014b[18]; Wang, Lee, 2010[20]). In FMCDM problems, some approaches (Cheng, 1997[4]; Gumus, 2009[5]; Lee, 2014[8]; Wang, Luo, Hua, 2008[21]) extended AHP under fuzzy environment into FAHP. Practically, transport modes for Taiwan off-shore islands' military logistics is a MCDM problem, so AHP is one of proper methods. However, some computation procedures in AHP are complicated and hard for processing numerous interviewees' messages. To resolve the above tie, we proposed a FAHP in this paper to solve the selecting decision-making problem. To numerous messages, FAHP is smaller on computational items than AHP for their necessary pair-wise comparison matrices. Additionally, the FAHP characteristic by a series of computations is able to do with and reserve complicated messages gathered from numerous interviewees.

For the sake of clarity, mathematical preliminaries of fuzzy sets and fuzzy numbers are presented in section 2. In section 3, FAHP in selecting transport modes is displayed. Based on FAHP, an empirical study about transport modes selection of Taiwan off-shore islands' military logistics is expressed in section 4.

2. PRELIMINARIES

In this section, fuzzy sets and fuzzy numbers (Zadeh, 1965[23]) are presented as follows.

Definition 2.1 Let U be a universe set. A fuzzy set A of U is defined by a membership function $\mu_A(x) \rightarrow [0,1]$, where $\mu_A(x)$, $\forall x \in U$, indicates the degree of x in A.

Definition 2.2 A fuzzy subset A of U is normal if $\sup_{x\in U} \mu_A(x)=1$.

Definition 2.3 A fuzzy subset A of U is convex if $\mu_A(\lambda x+(1-\lambda)y)\ge(\mu_A(x)\wedge\mu_A(y))$, $\forall x,y\in U$, $\forall\lambda\in[0,1]$, where $\wedge$ denotes the minimum operator.

Definition 2.4 A fuzzy subset A of U is a fuzzy number iff A is both normal and convex.

Definition 2.5 A triangular fuzzy number A is a fuzzy number with piecewise linear membership function μ_A defined by

$$\mu_A=\begin{cases}\dfrac{x-a_1}{a_2-a_1}, & a_1\le x\le a_2,\\ \dfrac{a_3-x}{a_3-a_2}, & a_2\le x\le a_3,\\ 0, & otherwise,\end{cases}$$

which can be denoted as a triplet (a_1,a_2,a_3).

Definition 2.6 Let A and B be two fuzzy numbers, and $\circ$ be a operation on real numbers, such as $+,-,*,\wedge,\vee$, etc. By extension principle (Zadeh, 1965[23]), the extended operation $\circ$ on fuzzy numbers is defined by

$$\mu_{A\circ B}(z)=\sup_{x,y:z=x\circ y}\{\mu_A(x)\wedge\mu_B(y)\}.$$

Definition 2.7 Let A be a fuzzy number. A_α^L and A_α^U are defined as $A_\alpha^L=\inf_{\mu A(z)\ge\alpha}(z)$ and $A_\alpha^U=\sup_{\mu A(z)\ge\alpha}(z)$ respectively.

Definition 2.8 A fuzzy preference relation R is a fuzzy subset of $\Re\times\Re$ with membership function $\mu_R(A,B)$ standing for preference degree of fuzzy number A over fuzzy number B (Nakamura, 1986[12]; Nurmi, 1981[13]; Yufei, 1991[22]).

(a) R is reciprocal if $\mu_R(A,B)=1-\mu_R(B,A)$ for all fuzzy numbers A and B.

(b) R is transitive if $\mu_R(A,B)\ge\dfrac{1}{2}$ and $\mu_R(B,C)\ge\dfrac{1}{2}\Rightarrow\mu_R(A,C)\ge\dfrac{1}{2}$ for all fuzzy numbers A, B and C.

(c) R is a total ordering relation if R is both reciprocal and transitive.

According to the fuzzy preference relation, A is greater than B if $\mu_R(A,B)>\dfrac{1}{2}$.

Definition 2.9 An extended preference relation R' is a fuzzy subset of $\Re\times\Re$ with membership function $-\infty\le\mu_{R'}(A,B)\le\infty$ standing for extended preference degree of fuzzy number A over fuzzy number B (Lee, 2005a; Lee, 2005b).

(a) R' is reciprocal iff $\mu_{R'}(A,B)=-\mu_{R'}(B,A)$ for all fuzzy numbers A and B.

