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A Bayesian-ANP-Based Expert Group Decision-Making Method to Evaluate the Location of Military Port

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Abstract—**Location of military port problem is a complex system engineering with the characteristics of general engineering site selection, but also a combination of military elements. To consider the correlation between evaluation indicators existing in the location of military port, as well as the strong subjectivity in the evaluation process, this study uses Analytic Network Process(ANP) to establish the evaluation model, then adopts expert group decision-making method and Bayesian fusion theory to optimize the system construction of ANP. Combined with case analysis and calculated by SUPER-DECISION software, the model is proved to be feasible.**

Keywords-location of military port; ANP evaluation system; bayesian fusion theory; expert group decision-making method

I. INTRODUCTION

The location of military engineering(LME) is an important aspect of battlefield environment construction in the future information condition. A success of LME, directly related to the realization of the national strategy, the rational use of national resources and the effective use of defense funds, operation command comprehensive coordination, the optimized allocation of battlefield target , etc. In the case of the construction of a large integrated strategic homeport, it is indispensable to support a growing fleet and the country's frontier maritime strategy. In existing port or the port group, to chose the basic conditions are relatively good, and had the potential to extend the facility for key construction and make it to its homeport, not only conform to the requirements of the future naval strategy and berthing ship's security requirements, but also can save construction investment, the navy can make full use of the facility results on the basis of the existing building, make more power for port shore facilities maintenance, update and supplement. In other words, a suitable location of the military port（LMP） is of great significance to improve the strategic value, to give full play of security efficiency and to improve the military economic benefits.

At present, there are a lot of existing location assessment methods, Xiao Ding et al. apply the method of entropy weight and ideal point method to select a site for civil port [1]. Huang Mingsheng and Taih-Cherng Lirn adopt AHP method to decided the weights of site selection [2] [3]; Liu Linhu et al. using principal component analysis to select candidate military logistics base, on the basis of the maximum coverage model are used to determine a location decision [4]. The mufti-objective decision model of military engineering location is constructed by Weng Dongfeng [5]. Halpern proposed a two-level standard plane model for the actual problem of site selection for the first time[6]. Ayfer and Ergin has applied ELECTRE method to the site selection of container ports [7]. It is required that when the above methods in constructing a model of the whole evaluation system has a complete cognitive structure, and the relationship between the accurate model covers the elements of information is less, but through the study found that the construction of port planning and site selection evaluation indicator is broad, the relevance between the indicators are hidden, the elements in the system is not absolutely independent, but mutual influence and interdependence. In order to make the result of LMP more reasonable and credible, this paper proposes a Bayesian-ANP-based assessment method, which is fused expert group of judgment through comprehensive consideration all experts preference indicator correlation of evaluation, and optimize the process of the construction of the ANP model, overcome the subjective arbitrariness of independent evaluation, improve the reliability of the ANP model.

II. ANALYSIS OF LMP

A. Analysis of Influencing Factors

The LME directly relates to whether the military base (military unit) can play a better military performance. Compared with civil engineering, MLE have the following characteristics:

- The demand for the battlefield environment under the background of military strategy.
- It must be closely integrated with the impact of weapons and military operations.
- It is a systematic project with a large scale, complex structure, huge investment, long construction cycle and lots of related factors.
- Although the project is limited by the development of the local society, the military decision has its own independence.
- Its research foundation must be based on the study of military geographic information.

During the MLE assessment process, decision makers are not only engineers, military construction experts, but also commander of the strategic level. The final decision is a

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combination of military and engineering conditions, the demands of a project should include the following aspects:

- The basic elements required performance evaluation indicators.
- The overall evaluation indicators.
- Some technical feasibility evaluation indicators.
- Secondary evaluation after artificial intervention.
- Comparison of site selection of similar projects.

The above five aspects are the common needs of various LME problem, different LME problem has special demands, such as LMP can be asked for air/sea defense capacity assessment. Therefore, the LME is not only an assessment of geographical location, but also another way to evaluate certain combat effectiveness in a certain region. In addition to the assessment of these common military requirements, there are also some non-common requirements, such as:

- Evaluation of the funding requirement.
- Evaluation indicator of ecological environment pollution.
- Evaluation indicators of regional economic, cultural and political conditions.

