Research progress on logistics support capability evaluation model and its application

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ABSTRACT

Logistics support capability (LSC) plays an important role in troop's combat effectiveness, therefore the evaluation on LSC is the key supporting means for its improvement. This paper compared several models and their applications in the LSC evaluation area, including the Fuzzy Comprehensive Evaluation Model, Grey Evaluation Model, Network DEA (Data Envelopment Analysis) Model, evaluation models based on Belief Rule-Base (BRB) as well as evaluation models based on D-S Evidence Theory. Among these models, Fuzzy Comprehensive Evaluation Model can quantify some factors with unclear border or hard to quantify; Grey Evaluation Model is suitable for the uncertain system; Network DEA Model effectively deals with multiple inputs and outputs on the same kind of Decision-Making Units (DMUs); evaluation model based on BRB handle effectively the information uncertainty and evaluation index types diversity; evaluation model based on D-S Evidence Theory could effectively analyze the consistency of evaluation index and increase the discrimination of the evaluation. However, these evaluations mainly focus on the theoretical research and hardly can be applied in reality. In this paper, the suggestions about attention to the purpose of LSC evaluation, application of new information technology, and evaluation practicality were proposed in order to improve LCS evaluation.

Keywords: Logistics support capability, evaluation model, evaluation improvement

1. INTRODUCTION

Logistics support capability means logistics support force's ability carrying on logistics support tasks[1]. It is an important part of the combat effectiveness of the troops. The LSC improves, the combat effectiveness upgrades. Evaluation on LSC can enhance the quantitative analysis on logistics information; grasp correctly the status of LSC; propose and implement targeted improvement methods; provide basis for training, establishment and management of logistics; solve the heavy and difficult problems restricting LSC; and set up a solid theoretical basis foundation for the improvement of LSC.

LSC is comprehensively determined by logistics support forces including personnel, equipment, facilities, quantity and quality of goods and materials; the scientific logistics organization system; the management of the logistics organization and the economic, natural, topographical and meteorological resources[1] which can be introduced into the logistics support activities. Therefore, the evaluation on LSC involves many factors different levels, and many sections. With the invisible and subjective evaluation indices, the evaluation seems hard to quantify and measure. A comprehensive, objective, exact and practicable evaluation on LSC is never easy.

Currently, the evaluation method on LSC is various, such as actual combat inspection and evaluation, verification-oriented exercises with real soldiers and equipment, experimental exercises with real soldiers and equipment, training and testing, statistics of number and quality, subitem integral judgment, expert judgment, etc.[1]. This paper mainly focuses on the comparison of several models and their applications in the LSC evaluation area, including the Fuzzy Comprehensive Evaluation Model used for warehouse material support capability evaluation[2], logistics competency construction of dealing with group emergencies[3], logistics support capability in forest fire fighting[4], competency assessment of tactical logistics[5], and military traffic and transportation support capabilities evaluation[6]; Grey Evaluation Model used for capability appraisement of logistics synthetical support[7]; Network DEA Model utilized for core support capability evaluation[8] and logistics emergency support capability evaluation[9]; evaluation models based on Belief Rule-Base (BRB) used in the logistics support capability evaluation of missile early-warning counter-attack

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combat system[10]; as well as evaluation model based on D-S Evidence Theory made use to evaluate logistics integrated support capability[11]. Although these models in LSC evaluation can were effective, little evaluation models can be applied in reality. Therefore, further improvements on LSC evaluation are urgent so that to establish the suitable evaluation model of LCS and provide support to the improve LCS.

2. FUZZY COMPREHENSIVE EVALUATION MODEL

Fuzzy Comprehensive Evaluation Model uses the idea of fuzzy mathematics and combines qualitative and quantitative for the unity of imprecision and precision, which can quantify some factors with unclear border or hard to quantify by the fuzzy relation synthesis theory and then proceed the comprehensive evaluation based on the membership degree of each evaluation factor[2-3].

The steps of the model establishment include[2]: (1) establish the evaluation object domain $U = \{u_1, u_2, \cdots, u_n\}$; (2) establish the evaluation set domain $V = \{v_1, v_2, \cdots, v_p\}$; (3) evaluate all evaluation indices for the fuzzy evaluation matrix $R = [r_{jk}]_{n\times p}$, in which the matrix element r_{ij} represents the membership degree of the with *j*th evaluation index rated as the *k*th slogan result; set up the weight vector $W = \{w_1, w_2, \cdots, w_n\}$ of the factors in each level; get fuzzy comprehensive evaluation result *B* by composing the composite operator and fuzzy evaluation membership matrix:

$$B = W * R = (w_1,\ w_{2,}\ \dots,\ w_n) * \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{np} \end{bmatrix}$$

and set up the fuzzy comprehensive evaluation model $B^{'}$:

$$B^{'} = W^{'} * B = \left(w_1^{'},\ w_2^{'}\ \dots,\ w_n'\right) * (w_1,\ w_{2,}\ \dots,\ w_n) * \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1p} \\ r_{21} & r_{22} & \cdots & r_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{np} \end{bmatrix}$$