(b) R' is transitive iff $\mu_{R'}(A,B)\ge 0$ and $\mu_{R'}(B,C)\ge 0\Rightarrow\mu_{R'}(A,C)\ge 0$ for all fuzzy numbers A, B and C.

(c) R' is additive if $\mu_{R'}(A,C)=\mu_{R'}(A,B)+\mu_{R'}(B,C)$.

(d) R' is a total ordering relation if R' is reciprocal, transitive and additive.

Based on the extended fuzzy preference relation, A is greater than B if $\mu_{R'}(A,B)>0$.

Definition 2.10 For any two fuzzy numbers A and B, the extended fuzzy preference relation $F(A,B)$ of fuzzy numbers A over B is defined by the following membership function (Lee, 2005a[9]; Lee, 2005b[10]; Wang, Lee, 2010[20])

$$\mu_F(A,B)=\int_0^1(A_\alpha^L-B_\alpha^U+A_\alpha^U-B_\alpha^L)d\alpha.$$

Lemma 2.1 Let $A=(a_1,a_2,a_3)$ and $B=(b_1,b_2,b_3)$ be two triangular fuzzy numbers. Thus $\mu_F(A,B)=\dfrac{a_1+2a_2+a_3-b_1-2b_2-b_3}{2}$.

Definition 2.11 Let $U(A)$, representing a utility representation function (Lee, 2005a[9]; Lee, 2005b[10]; Wang, Lee, 2010[20]) of fuzzy number A, be defined as

$$U(A)=\frac{1}{2}\mu_F(A,0)=\frac{1}{2}\int_0^1(A_\alpha^L+A_\alpha^U)d\alpha.$$

Lemma 2.2 Let $A=(a_1,a_2,a_3)$ be a triangular fuzzy number. Then $U(A)=\dfrac{1}{2}\mu_F(A,0)=\dfrac{a_1+2a_2+a_3}{4}$.

Definition 2.12 For any two triangular fuzzy numbers $A=(a_1,a_2,a_3)$ and $B=(b_1,b_2,b_3)$, the basic operations of A and B by extension principle (Zadeh, 1965[23]) are expressed as follows.

$$A \oplus B = (a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (1)$$

$$t \otimes A = t \otimes (a_1, a_2, a_3) = (ta_1, ta_2, ta_3), \quad \forall \quad t > 0 \text{ and } t \in R. \quad (2)$$

$$A^{-1} \approx (1/a_3, 1/a_2, 1/a_1). \quad (3)$$

Definition 2.13 For n triangular fuzzy numbers $A_1, A_2, ..., A_n$, we define

$$\sum_{i=1}^{n} A_i = A_1 \oplus A_2 \oplus ... \oplus A_n .$$

3. FAHP IN SELECTING TRANSPORT MODES FOR TAIWAN OFF-SHORE ISLANDS' MILITARY LOGISTICS

For selecting transport modes of Taiwan off-shore islands' military logistics by FAHP, objective, criteria, sub-criteria and candidate alternatives are listed in Table 1. Carrier service attributes for a shipper's perspective proposed by Lu (2003)[11] is referenced to construct the criteria and sub-criteria. Based on Table 1, hierarchy structure of objective, criteria, sub-criteria and candidate transport modes is displayed in Figure 1. Lu's recognized reasons of criteria and sub-criteria based business and enterprise viewpoints were stated and yielded in his pasted approach (2003). The criteria and sub-criteria based military considerations were also used in the recent approaches including Han et al. (2015)[6] and Wang et al.'s (2015)[19] approaches. The approaches are closely associated with the transport modes evaluation of Taiwan off-shore islands' military logistics. Further, the criteria and sub-criteria are carefully rechecked and reviewed through professional interviewees. Undoubtedly, criteria and sub-criteria are useful and critical for evaluating transport modes of Taiwan off-shore islands' military logistics. Additionally, fuzzy pair-wise comparison matrices between varied levels are developed according to the figure.