According to the above analysis and based on the studies of [8] [9] [10]，the main influencing factors of LMP are determined. Table 1 shows 5 dimensions and 27 indicators.

TABLE I. DIMENSIONS AND INDICATOR FOR LMP

Dimension	**Indicator**
C_1-Military demand	U_1-Defense strategy U_2-Campaign direction U_3-Port group location layout U_4-Defense and concealment U_5-Flexible development space
C_2-Natural conditions	U_6-Coastline and water conditions U_7-Natural cover conditions U_8-Hydrometeorological conditions U_9-Terrestrial conditions U_{10}-Natural resource conditions
C_3-Security hinterland condition	U_{11}-The distance and connectivity to cities U_{12}-Public and local government support U_{13}-Regional industrial and economic base U_{14}-Logistics level U_{15}-Environmental sustainability
C_4-Port functional capabilities	U_{16}-Storage capacity U_{17}-Collector-distributor capacity U_{18}-Material supply and unloading capacity U_{19}-Pier berth capacity U_{20}-Navigation capacity U_{21}-Protection and camouflage capacity U_{22}-Pollution control capacity U_{23}-Life service capacity
C_5-Military economic benefits	U_{24}-Basic cost of expansion U_{25}-Water and electricity cost U_{26}-Facilities and maintenance cost U_{27}-Transportation cost

B. *Analysis of Indicator Correlation*

At present, in the study of site selection problems such as ports, logistics centers and warehouses, the indicator system is mainly based on the vertical hierarchical structure, while the relative horizontal relation between indicators is insufficient. In order to make the indicator system more accurately reflect the relationship between the various elements of the system, this paper adopts the method of Bayesian decision making based on expert knowledge information fusion, introducing the concept of reliability association probability, in the form of probability to determine whether there is correlation between the indicators.

Used $G=(U,A)$ to express the underlying indicator system in the network. $U=\{U_1,U_2,...,U_n\}$ indicate the underlying elements. For any set of indicators U_i and U_j ,there is a relationship framework $\{U_i \to U_j, U_i \leftarrow U_j, U_i \leftrightarrow U_j\}$. the direction of the arrow points to the affected one, two-way arrows means the mutual impact. Directed arc $a_{ij} \in A$, indicates the association probability. E_i indicates expert i , D_i indicates the professional and authoritative of expert i in the relevant field. C_i indicates the confidence of expert i believe that there is a correlation between the two indicators, $0 \le D_i, C_i \le 1$, respectively use D_i , C_i as the horizontal and vertical coordinates, any point $R_i(D_i, C_i)$ in the coordinate system indicate the preference made by expert i .

The judgment of multiple experts can be seen as group decision-making problem. Bayesian decision-making theory can effectively integrate the similar knowledge information, which can help to obtain a comprehensive result. A according to the Bayesian extended form cited by Bruce [11], when assessment subject is $E=\{E_1,E_2,...,E_n\}$, there are the following equations：

$$P(\theta=A)=\mu\prod_{i=1}^{n}\left(C_iD_i+(1-C_i)(1-D_i)\right)_{E_i} \tag{1}$$

$$\mu=\left(\prod_{i=1}^{n}\left(C_iD_i+(1-C_i)(1-D_i)\right)_{E_i}+\prod_{i=1}^{n}\left(C_i(1-D_i)+(1-C_i)D_i\right)_{E_i}\right)^{-1} \tag{2}$$

Where $P(\theta=A)$ indicate that under a certain criteria, the expert group considers the probability that there is a correlation between the two indicators, μ is the standardization factor. According to above equations, the knowledge information obtained from the indicators by experts can be fused a probability value $a_{ij} \in [0,1]$, which reflects the overall judgment of indicator correlation. In the judgment process, a threshold σ is set which can be decided by the expert group. When $a_{ij} \le \sigma$, it can be determined that U_i has no affect on U_j .When $a_{ij} > \sigma$, while U_i has affect on U_j .

