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APPLYING FUZZY AHP IN SELECTION OF TRANSPORT MODES FOR KINMEN MILITARY LOGISTICS

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Key words: fuzzy pairwise comparison matrices, Kinmen, transport modes, military logistics.

ABSTRACT

Kinmen is suited as an important tactical location for Taiwan, despite being a small island with scarce resources. A number of soldiers defend Kinmen for essential military reasons. Therefore, logistics in Kinmen are very important, especially with regard to the military. Generally, necessary goods and materials for Kinmen are transported from Taiwan by ship or air. However, inclement weather in Kinmen often causes delays and difficulties in transportation. This is a serious problem for Kinmen military logistics. To enhance and increase transportation performance, military logistics centers need to evaluate feasible transport modes based on efficiency and cost, and then select an optimal transport mode. In this study, we applied a fuzzy analytic hierarchy process (fuzzy AHP) in the selection of transport modes for Kinmen military logistics. The pairwise comparison comments on selecting candidate transport modes for Kinmen military logistics were from interviews with practical users (i.e., soldiers in Kinmen). By converting interviewees' comments into fuzzy pairwise comparison matrices, fuzzy AHP was utilized to prioritize these matrices in order to find an optimal transport mode for the Kinmen military to execute logistics effectively and efficiently.

I. INTRODUCTION

Kinmen is a small island in the Taiwan Strait. Thus, it serves as a critical tactical position for Taiwan. However, resources in Kinmen are few, in particular, water is scarce. Furthermore, agricultural development in Kinmen is rather limited due to poor natural conditions. Due to these issues, necessary goods and materials for Kinmen are transported from Taiwan by ship or air. Moreover, harsh climates including northeast monsoons and dense fog often occur in Kinmen, especially in November, December, April, and May.

These situations make transportation between Kinmen and Taiwan difficult and delay progress in logistics. Due to the critical tactical position of the island, there is an army comprised of a number of soldiers in Kinmen. To achieve tactical tasks, military logistics in Kinmen are very important because the army requires heavy volumes of goods and materials. However, harsh climates often delay logistics, therefore creating a serious problem for the Kinmen military. To enhance transportation performance, military logistics centers have to evaluate different transport modes based on efficiency and cost, and then select an optimal transport mode for Kinmen.

Based on the above description, a proper transport mode is needed for military logistics in Kinmen to increase efficiency and decrease transportation costs. In this study, we used a questionnaire to query some soldiers in Kinmen regarding transportation modes in military logistics. We then applied a fuzzy analytic hierarchy process (fuzzy AHP) method to select an optimal transport mode from feasible alternatives. The analytic hierarchy process (AHP) (Saaty, 1980) is one of the many famous multi-criteria decision-making (MCDM) methods under certain environments. Generally, a decision-making problem with several evaluation criteria is a MCDM problem (Kacprzyk et al., 1992). Problems evaluated using MCDM under imprecise, subjective, and vague (i.e., fuzzy) environments are called fuzzy multi-criteria decision-making (FMCDM) problems (Jain, 1978; Saaty, 1980; Van Laarhoven and Predrycz, 1983; Yufei, 1991; Kacprzyk et al., 1992; Hsu and Chen, 1996; Cheng, 1997;Hsu and Chen, 1997; Weck et al., 1997; Liang, 1999; Zhu et al., 1999; Leung and Cao, 2000; Tsaur et al., 2002; Kahraman, 2004; Lee, 2005a; Lee, 2005b; Chang, 2008; Fu et al., 2008; Wang and Chen, 2008; Wang et al., 2008; Celik et al., 2009; Gumus, 2009; Akdag et al, 2014; Büyüközkan and Çifçi, 2012; Lee et al., 2014; Patil and Kant, 2014; Wang, 2014a; Wang, 2014b; Wang 2015). In FMCDM problems, some approaches extended AHP under fuzzy environments into fuzzy AHP (Van Laarhoven and Predrycz, 1983; Cheng, 1997; Weck et al., 1997; Zhu et al.,

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1999; Leung and Cao, 2000; Kahraman et al., 2004; Chang, 2008; Fu et al., 2008; Wang and Chen, 2008; Wang et al., 2008; Celik et al., 2009; Gumus, 2009; Lee et al., 2014). In reality, transport modes for Kinmen military logistics are selected under a fuzzy environment. Thus, fuzzy AHP is a suitable method in the selection of transport modes for Kinmen military logistics.

For the sake of clarity, mathematical preliminaries of fuzzy sets and fuzzy numbers are presented in Section 2. In Section 3, the fuzzy AHP procedure in the selection of transport modes is expressed. Based on the fuzzy AHP, an empirical study of transport modes selection in Kinmen military logistics is given in Section 4.