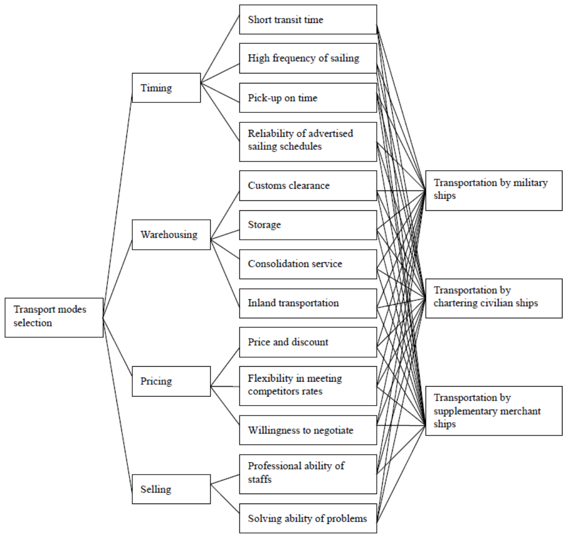

Figure 1 Hierarchy structure of objective, criteria, sub-criteria and candidate modes for selecting transport modes of Taiwan off-shore islands' military logistics

Through Figure 1, $(W_{ij})_{4\times4}$ is assumed to be a fuzzy pair-wise comparison matrix for criteria based on objective, where $W_{ij} = (w_{ij1}, w_{ij2}, w_{ij3})$ denotes fuzzy weight ratio of criterion i over criterion j, and $1 \le i, j \le 4$. The priority w_i of criterion i by associating normalization of row arithmetic averages(NRA) (Saaty, 1982[15]) with the utility representation function of Lemma 2.5 is yielded as

$$w_i = \frac{U(\sum_{j=1}^{4} W_{ij})}{U(\sum_{i=1}^{4} \sum_{j=1}^{4} W_{ij})}, \quad 1 \le i \le 4 .$$

Table 1 Objective, criteria, sub-criteria and modes for evaluating transport modes of Taiwan off-shore islands' military logistics

Level 1: Objective	Level 2: Criteria	Level 3: Sub-criteria	Level 4: Modes
The selection of transport modes for Taiwan off-shore islands' military logistics	Timing(C1)	Short transit time(C11) High frequency of sailing(C12) Pick-up on time(C13) Reliability of advertised sailing schedules(C14)	Transportation by military ships(A1) Transportation by chartering civilian ships(A2) Transportation by supplementary merchant ships(A3)
	Warehousing(C2)	Customs clearance(C21) Storage(C22) Consolidation service(C23) Inland transportation(C24)	
	Pricing(C3)	Price and discount (C31) Flexibility in meeting competitors rates (C32) Willingness to negotiate (C33)	
	Selling(C4)	Professional ability of staffs(C41) Solving ability of problems(C42)	

Table 2 Random indices for varied ranks

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Since $\sum_{i=1}^{n} w_i = 1$, normalizing the priorities of criteria will not be necessary. Then $(w_1, w_2, w_3, w_4)^T$ stands for priority vector of criteria, where $(w_1, w_2, w_3, w_4)^T$ is the transpose of (w_1, w_2, w_3, w_4). In addition, consistency index(CI) between levels 1 and 2 under fuzzy environment is yielded as

$$\lambda_{\max} = \sum_{i=1}^{4} \frac{\sum_{j=1}^{4} U(W_{ij}) w_j}{4 w_i} \text{ and}$$

$$CI_{\text{Between levels 1 and 2}} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - 4}{4 - 1},$$

where $N(e)$ is interviewees' number.

At the same time, random index(RI) (Saaty, 1980[14]) is expressed in Table 2.

Then consistency ratio(CR) of the fuzzy pair-wise comparison matrix $(W_{ij})_{4\times4}$ is obtained by calculating ratio of its CI over RI. That is to say, $CR_{\text{Between levels 1 and 2}} = \frac{CI_{\text{Between levels 1 and 2}}}{RI_{n=4}}$. Generally, CR<0.1 represents that the pair-wise comparison matrix conforms to rating consistency.

Likewise, $(W_{i\alpha\beta})_{n_i \times n_i}$ be a fuzzy pair-wise comparison matrix for sub-criteria of criterion i, where $W_{i\alpha\beta} = (w_{i\alpha\beta1}, w_{i\alpha\beta2}, w_{i\alpha\beta3})$ denotes fuzzy weight ratio of sub-criterion α over sub-criterion β for criterion i, and $1 \le \alpha, \beta \le n_i$. The priority $w_{i\alpha}$ of sub-criterion α within criterion i by combining Saaty's NRA method (Saaty, 1982[15]) with the utility representation function of Lemma 2.5 is derived as

$$w_{i\alpha} = \frac{U(\sum_{\alpha=1}^{n_i} W_{i\alpha\beta})}{U(\sum_{\alpha=1}^{n_i} \sum_{\beta=1}^{n_i} W_{i\alpha\beta})},$$

$1 \le i \le 4$; $1 \le \alpha \le n_i$.