III. ANP METHOD OF LMP INDICATOR SYSTEM

Multi criteria decision-making method, Analytic Network Process (ANP), has been widely used in the assessment of complex systems because of its comprehensive and authenticity [12]. It breaks through the hierarchical structure limitation, constructed the mutual relationship between evaluation indicators, which can reflect the feedback and dependence in the system. Using ANP to evaluate the LMP can make the result more responsive to the nature of the system.

According to the analysis of section 2, an ANP-Based LMP evaluation system can be constructed, in order to evaluate the weight of indicator, it is necessary to establish a weighted matrix that reflect the magnitude of the relationship between the clusters and a super matrix that reflects the degree of influence between the indicators. Alternative priority is required to construct the limit super matrix to achieve, the solving steps is as follows.

- Step 1: Calculate the super matrix

Assuming that the control layer in the model has clusters $C_1, C_2, ..., C_N$, C_i contains indicators $e_{i1}, e_{i2}, ..., e_{in_i}, ...$, where $i = 1, 2, ..., N$. C_j contains indicator e_{jl} , where $l = 1, 2, ..., n_j$, the impact on indicator e_{jl} in cluster C_j is reflected by means of pairwise comparisons.

$$W_{ij} = \begin{bmatrix} W_{i_1 j_1} & W_{i_1 j_2} & \cdots & W_{i_1 j_{n_j}} \\ W_{i_2 j_1} & W_{i_2 j_2} & \cdots & W_{i_2 j_{n_j}} \\ \vdots & \vdots & \ddots & \vdots \\ W_{i_{n_1} j_1} & W_{i_{n_2} j_2} & \cdots & W_{i_{n_i} j_{n_j}} \end{bmatrix} \to W = \begin{array}{c c} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_N \end{array} \\ \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_N \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix} \end{array} \tag{3}$$

In the above equation, W is the general form super matrix, where the column vector of W_{ij} denotes the influence arrange vector for cluster C_i to C_j . If it is the indicator that in cluster C_i , $W_{ij} = 0$.

- Step 2: Calculate the weighted super matrix

The super matrix above is non-negative matrix, but not a normalized, the sub block W_{ij} of W is normalized. therefore, considering the each column of W is not random, under a certain principle, the importance of each cluster relative to C_j is compared. Assume b_{ij} is the influence weight of C_i on C_j ,the weighted matrix can be obtained, where $i, j = 1, 2, ..., N$.

$$\overline{W} = \overline{W_{ij}} = b_{ij} W_{ij} \tag{4}$$

- Step 3: Calculate the limit super matrix

When ANP handling decision-making problem, the influence arrange of the network should be more considered, which must find the influence of limit state. The limit super matrix reflect the absolute priority of each alternative. Assume $\overline{W^t}$ is the t power of $\overline{W}$, if the limit of $\overline{W^t}$ exists when $t \to \infty$, then

$$\overline{W^\infty} = \lim_{t \to \infty} \overline{W^t} \tag{5}$$

IV. CASE ANALYSIS

Assuming that in a combat direction, it is planned to select a suitable military port for investment and construction in the coastal port group, in order to expand the scale and capacity of logistical security. There are four alternatives, A, B ,C and D, five expert are chosen to evaluate the LMP, the expert group is composed by two professors in the field of military operations, two military construction expert, and one senior engineer. Subject to the paper restriction, Table 2 gives a part of data about the indicator correlation analysis given by five experts. According to the equation (1) (2), the judgment of experts are fused to calculate the probability of indicator correlation.