II. PRELIMINARIES

In this section, fuzzy sets and fuzzy numbers (Zadeh, 1965; Zimmermann, 1987; Zimmermann, 1991) are presented.

Definition 2.1 Let U be a universal 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 iff $\sup_{x \in U} \mu_A(x) = 1$.

Definition 2.3 A fuzzy subset A of U is convex iff $\mu_A(\lambda x + (1 - \lambda)y) \geq (\mu_A(x) \wedge \mu_A(y))$, $\forall x, y \in U$, $\forall \lambda \in [0, 1]$, 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 a piecewise linear membership function μ_A defined by

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

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 an operation on real numbers, such as +, −, *, $\wedge$, $\vee$, etc. By the extension principle (Zadeh, 1965; Zimmermann, 1987; Zimmermann, 1991), 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 respectively defined as

$$A_\alpha^L = \inf_{\mu_A(z) \geq \alpha}(z) \text{ and } A_\alpha^U = \sup_{\mu_A(z) \geq \alpha}(z).$$

Definition 2.8 A fuzzy preference relation R is a fuzzy subset of $\Re \times \Re$ with the membership function $\mu_R(A, B)$ representing preference degree of fuzzy number A over fuzzy number B (Nakamura, 1986; Yufei, 1991).

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

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

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

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

Definition 2.9 An extended preference relation R' is a fuzzy subset of $\Re \times \Re$ with the membership function $-\infty \leq \mu_{R'}(A, B) \leq \infty$ representing an 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 $\mu_{R'}(A, B) \geq 0$ and $\mu_{R'}(B, C) \geq 0 \Rightarrow \mu_{R'}(A, C) \geq 0$ for all fuzzy numbers A, B, and C.
(c) R' is additive iff $\mu_{R'}(A, C) = \mu_{R'}(A, B) + \mu_{R'}(B, C)$.
(d) R' is a total ordering relation iff R' is reciprocal, transitive, and additive.

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

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; Lee, 2005b).

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

Lemma 2.1 F is reciprocal, i.e.,

$$\mu_F(A,B) = -\mu_F(B,A).$$

Lemma 2.2 F is transitive, i.e.,

Table 1. Objective, criteria, sub-criteria, and alternatives for selecting transport modes for Kinmen military logistics.

Level 1: Objective	Level 2: Criteria	Level 3: Sub-criteria	Level 4: Alternatives
The selection of transport modes for Kinmen 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 competitor rates (C32) Willingness to negotiate (C33)	
	Selling (C4)	Professional ability of staff (C41) Problem-solving ability (C42)	

$$\mu_F(A,B) \ge 0 \text{ and } \mu_F(B,C) \ge 0 \Rightarrow \mu_F(A,C) \ge 0 .$$

Lemma 2.3 F is additive, i.e.,

$$\mu_F(A,B) + \mu_F(B,C) = \mu_F(A,C) .$$

Lemma 2.4 Let $A = (a_1, a_2, a_3)$ and $B = (b_1, b_2, b_3)$ be two triangular fuzzy numbers. Then

$$\mu_F(A,B) = \frac{a_1 + 2a_2 + a_3 - b_1 - 2b_2 - b_3}{2} .$$

Definition 2.11 Let $U(A)$ representing a utility representation function (Lee, 2005a; Lee, 2005b) 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 2.5 Let $A = (a_1, a_2, a_3)$ be a triangular fuzzy number. Then $U(A) = \frac{1}{2}\mu_F(A,0) = \frac{a_1 + 2a_2 + a_3}{4}$.

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 the extension principle (Zadeh, 1965; Zimmermann, 1987; Zimmermann, 1991) are expressed as follows:

(1) $A \oplus B = (a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$.
(2) $t \otimes A = t \otimes (a_1, a_2, a_3) = (ta_1, ta_2, ta_3)$, $\forall\, t > 0$ and $t \in R$.
(3) $A^{-1} \approx (1/a_3, 1/a_2, 1/a_1)$.

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

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

Based on the above definitions, we used fuzzy AHP in the selection of transport modes for Kinmen military logistics.

III. FUZZY AHP IN SELECTING TRANSPORT MODES FOR KINMEN MILITARY LOGISTICS

In the fuzzy AHP for selecting transport modes for Kinmen military logistics, objective, criteria, sub-criteria, and candidate alternatives are listed in Table 1. In Table 1, Lu's approach (Lu, 2003) in analyzing carrier service attributes from a shipper's perspective was referenced to construct the criteria and sub-criteria. Based on Table 1, the hierarchy structure of objective, criteria, sub-criteria, and alternatives is expressed in Fig. 1. Then, fuzzy pairwise comparison matrices between varied levels were developed through Fig. 1.