Since $\sum_{\alpha=1}^{n_i} w_{i\alpha} = 1$, $w_i \times w_{i\alpha}$ will represent the weight of sub-criterion α of criterion i for transport modes, where $1 \le i \le 4$; $1 \le \alpha \le n_i$. For criterion i, CI between levels 2 and 3 is computed as

$$\lambda_{\max} = \sum_{\alpha=1}^{n_i} \frac{\sum_{\beta=1}^{n_i} U(W_{i\alpha\beta}) w_{i\beta}}{n_i w_{i\alpha}} \text{ and}$$

$$CI_{\text{Between levels 2 and 3 for } i} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - n_i}{n_i - 1}.$$

In addition, $CR_{\text{Between levels 2 and 3 for } i} = \frac{CI_{\text{Between levels 2 and 3 for } i}}{RI_{n=n_i}}$.

Let $(G_{i\alpha rs})_{3\times3}$ be a fuzzy pair-wise comparison matrix for candidate transport modes based on sub-criterion α of criterion i, where $G_{i\alpha rs} = (g_{i\alpha rs1}, g_{i\alpha rs2}, g_{i\alpha rs3})$ indicates rating ratio of transport mode r over transport mode s on sub-criterion α of criterion i, and $1 \le r, s \le 3$. The priority $g_{i\alpha r}$ of transport mode r based on sub-criterion α of criterion i by associating Saaty's NRA method (Saaty, 1982[15]) with the utility representation function of Lemma 2.5 is yielded as

$$g_{i\alpha r} = \frac{U(\sum_{s=1}^{3} G_{i\alpha rs})}{U(\sum_{r=1}^{3} \sum_{s=1}^{3} G_{i\alpha rs})},$$

$1 \le i \le 4$; $1 \le \alpha \le n_i$; $1 \le r \le 3$.

Since $\sum_{r=1}^{3} g_{i\alpha r} = 1$, $g_{i\alpha r} \times w_i \times w_{i\alpha}$ will stand for the weighted rating of transport mode r based on sub-criterion α of criterion i, where $1 \le i \le 4$; $1 \le \alpha \le n_i$; $1 \le r \le 3$. For sub-criterion α of criterion i, CI between levels 3 and 4 is yielded as

$$\lambda_{\max} = \sum_{r=1}^{3} \frac{\sum_{s=1}^{3} U(G_{i\alpha rs}) g_{i\alpha s}}{3 w_{i\alpha}} \text{ and}$$

$$CI_{\text{Between levels 3 and 4 for } \alpha \text{ of } i} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - 3}{3-1}.$$

Moreover,

$$CR_{\text{Between levels 3 and 4 for } \alpha \text{ of } i} = \frac{CI_{\text{Between levels 3 and 4 for } \alpha \text{ of } i}}{RI_{n=3}}.$$

Then the CR for the whole hierarchy (CRH) is defined as

$CRH =$

$$\frac{CI_{\text{Between levels 1 and 2}} + \sum_{i=1}^{4} w_i CI_{\text{Between levels 2 and 3 for } n_i} + \sum_{i=1}^{4} \sum_{\alpha=1}^{n_i} w_i w_{i\alpha} CI_{\text{Between levels 3 and 4 for } \alpha \text{ of } n_i}}{RI_{\text{Between levels 1 and 2}} + \sum_{i=1}^{4} w_i RI_{\text{Between levels 2 and 3 for } n_i} + \sum_{i=1}^{4} \sum_{\alpha=1}^{n_i} w_i w_{i\alpha} RI_{\text{Between levels 3 and 4 for } \alpha \text{ of } n_i}}$$

In the problem of selecting transport modes for Taiwan off-shore islands' military logistics, the situations of n_1 =4, n_2 =4, n_3 =3 and n_4 =2 indicate 13 final criteria weights and ratings. Therefore,