In practice, the ways to get weights in Fuzzy Comprehensive Evaluation Model are various. Aiming at the evaluation of warehouse material support ability, Zhang et al.[2] proposed a new fuzzy comprehensive evaluation method based on Delphi-Entropy Weight comprehensive weight calculation method. And through making full use of Delphi Method's subjective characteristics and Entropy Weight Method's (EWM) objective characteristics of more attention paid to weight, the research by Zhang got the comprehensive weight through the two methods in a more comprehensive way, which is more practicable. And this was verified by Zhang[2] using two warehouses as examples. After testing and evaluating the two warehouses' material support abilities by the Delphi-Entropy Weight comprehensive method, the result showed its good applicability and scientificity.

Analytic Hierarchy Process (AHP) is always used for the calculation of index weight. And it is a systematic, qualitative and quantitative decision-making method. AHP's data requirement is relatively low and depends more on operator's personal thinking and experience. It decomposes every hierarchy of elements related to decision-making stepwisely and calculates the final decomposed elements' weights based on the two elements' importance[3, 12-14]. Lei[3] proposed an AHP-based Fuzzy Comprehensive Evaluation Model in the light of the construction of the emergency LSC of People's Armed Police Force dealing with mass emergencies. The research took a mass emergency handled by Qinghai People's Armed Police Force as an example, implemented the evaluation on the relevant support capability, and confirmed all the specific factors affecting emergency LSC, which provided reliable basis for the system upgrade and construction in a targeted way. Jiang[4] put forward his AHP-based research of evaluating single index by Grey Evaluation Method as well as evaluating multiple indices by comprehensive evaluation method, proceeded a LSC evaluation on a verification-oriented exercise of a military subarea attending forest fire fighting and achieved good performance. For tactical LSC evaluation, Jiao[5] proposed his AHP-based fuzzy comprehensive evaluation method, and took the comprehensive LSC evaluation of three regiments in a division as the management capability evaluation and a regiment's maneuverability evaluation in the preparation stage of one motorized mobile logistics support as the support capability evaluation. It made the fuzzy evaluation objects clarified relatively, strengthened the evaluation results in a more persuasive and accurate way and provided some basis for tactical logistics.

3. GREY EVALUATION MODEL

The main study object of Grey System Theory is the uncertain system with information "partially uncertain and partially certain, partially incomplete and partially complete, partially known and partially unknown". And the main theory basis is to describe, analyze, integrate and handle study object by information coverage. On the basis of Grey System Theory, grey evaluation analyses the system towards evaluation objectives and makes certain qualitative and quantitative comments and descriptions and further evaluates the system in a higher layer[4, 15-16]. The main idea of the theory is transferring the evaluation sample queue to the membership degrees of all the grey evaluation classes through applying whitening function and then obtaining the single index grey evaluation sequence. In accord to the principle of maximum membership degree, the single index qualitative evaluation results can be achieved; and the single index quantitative evaluation results can be achieved by the matrix multiplication of grey evaluation sequence with grade parameter vectors[4].

The main calculation steps[17-18] of grey evaluation model include: establishing evaluation objects' hierarchical structure; formulating evaluation objects' rating grade standard; defining the weights of the evaluation indices; putting out the evaluation index matrix; determining the grey evaluation class; calculating the grey evaluation weight vector and weight matrix; performing evaluation with different evaluation indices; performing comprehensive evaluation. Among them, the determination of the grey evaluation class is followed[18]:

If U_i represents first-grade index, V_{ij} represents second-grade index, the grade from the *k*th Rater on the *s*th Ratee is $d_{ijk}^{(s)}$ by evaluation index V_{ij}, the *s*th Ratee's evaluation sample matrix is $D^{(s)}$. Confirmation of the grey evaluation class means to confirm the class's grade, grey number and its whitening weight function, which depends on the real evaluation situation.