Through the hierarchy structure in Fig. 1, $(W_{ij})_{4\times 4}$ was assumed to be a fuzzy pairwise comparison matrix for criteria based on objective, where $W_{ij} = (w_{ij1}, w_{ij2}, w_{ij3})$ indicates fuzzy weight ratio of criterion i over criterion j, and $1 \le i, j \le 4$. The priority w_i of criterion i was achieved by associating an approximating solution called the normalization of row arithmetic averages (NRA) method (Saaty, 1982), with the utility representation function of Lemma 2.5 derived as

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

Since $\sum_{i=1}^{n} w_i = 1$, priorities of criteria will not be normalized. Then $(w_1, w_2, w_3, w_4)^T$ represents a 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).

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

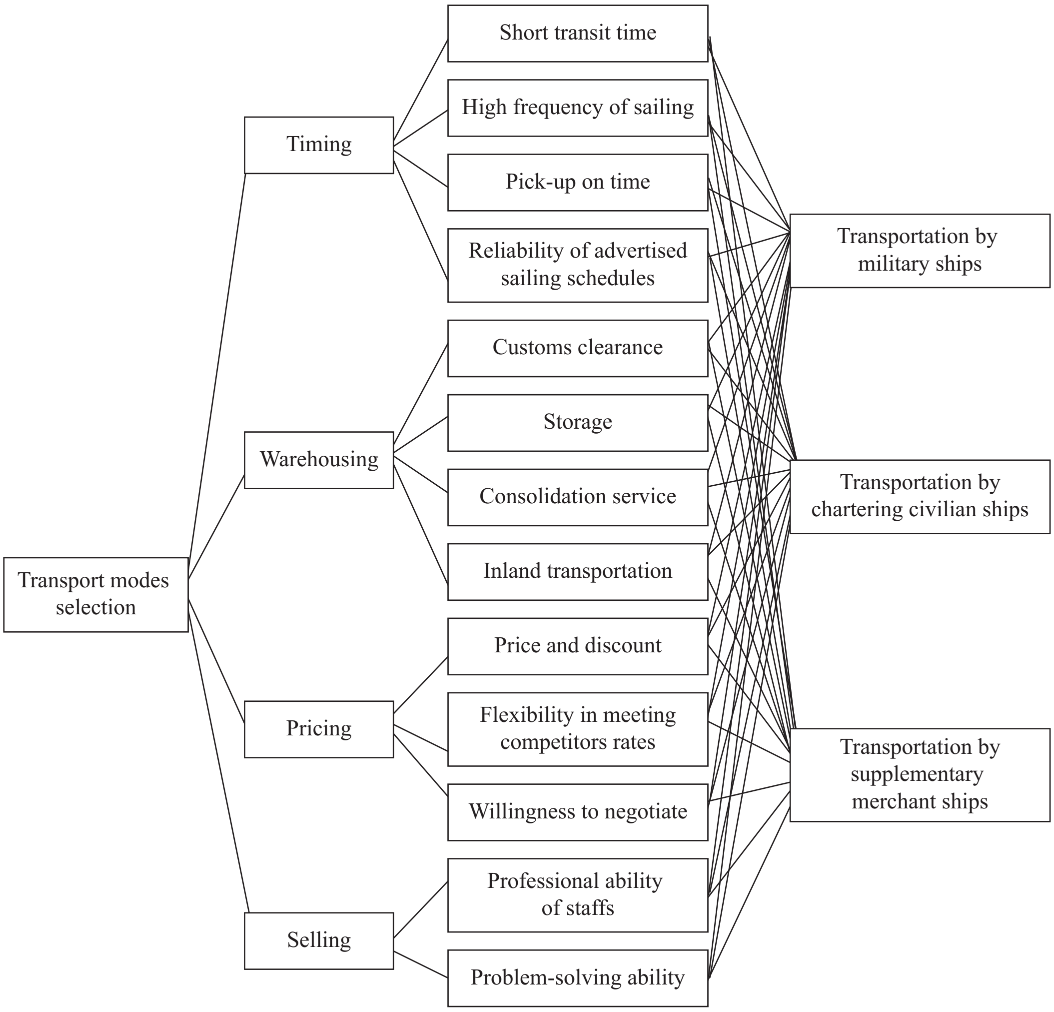

Fig. 1. Hierarchy structure of objective, criteria, sub-criteria, and alternatives for evaluating transport modes of Kinmen military logistics.