$G = (g_{i\alpha r})_{3\times 13}$

$=$

$$\begin{bmatrix} g_{111} & g_{121} & g_{131} & g_{141} & g_{211} & g_{221} & g_{231} & g_{241} & g_{311} & g_{321} & g_{331} & g_{411} & g_{421} \\ g_{112} & g_{122} & g_{132} & g_{142} & g_{212} & g_{222} & g_{232} & g_{242} & g_{312} & g_{322} & g_{332} & g_{412} & g_{422} \\ g_{113} & g_{123} & g_{133} & g_{143} & g_{213} & g_{223} & g_{233} & g_{243} & g_{313} & g_{323} & g_{333} & g_{413} & g_{423} \end{bmatrix},$$

where $1 \le i \le 4$; $1 \le \alpha \le n_i$ (n_1 =4, n_2 =4, n_3 =3 and n_4 =2); $1 \le r \le 3$.

Let PA be performance index matrix composed of three candidate transport modes, and

$$PA = \begin{bmatrix} pa_1 \\ pa_2 \\ pa_3 \end{bmatrix}$$

$=$

$$\begin{bmatrix} g_{111} & g_{121} & g_{131} & g_{141} & g_{211} & g_{221} & g_{231} & g_{241} & g_{311} & g_{321} & g_{331} & g_{411} & g_{421} \\ g_{112} & g_{122} & g_{132} & g_{142} & g_{212} & g_{222} & g_{232} & g_{242} & g_{312} & g_{322} & g_{332} & g_{412} & g_{422} \\ g_{113} & g_{123} & g_{133} & g_{143} & g_{213} & g_{223} & g_{233} & g_{243} & g_{313} & g_{323} & g_{333} & g_{413} & g_{423} \end{bmatrix}$$

$$\begin{bmatrix} w_1 \times w_{11} \\ w_1 \times w_{12} \\ \vdots \\ w_4 \times w_{42} \end{bmatrix}.$$

Finally, the three candidate transport modes are ranked according to their corresponding pa_1, pa_2, pa_3, and FAHP in selecting transport modes for Taiwan off-shore islands' military logistics is finished.

4. EMPIRICAL STUDY

By random sampling, one hundred and ninety questionnaires are collected from soldiers in Penghu, Kinmen and Matsu. Their opinions are represented by pair-wise comparison ratings including absolute unimportance(=1/9), very strong unimportance(=1/7), essential unimportance(=1/5), weak unimportance(=1/3), equal importance(=1), weak importance(=3), essential importance(=5), very strong importance(=7) and absolute importance(=9). Then the ratings are aggregated into fuzzy numbers shown in fuzzy pair-wise comparison matrices along criteria, sub-criteria and candidate transport modes in the questionnaires. For instance in the fuzzy pair-wise comparison matrix between levels 1 and 2, let q_{ijt} indicate relative weight ratio of criterion i over criterion j employed by the t th interviewee, where $t = 1, 2, ..., 190$. The converting method is shown as follows.

$$W_{ij} = (w_{ij1}, w_{ij2}, w_{ij3}),$$

where

$$w_{ij1} = \min_{t=1,2,...,190}(q_{ijt}),$$

$$w_{ij2} = \sum_{t=1}^{190} q_{ijt} / 190,$$

$$w_{ij3} = \max_{t=1,2,...,190}(q_{ijt}),$$

$$1 \le i \le j \le 4.$$

In addition, $W_{ji} = (W_{ij})^{-1} \approx (1/w_{ij3}, 1/w_{ij2}, 1/w_{ij1})$ denotes the reciprocal of W_{ij}, where $1 \le i \le j \le 4$. The fuzzy pair-wise comparison matrix between levels 1 and 2 is shown in Table 3.

Table 3. Fuzzy pair-wise comparison matrix between levels 1 and 2

	C1	C2	C3	C4
C1	(1, 1, 1)	(0.1111, 3.9913, 9)	(0.1111, 3.1804, 9)	(0.1111, 3.0602, 9)
C2	(0.1111, 0.2505, 9)	(1, 1, 1)	(0.1111, 2.7617, 9)	(0.1111, 2.4337, 9)
C3	(0.1111, 0.3144, 9)	(0.1111, 0.3621, 9)	(1, 1, 1)	(0.1111, 2.2132, 9)
C4	(0.1111, 0.3268, 9)	(0.1111, 0.4109, 9)	(0.1111, 0.4518, 9)	(1, 1, 1)

CI =0.0108 and CR = 0.0120<0.1 between levels 1 and 2.