Let the sequence number of the grey evaluation classes be $e = 1, \cdots, g$. For example, if the grey evaluation classes are separated into three grades: "high" "medium" "low", that is to say g = 3. Usually, there are the following three whitening weight functions:

(1) The first-grade grey class "high" ($e = 1$), grey number $\otimes_1 \in [d_1, \infty)$, and the whitening weight function is f_1, and the expression of the function is

$$f_1\left(d_{ijk}^{(s)}\right) = \begin{cases} \dfrac{d_{ijk}^{(s)}}{d_2} & d_{ijk}^{(s)} \in [0, d_2] \\ 1 & d_{ijk}^{(s)} \in \left[d_1, \infty\right) \\ 0 & d_{ijk}^{(s)} \notin \left[0, \infty\right) \end{cases}$$

(2) The second-grade grey class "medium" ($e = 2$), grey number $\otimes_2 \in [0, d_2, 2d_2]$, and the whitening weight function is f_2, and the expression of the function is

$$f_2\left(d_{ijk}^{(s)}\right) = \begin{cases} \dfrac{d_{ijk}^{(s)}}{d_2} & d_{ijk}^{(s)} \in [0, d_2] \\ \dfrac{d_{ijk}^{(s)} - 2d_2}{-2d_2} & d_{ijk}^{(s)} \in [d_2, 2d_2] \\ 0 & d_{ijk}^{(s)} \notin [0, 2d_2] \end{cases}$$

(3) The third-grade grey class "low" ($e = 3$), grey number $\otimes_3 \in [0, d_3, 2d_3]$, and the whitening weight function is f_3, and the expression of the function is

$$f_3\left(d_{ijk}^{(s)}\right) = \begin{cases} \dfrac{d_{ijk}^{(s)} - 2d_3}{-2d_3} & d_{ijk}^{(s)} \in [d_3, 2d_3] \\ 1 & d_{ijk}^{(s)} \in [0, d_3] \\ 0 & d_{ijk}^{(s)} \notin [0, 2d_3] \end{cases}$$

Luo et al.[7] used the multilevel grey evaluation method for the comprehensive evaluation of LSC and made some improvements of it. They have achieved more practical evaluation results which are good for the comparison by sequencing all evaluated units in one hand, and for mastering the LSCs' strong and weak points of all evaluated units in another hand.

4. NETWORK DEA MODEL

Data Envelopment Analysis (DEA) was proposed by Charnes, Coopor and Rhodes in 1978. The main principle of this method is keeping the inputs or outputs of Decision-Making Units (DMU) fixed, taking mathematical programming and statistics to confirm the relatively effective production frontier, making each of the DMU projected into DEA's production frontier and comparing the degree of the deviation of DMU from DEA's production frontier to evaluate their relative effectiveness[19]. There is no need to not only set the weight of each input, but also define the functional relationship between input and output in this method. But it can show out the improvement direction for the evaluation object from the effectiveness analysis on the same kind of DMUs and is suitable for the effectiveness analysis with multiple inputs and outputs on the same kind of DMUs[8].

DEA model can be divided into CCR model and BCC model. In 1978, CCR model was proposed to evaluate the relative efficiency of multiple inputs and outputs and the principle is Evaluation DMU's efficiency = Linear combination of outputs / Linear combination of inputs, and the model is followed[19]:

$$Max \frac{\sum_{r=1}^{s} u_r y_{r_0}}{\sum_{i=1}^{m} v_i y_{i_0}}$$

$$s.t. \ \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i y_{ij} \le 0 \quad j = 1, \cdots, n$$

$$u_r, v_i \ge \varepsilon, r = 1, \cdots, s; i = 1, \cdots, m$$

By C^2 Transformation, the above model was transformed from nonlinear programming to linear programming and then Duality theory was applied for the following model:

$$\begin{cases} Min\left[\theta - \varepsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right)\right] \\ s.t. \ \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i_0}, \qquad i = 1, \cdots, m \\ \quad \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = y_{r_0}, \qquad r = 1, \cdots, s \\ \quad \lambda_j, s_i^-, s_r^+ \ge 0, j = 1, \cdots, n \end{cases}$$

Considering that the number of DMU in DEA model was large, the solution of the model was relatively difficult. Then the software DEAP could be used for the solution and the three outputs from which were followed:

(1) $\theta^* = 1$, and $s^{*+} = 0$, $s^{*-} = 0$, which showed that all DMUs are valid; therefore, the overall situation represents DEA is valid.

(2) $\theta^* = 1$, and $s^{*+} > 0$ or $s^{*-} > 0$, which represents that part of the DMUs is not valid and led to the overall DEA invalid. But due to $\theta^* = 1$, it was not completely invalid but showed in a weak-valid way.

(3) $\theta^* < 1$, which certified that all DMU is invalid and therefore overall DEA is invalid.

Li et al.[9] proposed a DEA-CCR evaluation method for the evaluation issues in emergency LSC. After example verification, the research found out the key factors affecting emergency LSC, which provided the theory basis for the upgrade of LSC.

5. EVALUATION MODEL BASED ON BELIEF RULE-BASE (BRB)

Sun et al.[10] proposed an evaluation model based on BRB in the light of the evaluation LSC of missile early-warning and counterattack operation system. The main steps of the evaluation model consist of calculating the matching degree of the belief rule, calculating the activation degree of the belief rule, activating the rule integration.