Additionally, the consistency index (CI) between levels 1 and 2 under a fuzzy environment is yielded as

$$\lambda_{\max} = \sum_{i=1}^{4} \frac{\sum_{j=1}^{4} U(W_{ij}) w_j}{4 w_i} \text{ and } CI_{Between\ levels\ 1\ and\ 2} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - 4}{4-1},$$

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

In addition, the random index (RI) (Saaty, 1980) is expressed in Table 2.

Then the consistency ratio (CR) of the fuzzy pairwise comparison matrix $(W_{ij})_{4\times 4}$ is obtained by calculating the ratio of its consistency index over random index. That is to say, $CR_{Between\ levels\ 1\ and\ 2} = \dfrac{CI_{Between\ levels\ 1\ and\ 2}}{RI_{n=4}}$. Generally, CR < 0.1 means that the pairwise comparison matrix conforms to rating consistency.

Likewise, $(W_{i\alpha\beta})_{n_i \times n_i}$ is a fuzzy pairwise comparison matrix for sub-criteria of criterion i, where $W_{i\alpha\beta} = (w_{i\alpha\beta 1}, w_{i\alpha\beta 2}, w_{i\alpha\beta 3})$ indicates a 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 associating Saaty's NRA method (Saaty, 1982) 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 $\sum_{\alpha=1}^{n_i} w_{i\alpha} = 1$, the weight of sub-criterion α of criterion i for alternatives will be represented by $w_i \times w_{i\alpha}$, where $1 \le i \le 4$; $1 \le \alpha \le n_i$. For criterion i, the consistency index (CI) between levels 2 and 3 is computed as

$$\lambda_{\max} = \sum_{\alpha=1}^{n_i} \frac{\sum_{\beta=1}^{n_i} U(W_{i\alpha\beta}) w_{i\beta}}{n_i w_{i\alpha}} \text{ and } CI_{\textit{Between levels 2 and 3 for } i} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - n_i}{n_i - 1}.$$

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

Let $(G_{i\alpha rs})_{3 \times 3}$ be a fuzzy pairwise comparison matrix for candidate transport modes (i.e., alternatives) based on the sub-criterion α of criterion i, where $G_{i\alpha rs} = (g_{i\alpha rs1}, g_{i\alpha rs2}, g_{i\alpha rs3})$ indicates the rating ratio of transport mode r over transport mode s on the sub-criterion α of criterion i, and $r = 1, 2, 3$; $s = 1, 2, 3$. 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) with the utility representation function of Lemma 2.5 is derived as

$$g_{i\alpha r} = \frac{U(\sum_{s=1}^{3} G_{i\alpha rs})}{U(\sum_{r=1}^{3}\sum_{s=1}^{3} G_{i\alpha rs})}, 1 \le i \le 4; 1 \le \alpha \le n_i; r = 1,2,3.$$

Since $\sum_{r=1}^{3} g_{i\alpha r} = 1$, the weighted rating of transport mode r based on the sub-criterion α of criterion i will be represented by $g_{i\alpha r} \times w_{i\alpha} \times w_{i\alpha}$, where $1 \le i \le 4$; $1 \le \alpha \le n_i$; $r = 1, 2, 3$. For the sub-criterion α of criterion i, the consistency index (CI) between levels 3 and 4 is yielded as

$$\lambda_{\max} = \sum_{r=1}^{3} \frac{\sum_{s=1}^{3} U(G_{i\alpha rs}) g_{i\alpha s}}{3 w_{i\alpha}} \text{ and } CI_{\textit{Between levels 3 and 4 for } \alpha \textit{ of } i} = \frac{1}{N(e)} \times \frac{\lambda_{\max} - 3}{3 - 1}.$$

In addition,

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

Based on the above, the CR for the whole hierarchy (CRH) is defined as

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

In this problem of selecting transport modes for Kinmen military logistics, the situations where $n_1 = 4$, $n_2 = 4$, $n_3 = 3$, and $n_4 = 2$ denote 13 final criteria weights and ratings. Thus,

$$G = (g_{i\alpha r})_{3\times 13} = \begin{bmatrix} g_{111} & g_{121} & g_{131} & g_{141} & g_{211} & g_{221} & g_{231} & g_{241} & g_{311} & g_{321} & g_{331} & g_{411} & g_{421} \\ g_{112} & g_{122} & g_{132} & g_{142} & g_{212} & g_{222} & g_{232} & g_{242} & g_{312} & g_{322} & g_{332} & g_{412} & g_{422} \\ g_{113} & g_{123} & g_{133} & g_{143} & g_{213} & g_{223} & g_{233} & g_{243} & g_{313} & g_{323} & g_{333} & g_{413} & g_{423} \end{bmatrix},$$