TABLE II. JUDGMENT OF EXPERT GROUP

	E_1	**E_2**	**E_3**	**E_4**	**E_5**	**a_{ij}**
	(D_1,C_1)	**(D_2,C_2)**	**(D_3,C_3)**	**(D_4,C_4)**	**(D_5,C_5)**	
U_1→U_2	0.9,0.8	0.8,0.7	0.7,0.6	0.7,0.7	0.6,0.8	**0.85**
U_2→U_3	0.9,0.7	0.8,0.4	0.7,0.5	0.7,0.6	0.6,0.7	**0.63**
U_2→U_4	0.9,0.6	0.8,0.6	0.7,0.4	0.7,0.7	0.6,0.7	**0.95**
U_9→U_4	0.8,0.8	0.9,0.9	0.7,0.9	0.6,0.9	0.7,0.8	**0.43**
U_{22}→U_{15}	0.7,0.9	0.8,0.9	0.6,0.9	0.7,0.9	0.9,0.9	**0.84**
U_{14}→U_{19}	0.7,0.7	0.8,0.6	0.7,0.6	0.9,0.6	0.6,0.7	**0.37**

Set thresholds $\sigma = 0.5$, the ultimate relationship between indicators can be determined by comparing with the correlation probability. A LMP evaluation system is established and as shown in Figure 1.

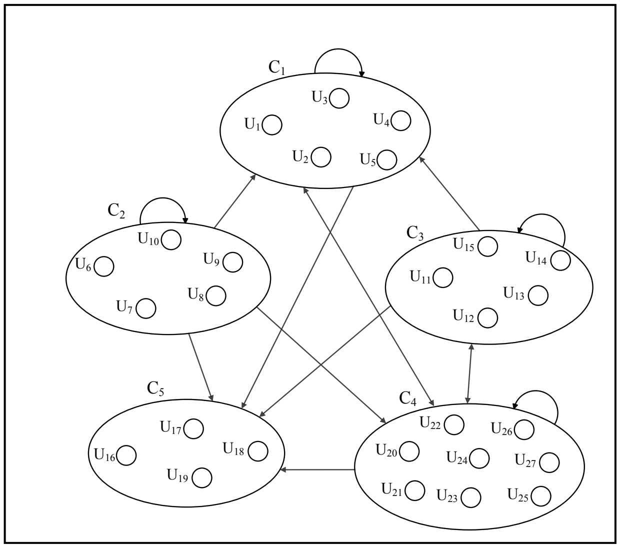


Figure 1. Network of LMP evaluation system.

According to the calculating process of ANP method, respectively calculate unweighted super matrix, the weighted matrix and ultimate super matrix. Due to the complexity of calculation, this paper applied the SUPER-DECISON software to do auxiliary calculation, the part of results are shown in Table 3-5.

TABLE III. PARTIAL RESULT OF UNWEIGHTED SUPER MATRIX

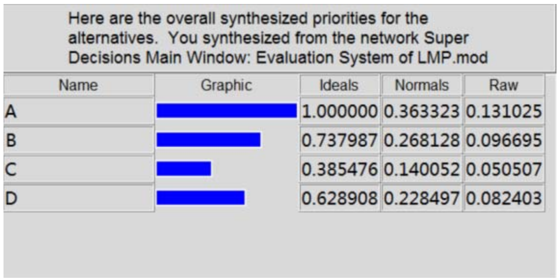
	A	B	C	D	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
A	0.00000	0.00000	0.00000	0.00000	0.25947	0.45117	0.49463	0.41816	0.46424	0.10343	0.51671	0.15442	0.26973	0.15037
B	0.00000	0.00000	0.00000	0.00000	0.28650	0.26094	0.21830	0.19063	0.25441	0.25073	0.26004	0.08181	0.08181	0.08539
C	0.00000	0.00000	0.00000	0.00000	0.12204	0.11896	0.13371	0.12050	0.09749	0.15748	0.14197	0.26972	0.15442	0.25991
D	0.00000	0.00000	0.00000	0.00000	0.33199	0.16893	0.15336	0.27071	0.18386	0.48836	0.08128	0.49405	0.49404	0.50433
U1	0.37025	0.38630	0.42987	0.38377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U2	0.26994	0.24564	0.22125	0.25090	0.59363	0.00000	0.00000	0.00000	0.00000	0.00000	0.75000	0.00000	0.00000	0.00000
U3	0.17533	0.16112	0.16744	0.16888	0.24931	0.49339	0.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U4	0.10054	0.12170	0.10045	0.12568	0.00000	0.31081	1.00000	0.00000	1.00000	0.00000	0.25000	0.00000	0.00000	0.00000
U5	0.08394	0.08524	0.08098	0.07076	0.15706	0.19580	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	1.00000	1.00000
U6	0.41611	0.42536	0.42387	0.40359	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.33333	0.00000	0.00000	0.00000
U7	0.17034	0.20699	0.18277	0.09190	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000
U8	0.22459	0.15721	0.18277	0.24560	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U9	0.10080	0.07845	0.10530	0.12036	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.66667	0.00000	0.00000	0.00000
U10	0.08816	0.13198	0.10530	0.13855	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