Table 4. Fuzzy pair-wise comparison matrices based on four criteria between levels 2 and 3

		C11	C12	C13	C14
C1	C11	(1, 1, 1)	(0.1111, 3.2156, 9)	(0.1111, 3.1724, 9)	(0.1111, 3.1329, 9)
	C12	(0.1111, 0.3110, 9)	(1, 1, 1)	(0.1111, 3.1970, 9)	(0.1111, 2.9696, 9)
	C13	(0.1111, 0.3152, 9)	(0.1111, 0.3128, 9)	(1, 1, 1)	(0.1111, 3.3755, 9)
	C14	(0.1111, 0.3192, 9)	(0.1111, 0.3368, 9)	(0.1111, 0.2963, 9)	(1, 1, 1)
		C21	C22	C23	C24
C2	C21	(1, 1, 1)	(0.1111, 3.0528, 9)	(0.1429, 2.5410, 9)	(0.1429, 2.1514, 9)
	C22	(0.1111, 0.3726, 9)	(1, 1, 1)	(0.1111, 2.8842, 9)	(0.1111, 2.5666, 9)
	C23	(0.1111, 0.3936, 7)	(0.1111, 0.3467, 9)	(1, 1, 1)	(0.1111, 2.5556, 9)
	C24	(0.1111, 0.4648, 7)	(0.1111, 0.3896, 9)	(0.1111, 0.3913, 9)	(1, 1, 1)
		C31	C32	C33	
C3	C31	(1, 1, 1)	(0.1111, 3.1355, 9)	(0.1111, 2.6516, 9)	
	C32	(0.1111, 0.3189, 9)	(1, 1, 1)	(0.1111, 2.5027, 9)	
	C33	(0.1111, 0.3771, 9)	(0.1111, 0.3996, 9)	(1, 1, 1)	
		C41	C42		
C4	C41	(1, 1, 1)	(0.1111, 3.0367, 9)		
	C42	(0.1111, 0.3293, 9)	(1, 1, 1)		

Table 5. Fuzzy pair-wise comparison matrices based on thirteen sub-criteria between levels 3 and 4

		A1	A2	A3
C11	A1	(1, 1, 1)	(0.1111, 2.4711, 9)	(0.1111, 2.2694, 9)
	A2	(0.1111, 0.4047, 9)	(1, 1, 1)	(0.1111, 2.7207, 9)
	A3	(0.1111, 0.4407, 9)	(0.1111, 0.3675, 9)	(1, 1, 1)
		A1	A2	A3
C12	A1	(1, 1, 1)	(0.1111, 2.1808, 9)	(0.1111, 1.9739, 9)
	A2	(0.1111, 0.4585, 9)	(1, 1, 1)	(0.1111, 2.4340, 9)
	A3	(0.1111, 0.5066, 9)	(0.1111, 0.4108, 9)	(1, 1, 1)
		A1	A2	A3
C13	A1	(1, 1, 1)	(0.1111, 2.3648, 9)	(0.1111, 2.1117, 9)
	A2	(0.1111, 0.4229, 9)	(1, 1, 1)	(0.1111, 2.4169, 9)