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 a performance index matrix composed of three candidate transport modes, and thus,

$$PA = \begin{bmatrix} pa_1 \\ pa_2 \\ pa_3 \end{bmatrix} = \begin{bmatrix} g_{111} & g_{121} & g_{131} & g_{141} & g_{211} & g_{221} & g_{231} & g_{241} & g_{311} & g_{321} & g_{331} & g_{411} & g_{421} \\ g_{112} & g_{122} & g_{132} & g_{142} & g_{212} & g_{222} & g_{232} & g_{242} & g_{312} & g_{322} & g_{332} & g_{412} & g_{422} \\ g_{113} & g_{123} & g_{133} & g_{143} & g_{213} & g_{223} & g_{233} & g_{243} & g_{313} & g_{323} & g_{333} & g_{413} & g_{423} \end{bmatrix} \begin{bmatrix} w_1 \times w_{11} \\ w_1 \times w_{12} \\ \vdots \\ w_4 \times w_{42} \end{bmatrix}.$$

Finally, candidate transport modes are ranked according to their corresponding performance indices pa_1, pa_2, pa_3 and fuzzy AHP in selecting transport modes for Kinmen military logistics is completed.

IV. EMPIRICAL STUDY

Through random sampling, we collected sixty-five questionnaires from soldiers in Kinmen. Their pairwise comparison rating comments converted into fuzzy numbers are presented in fuzzy comparison matrices for each criteria, sub-criteria, and candidate transport modes in the questionnaires. For instance, in the fuzzy pairwise comparison matrix between levels 1 and 2, let q_{ijt} denote relative weight ratio of criterion i over criterion j employed by the t th interviewee, where $t = 1, 2, \ldots, 65$. The converting method is expressed below.

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

where

$$w_{ij1} = \min_{t=1,2,\ldots,65}(q_{ijt}),$$

$$w_{ij1} = \min_{t=1,2,\ldots,65}(q_{ijt}),$$

$$w_{ij2} = \sum_{t=1}^{65} q_{ijt} / 65,$$

Table 3. Fuzzy pairwise comparison matrix between levels 1 and 2 as well as corresponding priorities.

	C1	C2	C3	C4
C1	(1, 1, 1)	(0.1111, 3.9853, 9)	(0.2, 3.1251, 9)	(0.1429, 2.6094, 7)
C2	(0.1111, 0.2509, 9)	(1, 1, 1)	(0.2, 3.1559, 9)	(0.1429, 2.3213, 9)
C3	(0.1111, 0.3200, 5)	(0.1111, 0.3169, 5)	(1, 1, 1)	(0.1429, 2.3003, 9)
C4	(0.1429, 0.3832, 7)	(0.1111, 0.4308, 7)	(0.1111, 0.4347, 7)	(1, 1, 1)
Priorities	0.3284	0.2882	0.1964	0.1871

$CI = 0.0255$ and $CR = 0.0283 < 0.1$ between levels 1 and 2.

Table 4. Fuzzy pairwise comparison matrix based on timing (C1) between levels 2 and 3 as well as corresponding priorities.

	C11	C12	C13	C14
C11	(1, 1, 1)	(0.1429, 3.5717, 9)	(0.1429, 2.6299, 9)	(0.1111, 2.7539, 9)
C12	(0.1111, 0.2800, 7)	(1, 1, 1)	(0.1429, 2.9317, 9)	(0.1429, 2.4813, 9)
C13	(0.1111, 0.3802, 7)	(0.1111, 0.3411, 7)	(1, 1, 1)	(0.1429, 3.1020, 9)
C14	(0.1111, 0.3631, 9)	(0.1111, 0.4030, 7)	(0.1111, 0.3224, 7)	(1, 1, 1)
Priorities	0.3189	0.2638	0.2264	0.1909

$CI = 0.0277$ and $CR = 0.0308 < 0.1$ based on timing between levels 2 and 3.

Table 5. Fuzzy pairwise comparison matrix based on warehousing (C2) between levels 2 and 3 as well as corresponding priorities.

	C21	C22	C23	C24
C21	(1, 1, 1)	(0.1111, 2.8172, 9)	(0.2000, 2.6062, 9)	(0.1429, 1.9612, 9)
C22	(0.1111, 0.3550, 9)	(1, 1, 1)	(0.1111, 2.3876, 9)	(0.1111, 2.4733, 9)
C23	(0.1111, 0.3837, 5)	(0.1111, 0.4188, 9)	(1, 1, 1)	(0.1111, 2.8017, 9)
C24	(0.1111, 0.5099, 7)	(0.1111, 0.4043, 9)	(0.1111, 0.3569, 9)	(1, 1, 1)
Priorities	0.2994	0.2705	0.2237	0.2064

$CI = 0.0279$ and $CR = 0.0310 < 0.1$ based on warehousing between levels 2 and 3.