TABLE IV. PARTIAL RESULT OF WEIGHTED SUPER MATRIX

	A	B	C	D	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
A	0.00000	0.00000	0.00000	0.00000	0.13110	0.20011	0.21938	0.22513	0.24994	0.04729	0.20661	0.10845	0.10177	0.06875
B	0.00000	0.00000	0.00000	0.00000	0.14475	0.11574	0.09682	0.10263	0.13697	0.11463	0.10397	0.05745	0.03087	0.03904
C	0.00000	0.00000	0.00000	0.00000	0.06166	0.05276	0.05930	0.06488	0.05248	0.07200	0.05677	0.18942	0.05826	0.11883
D	0.00000	0.00000	0.00000	0.00000	0.16774	0.07492	0.06802	0.14575	0.09899	0.22328	0.03250	0.34697	0.18640	0.23058
U1	0.17048	0.17787	0.19793	0.17671	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U2	0.12429	0.11310	0.10187	0.11552	0.19924	0.00000	0.00000	0.00000	0.00000	0.00000	0.22890	0.00000	0.00000	0.00000
U3	0.08073	0.07419	0.07710	0.07776	0.08368	0.14536	0.00000	0.35764	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U4	0.04629	0.05603	0.04625	0.05787	0.00000	0.09157	0.29463	0.00000	0.35764	0.00000	0.07630	0.00000	0.00000	0.00000
U5	0.03865	0.03925	0.03729	0.03258	0.05271	0.05769	0.00000	0.00000	0.00000	0.34899	0.00000	0.00000	0.28800	0.34899
U6	0.10471	0.10704	0.10667	0.10156	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.06173	0.00000	0.00000	0.00000
U7	0.04287	0.05209	0.04599	0.02313	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.17476	0.00000
U8	0.05652	0.03956	0.04599	0.06181	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
U9	0.02537	0.01974	0.02650	0.03029	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.12347	0.00000	0.00000	0.00000
U10	0.02219	0.03321	0.02650	0.03487	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

TABLE V. PARTIAL RESULT OF LIMIT SUPER MATRIX

	A	B	C	D	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
A	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103	0.13103
B	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670	0.09670
C	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051	0.05051
D	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240	0.08240
U1	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409	0.06409
U2	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851	0.05851
U3	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873	0.07873
U4	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190	0.07190
U5	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183	0.04183
U6	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887	0.03887
U7	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683	0.01683
U8	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865	0.01865
U9	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115	0.01115
U10	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033	0.01033



Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: Evaluation System of LMP.mod

Name	Graphic	Ideals	Normals	Raw
A		1.000000	0.363323	0.131025
B		0.737987	0.268128	0.096695
C		0.385476	0.140052	0.050507
D		0.628908	0.228497	0.082403

Figure 2. Priority of alternatives.

Based on the above calculation, the priority of alternatives is shown in the Figure 2. The final ranking of LMP alternatives can be obtained as follows: $A > B > D > C$. Military port A is considered to be the best location of investment and construction.

V. CONCLUSION

This paper has analyzed characteristics and main influence factors of LMP. Combined with expert decision-making and model calculation, a semi-structural framework system has been adopted, which puts forward the expert information decision method based on Bayesian fusion theory, and constructs the ANP evaluation system of LMP. This method provides effective methodological guidance and technical support for the field of military location, which lays the foundation for improving the scientific level of military construction.

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