	A3	(0.1111, 0.4376, 9)	(0.1111, 0.4137, 9)	(1, 1, 1)
C14		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.5089, 9)	(0.1111, 2.2499, 9)
	A2	(0.1111, 0.3986, 9)	(1, 1, 1)	(0.1111, 2.4990, 9)
	A3	(0.1111, 0.4445, 9)	(0.1111, 0.4002, 9)	(1, 1, 1)
C21		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.5029, 9)	(0.1111, 2.4048, 9)
	A2	(0.1111, 0.3995, 9)	(1, 1, 1)	(0.1111, 2.5030, 9)
	A3	(0.1111, 0.4518, 9)	(0.1111, 0.3995, 9)	(1, 1, 1)
C22		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.8998, 9)	(0.1429, 2.5635, 9)
	A2	(0.1111, 0.3449, 9)	(1, 1, 1)	(0.1111, 2.5935, 9)
	A3	(0.1111, 0.3901, 7)	(0.1111, 0.3856, 9)	(1, 1, 1)
C23		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.7971, 9)	(0.1429, 2.4835, 9)
	A2	(0.1111, 0.3575, 9)	(1, 1, 1)	(0.1429, 2.3297, 9)
	A3	(0.1111, 0.4027, 9)	(0.1111, 0.4292, 7)	(1, 1, 1)
C24		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.6027, 9)	(0.1111, 2.3281, 9)
	A2	(0.1111, 0.3842, 9)	(1, 1, 1)	(0.1111, 2.3803, 9)
	A3	(0.1111, 0.4295, 9)	(0.1111, 0.4201, 9)	(1, 1, 1)
C31		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.7737, 9)	(0.1111, 2.5813, 9)
	A2	(0.1111, 0.3605, 9)	(1, 1, 1)	(0.1111, 2.2732, 9)
	A3	(0.1111, 0.3874, 9)	(0.1111, 0.4399, 9)	(1, 1, 1)
C32		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.6973, 9)	(0.1111, 2.3494, 9)
	A2	(0.1111, 0.3707, 9)	(1, 1, 1)	(0.1111, 2.0212, 9)
	A3	(0.1111, 0.4256, 9)	(0.1111, 0.4948, 9)	(1, 1, 1)
C33		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.5232, 9)	(0.1111, 2.3208, 9)
	A2	(0.1111, 0.3945, 9)	(1, 1, 1)	(0.1429, 2.3646, 9)
	A3	(0.1111, 0.4309, 9)	(0.1111, 0.4229, 9)	(1, 1, 1)
C41		A1	A2	A3
	A1	(1, 1, 1)	(0.1429, 2.7907, 9)	(0.1429, 2.6286, 9)
	A2	(0.1111, 0.3583, 7)	(1, 1, 1)	(0.1111, 2.3499, 9)
	A3	(0.1111, 0.3204, 7)	(0.1111, 0.4255, 9)	(1, 1, 1)
C42		A1	A2	A3
	A1	(1, 1, 1)	(0.1111, 2.8161, 9)	(0.1111, 2.6321, 9)
	A2	(0.1111, 0.3551, 9)	(1, 1, 1)	(0.1111, 2.3999, 9)
	A3	(0.1111, 0.3799, 9)	(0.1111, 0.4167, 9)	(1, 1, 1)

Likewise, fuzzy pair-wise comparison matrices based on four criteria between levels 2 and 3 are shown in Table 4.

In Table 4, CI =0.0110 and CR = 0.0122<0.1 based on timing(C1), CI =0.0099 and CR = 0.0110<0.1 based on warehousing(C2), CI =0.0106 and CR =0.0183<0.1 based on pricing(C3), whereas CI =0.0109 and CR is ignored based on selling(C4) due to n =2.

Similarly, fuzzy pair-wise comparison matrices based on thirteen sub-criteria between levels 3 and 4 are displayed in Table 5.

In Table 5, CI =0.0103 and CR =0.0178<0.1 based on short transit time(C11), CI =0.0101 and CR =0.0174<0.1 based on high frequency of sailing(C12), CI =0.0102 and CR =0.0175<0.1 based on pick-up on time(C13), CI =0.0103 and CR = 0.0177<0.1 based on reliability of advertised sailing schedules(C14), CI =0.0103 and CR =0.0178<0.1 based on customs clearance(C21), CI =0.0100 and CR = 0.0172<0.1 based on storage(C22), CI =0.0104 and CR = 0.0179<0.1 based on consolidation service(C23), CI =0.0103 and CR = 0.0177<0.1 based on inland transportation(C24), CI =0.0104 and CR =0.0179<0.1 based on price and discount(C31), CI =0.0102 and CR = 0.0176<0.1 based on flexibility in meeting competitors rates(C32), CI =0.0103 and CR = 0.0177<0.1 based on willingness to negotiate(C33), CI =0.0093 and CR =0.0160<0.1 based on professional ability of staffs(C41), and CI =0.0105 and CR =0.0180<0.1 based on solving ability of problems(C42). Obviously, all CR values are smaller than 0.1.

Based on the previous values of CI, RI and related weights, the CR for the whole hierarchy is derived as CRH=0.0138<0.1. Therefore, the work conforms to the whole rating consistency. Obviously, the whole hierarchy can conform to rating consistency as all CI values in corresponding hierarchies respectively conform to their rating consistency. Associating priorities form Tables 3 to 5, and the ratings and weights of the three transport modes for thirteen sub-criteria based on four criteria are displayed in Table 6.