Table 6. Fuzzy pairwise comparison matrix based on pricing (C3) between levels 2 and 3 as well as corresponding priorities.

	C31	C32	C33
C31	(1, 1, 1)	(0.2000, 3.3774, 9)	(0.1111, 2.1178, 9)
C32	(0.1111, 0.2961, 5)	(1, 1, 1)	(0.1111, 2.2661, 9)
C33	(0.1111, 0.4722, 9)	(0.1111, 0.4413, 9)	(1, 1, 1)
Priorities	0.4127	0.2893	0.2980

$CI = 0.0273$ and $CR = 0.0471 < 0.1$ based on pricing between levels 2 and 3.

Table 7. Fuzzy pairwise comparison matrix based on selling (C4) between levels 2 and 3 as well as corresponding priorities.

	C41	C42
C41	(1, 1, 1)	(0.1111, 2.7997, 9)
C42	(0.1111, 0.3572, 9)	(1, 1, 1)
Priorities	0.5751	0.4249

$CI = 0.0311$ and CR is ignored based on selling between levels 2 and 3 because $n = 2$.

$$w_{ij3} = \max_{t=1,2,\ldots,65} (q_{ijt}) \text{ and } 1 \le i \le j \le 4 .$$

Additionally, $W_{ji} = (W_{ij})^{-1} \approx (1/w_{ij3}, 1/w_{ij2}, 1/w_{ij1})$ represents the reciprocal of W_{ij}, where $1 \le i \le j \le 4$. The fuzzy pairwise comparison matrix between levels 1 and 2 is shown in Table 3, and the corresponding priorities are also expressed in this table.

Likewise, fuzzy pairwise comparison matrices based on four criteria (i.e., timing (C1), warehousing (C2), pricing (C3), and selling (C4)) between levels 2 and 3 are respectively shown in Tables 4 to 7, and their corresponding priorities are also displayed in these tables.

Furthermore, fuzzy pairwise comparison matrices based on thirteen sub-criteria (i.e., short transit time (C11), high frequency of sailing (C12), pick-up on time (C13), reliability

Table 8. Fuzzy pairwise comparison matrix based on short transit time (C11) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.9831, 9)	(0.1111, 2.0401, 9)
A2	(0.1111, 0.3352, 9)	(1, 1, 1)	(0.1111, 2.7248, 9)
A3	(0.1111, 0.4902, 9)	(0.1111, 0.3670, 9)	(1, 1, 1)
Priorities	0.3817	0.3352	0.2831

CI = 0.0306 and *CR* = 0.0527 < 0.1 based on short transit time between levels 3 and 4.

Table 9. Fuzzy pairwise comparison matrix based on high frequency of sailing (C12) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.2318, 9)	(0.1111, 1.8732, 7)
A2	(0.1111, 0.4481, 9)	(1, 1, 1)	(0.1429, 2.3586, 9)
A3	(0.1429, 0.5338, 9)	(0.1111, 0.4240, 7)	(1, 1, 1)
Priorities	0.3623	0.3551	0.2825

CI = 0.0270 and *CR* = 0.0465 < 0.1 based on high frequency of sailing between levels 3 and 4.

Table 10. Fuzzy pairwise comparison matrix based on pick-up on time (C13) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.2365, 9)	(0.1111, 1.7219, 9)
A2	(0.1111, 0.4471, 9)	(1, 1, 1)	(0.1111, 2.6001, 9)
A3	(0.1111, 0.5807, 9)	(0.1111, 0.3846, 9)	(1, 1, 1)
Priorities	0.3648	0.3428	0.2924

CI = 0.0295 and *CR* = 0.0509 < 0.1 based on pick-up on time between levels 3 and 4.

Table 11. Fuzzy pairwise comparison matrix based on reliability of advertised sailing schedules (C14) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.6955, 9)	(0.1111, 2.2497, 9)
A2	(0.1111, 0.3710, 9)	(1, 1, 1)	(0.1111, 2.3639, 9)
A3	(0.1111, 0.4445, 9)	(0.1111, 0.4230, 9)	(1, 1, 1)
Priorities	0.3834	0.3306	0.2860

CI = 0.0301 and *CR* = 0.0519 < 0.1 based on reliability of advertised sailing schedules between levels 3 and 4.