(1) The calculation of the matching degree of the belief rule

Calculation of inputs on the matching degree of the attribute premise of the belief rule:

$$\alpha_{ij} = \frac{\varphi(x_i, A_{ij})\varepsilon_i}{\sum_{|A_i|} \varphi(x_i, A_{ij})}$$

in which, $\varphi(x_i, A_{ij})$ represents the selection of the calculation methods on x_i and A_{ij} is related to types and characteristics of indices. When the attribute premise is discrete values, the following equation could be obtained:

$$\varphi\left(x_i, A_{ij}\right) = \begin{cases} \dfrac{A_{i(k+1)} - x_i}{A_{i(k+1)} - A_{ik}} & j = k\left(A_{ik} \le x_i \le A_{i(k+1)}\right) \\ \dfrac{x_i - A_{ik}}{A_{i(k+1)} - A_{ik}} & j = k+1 \\ j = 1, \cdots, |A_i|, & j \ne k, k+1 \end{cases}$$

(2) The calculation of the activation degree of the belief rule

The core of the activation is to compare and match all the data to be evaluated with the rules in BRB and then give the activated rules weights according to the match degrees. The *k*th rule's normalization activation degree can be calculated by

$$\omega_k = \frac{\theta_k \prod_{i=1}^{T_k} (\alpha_i^k)^{\frac{\delta_i^k}{\max(\delta_i^k)}}}{\sum_{l=1}^{L} \theta_l \alpha_l}$$

(3) Activating the rule integration

ER algorithm is applied for the integration of the activated rules:

$$\beta_l = \frac{\mu[\prod_{k=1}^{K}(\omega_k\beta_{lk} + 1 - \omega_k \sum_{l=1}^{L} \beta_{lk}) - \prod_{k=1}^{K}(1 - \omega_k \sum_{l=1}^{L} \beta_{lk})]}{1 - \mu[\prod_{k=1}^{K}(1 - \omega_k)]}$$

$$\mu = [\sum_{l=1}^{L}\prod_{k=1}^{K}\left(\omega_k\beta_{lk} + 1 - \omega_k \sum_{l=1}^{L} \beta_{lk}\right) - (L-1)\prod_{k=1}^{K}(1 - \omega_k \sum_{l=1}^{L} \beta_{lk})]^{-1}$$

Sun et al.[10] proposed a method based on the hypothesis of reducing the scale of the LSC evaluation's BRB to solve the problem of the number of the belief rules growing exponentially due to the number of evaluation indices increasing. And by the case study of one Missile Brigade's LSC evaluation, they certified the feasibility and potential of the LSC evaluation method based on BRB. And the research results showed that this method can handle effectively the information uncertainty and index types diversity during the evaluation process. Compared to other methods, it was more reliable in real world situation. And the model based on union hypothesis could not only reduce the amount of the belief rules, cut down the optimization complexity, but also avoid the differential information attenuation generated during the multilayer index aggregation process and obtain evaluation results with relatively higher identification degree.

6. EVALUATION MODEL BASED ON D-S EVIDENCE THEORY

D-S Evidence Theory is suitable for LSC evaluation[11]. The theory was firstly proposed by Dernpster and extended and developed by Shafer. Its basic conceptions contain: discernible set, basic probability distribution, evidence combination, etc. The model's comprehensive evaluation consists of evaluation index analysis, index weight determination, basic probability distribution of indices on each of the evaluation grade, calculation of the supportive degree of the evaluation grade, calculation of the conflict value between indices, evidence synthesis of the indices, evaluation grade confirmation, and other processes. Wei et al.[11] brought out an evaluation model based on D-S evidence theory for the comprehensive LSC evaluation and the research showed that the theory could effectively analyze the consistency of each evaluation index and increase the discrimination of the evaluation.

7. CONCLUSION

This paper summarized the current situation of LSC evaluation on the two key aspects: the methods and their applications. In the field of LSC evaluation, multiple evaluation models are used in parallel. Even fuzzy comprehensive evaluation model is used more often, other models can also be used and good evaluation results can be obtained. At the same time, the evaluation on LSC is still in the research stage with weak practicality and little evaluation models can be applied in reality. Therefore, further improvements on LSC evaluation are urgent. It can be seen that the new generation information technologies like big data, artificial intelligence will give the LSC evaluation new concepts and methods.

On the basis of the status, this paper proposed several suggestions for the development of LSC evaluation: firstly, the purpose of the evaluation should be paid special attention, which is the start and the end of the evaluation index confirmation, evaluation method and evaluation results analysis; secondly, the integration of evaluation methods, special focus can be put in the study, absorption, and application of the new technologies like big data, artificial intelligence and the integration between not only traditional methods but also traditional and new methods, updating the evaluation models for the simpler, faster and more accurate evaluation; thirdly, the practicability should be taken into consideration to make the LSC evaluation get out from theory to a real supportive decision-making measure for the backup of forces.

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