Yielding the performance indices along varied criteria by entries of Table 6, the preference order of the three transport modes is A1(0.1179)>A2(0.1060)>A3(0.0903) in timing(C1), the preference order of the three transport modes is A1(0.0995)>A2(0.0853)>A3(0.0713) in warehousing(C2), the preference order of the three transport modes is A1(0.0872)>A2(0.0736)>A3(0.0643) in pricing(C3), and the preference order of the three transport modes is A1(0.0824)>A2(0.0659)>A3(0.0563) in selling(C4). The figures inside parentheses refer to relative performance indices as stated as the situations of varied criteria. The larger the figure is, the higher the criteria performance is. In the four criteria, transportation by military ships(A1) is superior to the others, transportation by chartering civilian ships(A2) is the second and transportation by supplementary merchant ships(A3) is the last.

Finally, total performance indices of three varied transport modes are yielded as Table 7.

Table 6. Ratings and weights of three transport modes for thirteen sub-criteria based on four criteria

Criteria	Sub-criteria	Candidate transport modes			Weights
		A1	A2	A3	
C1	C11	0.3774	0.3389	0.2837	0.0946
	C12	0.3697	0.3391	0.2913	0.0832
	C13	0.3753	0.3359	0.2889	0.0739
	C14	0.3794	0.3349	0.2858	0.0624
C2	C21	0.3818	0.3340	0.2842	0.0762
	C22	0.3995	0.3383	0.2622	0.0697
	C23	0.3890	0.3275	0.2835	0.0584
	C24	0.3831	0.3313	0.2856	0.0517
C3	C31	0.3907	0.3261	0.2832	0.0891
	C32	0.3875	0.3239	0.2886	0.0734
	C33	0.3820	0.3318	0.2862	0.0627
C4	C41	0.4110	0.3181	0.2709	0.1191
	C42	0.3912	0.3275	0.2813	0.0855

Table 7. Performance indices for three varied transport modes

Transport modes	Performance indices
A1	0.3870
A2	0.3308
A3	0.2822

The order of three candidate transport modes in total performance is A1(0.3870)>A2(0.3308)>A3(0.2822). It is obvious that transportation by military ships is better than the others. Thus transportation by military ships(A1) is the best transport mode for Taiwan off-shore islands' military logistics. In fact, the same ranking result was also found out from Han et al.'s research (2015)[6] that applied AHP to choose the optimal transport mode of army logistics between Taiwan and off-shore islands. Differently, Han et al.'s the same ranking result was yielded by an AHP computer system called Expert Choice 11.5 due to interviewees' numerous pair-wise comparison matrices. Expert Choice 11.5 is a well-known software package that is able to process priorities and consistency test of pair-wise comparison matrices in traditional AHP, especially for numerous and complicated matrices. For instance, AHP has to yield 3420 (i.e., $(17+1)\times 190$) pair-wise comparison matrices and corresponding consistency tests because criteria and sub-criteria number is 17, and interviewees' numbers is 190 in the evaluation problem. In other words, the processing of numerous and complicated pair-wise comparison matrices in AHP is generally a complex and hard work if we do not use an AHP computer system as similar as Expert Choice 11.5. On the other hand, our FAHP based on fuzzy number characteristic only derives 18 pair-wise comparison matrices and corresponding consistency tests no matter whether interviewees' number is large or not. Practically, the software package will be unnecessary through our FAHP. This is the strength of FAHP over AHP.

5. CONCLUSIONS

In this paper, we use FAHP to select the optimal transport mode for Taiwan off-shore islands' military logistics and find transportation by military ships to be the best transport mode from three candidate transport mode. Practically, transportation by military ships is superior to the others in the four criteria including timing, warehousing, pricing and selling, so it is the best selection of the three candidate transport modes in total performance. Further, FAHP in this paper provides corresponding values on varied criteria beside the total performance indices, so the decision-makers can evaluate the three transport modes according to their desired perspectives. Moreover, each interviewee has 18 pair-wise comparison matrices that are computed, and then 190 interviewees will have 3420 comparison matrices yielded by AHP. This is a heavy work for decision-makers. Through the fuzzy converting technique in Section 4, the number of fuzzy pair-wise comparison matrices based on the number of criteria and sub-criteria being 17 is only 18 in this empirical study. As the number of criteria and sub-criteria is 17, the number of fuzzy pair-wise comparison matrices is always 18 in the empirical study no matter the number of interviewees is 190 or more due to the FAHP computation. Obviously, FAHP easily and efficiently solves the selecting problem for Taiwan off-shore islands' military logistics.

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