Table 12. Fuzzy pairwise comparison matrix based on customs clearance (C21) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.4207, 9)	(0.1111, 2.1000, 9)
A2	(0.1111, 0.4131, 9)	(1, 1, 1)	(0.1111, 2.3420, 9)
A3	(0.1111, 0.4762, 9)	(0.1111, 0.4270, 9)	(1, 1, 1)
Priorities	0.3766	0.3340	0.2894

CI = 0.0297 and *CR* = 0.0512 < 0.1 based on customs clearance between levels 3 and 4.

of advertised sailing schedules (C14), customs clearance (C21), storage (C22), consolidation service (C23), inland transportation (C24), price and discount (C31), flexibility in meeting competitors rates (C32), willingness to negotiate (C33), professional ability of staff (C41) and problem-solving ability (C42)) between levels 3 and 4 are respectively displayed in Tables 8 to 20, and their corresponding priorities are also shown in these tables.

Table 13. Fuzzy pairwise comparison matrix based on storage (C22) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.7730, 9)	(0.1429, 2.1130, 9)
A2	(0.1111, 0.3606, 9)	(1, 1, 1)	(0.1429, 2.6085, 9)
A3	(0.1111, 0.4733, 7)	(0.1111, 0.3834, 7)	(1, 1, 1)
Priorities	0.3996	0.3517	0.2487

$CI = 0.0273$ and $CR = 0.0471 < 0.1$ based on storage between levels 3 and 4.

Table 14. Fuzzy pairwise comparison matrix based on consolidation service (C23) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.9567, 9)	(0.1429, 2.2671, 7)
A2	(0.1111, 0.3382, 9)	(1, 1, 1)	(0.1429, 2.2188, 9)
A3	(0.1429, 0.4411, 7)	(0.1111, 0.4507, 7)	(1, 1, 1)
Priorities	0.3931	0.3504	0.2565

$CI = 0.0264$ and $CR = 0.0455 < 0.1$ based on consolidation service between levels 3 and 4.

Table 15. Fuzzy pairwise comparison matrix based on inland transportation (C24) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.4897, 9)	(0.1111, 1.9302, 9)
A2	(0.1111, 0.4017, 9)	(1, 1, 1)	(0.1429, 2.5007, 9)
A3	(0.1111, 0.5181, 9)	(0.1111, 0.3999, 7)	(1, 1, 1)
Priorities	0.3826	0.3456	0.2717

$CI = 0.0285$ and $CR = 0.0491 < 0.1$ based on inland transportation between levels 3 and 4.

Table 16. Fuzzy pairwise comparison matrix based on price and discount (C31) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1429, 2.7061, 9)	(0.1429, 2.7111, 9)
A2	(0.1111, 0.3695, 7)	(1, 1, 1)	(0.1111, 2.2644, 9)
A3	(0.1111, 0.3689, 7)	(0.1111, 0.4416, 9)	(1, 1, 1)
Priorities	0.4117	0.3168	0.2715

$CI = 0.0271$ and $CR = 0.0467 < 0.1$ based on price and discount between levels 3 and 4.

Table 17. Fuzzy pairwise comparison matrix based on flexibility in meeting competitors rates (C32) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 3.1610, 9)	(0.1111, 2.5474, 9)
A2	(0.1111, 0.3164, 9)	(1, 1, 1)	(0.1111, 1.7937, 9)
A3	(0.1111, 0.3925, 9)	(0.1111, 0.5575, 9)	(1, 1, 1)
Priorities	0.3995	0.3140	0.2865

$CI = 0.0303$ and $CR = 0.0523 < 0.1$ based on flexibility in meeting competitors rates between levels 3 and 4.

Table 18 Fuzzy pairwise comparison matrix based on willingness to negotiate (C33) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.5557, 9)	(0.1111, 2.0880, 9)
A2	(0.1111, 0.3913, 9)	(1, 1, 1)	(0.1429, 2.4740, 9)
A3	(0.1111, 0.4789, 9)	(0.1111, 0.4042, 7)	(1, 1, 1)
Priorities	0.3867	0.3434	0.2699

$CI = 0.0286$ and $CR = 0.0493 < 0.1$ based on willingness to negotiate between levels 3 and 4.

Table 19. Fuzzy pairwise comparison matrix based on professional ability of staffs (C41) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1429, 2.9051, 9)	(0.1429, 2.4681, 9)
A2	(0.1111, 0.3442, 7)	(1, 1, 1)	(0.1429, 2.5798, 9)
A3	(0.1111, 0.4052, 7)	(0.1111, 0.3876, 7)	(1, 1, 1)
Priorities	0.4184	0.3306	0.2509

$CI = 0.0260$ and $CR = 0.0449 < 0.1$ based on professional ability of staffs between levels 3 and 4.

Table 20. Fuzzy pairwise comparison matrix based on problem-solving ability (C42) between levels 3 and 4 as well as corresponding priorities.

	A1	A2	A3
A1	(1, 1, 1)	(0.1111, 2.8550, 9)	(0.1429, 2.4166, 9)
A2	(0.1111, 0.3503, 9)	(1, 1, 1)	(0.1111, 2.2261, 9)
A3	(0.1111, 0.4138, 7)	(0.1111, 0.4492, 9)	(1, 1, 1)
Priorities	0.3994	0.3334	0.2673

$CI = 0.0287$ and $CR = 0.0494 < 0.1$ based on problem-solving ability between levels 3 and 4.

Table 21. 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	0.3817	0.3352	0.2831	0.1047
	C12	0.3623	0.3551	0.2825	0.0866
	C13	0.3648	0.3428	0.2924	0.0744
	C14	0.3834	0.3306	0.2860	0.0627
C2	C21	0.3766	0.3340	0.2894	0.0863
	C22	0.3996	0.3517	0.2487	0.0780
	C23	0.3931	0.3504	0.2565	0.0645
	C24	0.3826	0.3456	0.2717	0.0595
C3	C31	0.4117	0.3168	0.2715	0.0811
	C32	0.3995	0.3140	0.2865	0.0568
	C33	0.3867	0.3434	0.2699	0.0585
C4	C41	0.4184	0.3306	0.2509	0.1076
	C42	0.3994	0.3334	0.2673	0.0795

Through the previous values of CI, RI, and related weights, the CR for the whole hierarchy is derived as CRH = 0.0355 < 0.1. Thus, 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 consistencies. The associating priorities form Tables 3 to 20, with ratings and weights of three transport modes for thirteen sub-criteria based on four criteria displayed in Table 21.

Yielding the performance indices for the varied criteria

Table 22. Performance indices for three varied transport modes.

Transport modes	Performance indices
A1	0.3897
A2	0.3372
A3	0.2732

displayed in Table 21, the preference order of the three transport modes is A1(0.1225) > A2(0.1121) > A3(0.0938) in timing (C1), A1(0.1117) > A2(0.0994) > A3(0.0771) in warehousing (C2), A1(0.0787) > A2(0.0636) > A3(0.0541) in pricing (C3), and A1(0.0768) > A2(0.0621) > A3(0.0482) in selling (C4). The figures inside parentheses refer to relative performance indices with respect to the varied criteria, i.e., the larger the figure is, the higher the criteria performance is. Undoubtedly, transportation by military ships (A1) is superior to the others in the four criteria, with transportation by chartering civilian ships (A2) second and transportation by supplementary merchant ships (A3) last.

Finally, the total performance indices of three varied transport modes are shown in Table 22.

The order of the three transport modes in their total performance is A1(0.3897) > A2(0.3372) > A3(0.2732). The transportation by military ships is better than the others through the total performance computations. Furthermore, A1 is superior across the four criteria (i.e., timing, warehousing, pricing, and selling). Summarizing the four criteria ratings into total performance indices, the transportation by military ships (A1) is obviously the optimal transport mode in total performance. The above ranking results are able to tell us that transportation by military ships is the best in terms of timing, warehousing, pricing, selling, and even total performance for the three candidate transportations. The opinions are collected from soldiers in the Kinmen military. Although the military belongs to non-profit organizations, performance in financial aspects is still important as to avoid wasting government properties. Therefore, the two criteria, pricing and selling, are also taken into consideration for the selection of transport modes in Kinmen military logistics because sustainability is very critical for government organizations.

V. CONCLUSIONS

In this study, we applied fuzzy AHP to select the optimal transport mode for military logistics in Kinmen. Through the fuzzy AHP computation, we found that transportation by military ships is the optimal transport mode. In practice, transportation by military ships is superior in terms of four criteria that include timing, warehousing, pricing, and selling. Therefore, it is better than the other modes of transportation in total performance. Furthermore, the fuzzy AHP method provided corresponding values for varied criteria besides the total performance indices, so decision-makers can select the three transport modes based on their desired perspectives. Additionally, an interviewee has eighteen pairwise comparison matrices that are computed, and fifty-six interviewees will have one thousand and eight (i.e., 18 × 56) pairwise comparison matrices that are yielded as the empirical study is executed in general AHP. This is difficult and laborious work. However, utilizing the fuzzy converting method in Section 4, the number of fuzzy pairwise comparison matrices was merely eighteen. In fact, the number of fuzzy pairwise comparison matrices was always eighteen in the empirical study no matter what the number of interviewees was, be it fifty-six or more. Thus, utilizing fuzzy AHP can solve the selection problem easily. Therefore, we can decrease the computation complexity in the selection of transport modes for Kinmen military logistics by combining the fuzzy AHP with the fuzzy converting method.

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