Risk Evaluation and Selection of Lithium Power Battery Suppliers for New Energy Vehicles Based on TRIT Method

Yunchong Hua, Yu Yang(✉), and Zhichao Liang

College of Mechanical and Vehicle Engineering, Chongqing University,
Shapingba, Chongqing, China
`{yuyang,zhichaoliang}@cqu.edu.cn`

Abstract. Aiming at the problem of power battery suppliers evaluation and selection from the perspective of risk, a two-stage risk assessment and selection model was constructed based on Trust Risk and Improved TOPSIS (TRIT method) focusing on lithium power battery suppliers to achieve the goal of improving the reliability of evaluation results and decision-making efficiency. Firstly, a preliminary screening model of suppliers evaluation under the influence of trust risk is established. Secondly, experts with high consensus degree preference are organized to form an internal low-risk decision-making team. Thirdly, a risk evaluation indexes system containing reverse logistics capability risk is established and the indexes weights are determined by fuzzy AHP method. Then, the improved TOPSIS method is introduced in the secondary screening to evaluate the risk status of different suppliers, and the ranking results of the risk size of different suppliers are obtained, so as to assist enterprises to choose cooperation partners more scientifically and efficiently. Finally, taking the risk evaluation and selection of lithium battery suppliers of a new energy vehicle manufacturer as an example, the final selection results are analyzed and verified the feasibility and effectiveness of the proposed method.

Keywords: supplier selection · supplier risk evaluation · lithium power battery · trust risk · improved TOPSIS · expert consensus

1 Introduction

According to the 14th Five-year Plan and The New Energy Vehicle Industry Development Plan (2021–2035), the development of new energy vehicles has become an important part of the implementation of China's manufacturing power strategy [18]. As one of the many power batteries of new energy vehicles, lithium power battery has the following characteristics: a high proportion in the cost of the vehicle, strong innovation capability, particularity of component research and development and great impact on the environment [28]. On the demand side, its shipments are increasing year by year and the market size is constantly expanding [21]. The supply level of lithium power battery will directly affect whether automobile manufacturers can complete the production task on

J. Yang et al. (Eds.): ICMSEM 2022, AHE 12, pp. 194–212, 2023.
https://doi.org/10.2991/978-94-6463-038-1_20

time, if the suppliers of lithium power battery located in the upstream of the supply chain has a risk, it will have a negative impact on the whole new energy vehicle supply chain, and even lead to the interruption of the supply chain, resulting in irreparable losses. Therefore, it is of great practical significance to risk evaluate and select lithium battery suppliers for new energy vehicle manufacturers.

At present, researches on supplier evaluation and selection mostly solve problems by putting forward decision-making methods. For example, scholars integrated qualitative and quantitative factors to build a two-stage comprehensive mathematical model to deal with supplier selection and order allocation [5]. Scholars applied the mixed methods of BWM, MULTIMOORA and EDAS to evaluate the suppliers of new energy vehicles [17]. Aiming at the research on lithium power battery suppliers, some scholars combined the balanced scorecard and AHP method to build a selection and evaluation analysis model to propose an optimization scheme for supplier management [22]. In addition, some scholars applied two maximum variance decision methods and AHP method to propose the method and process of supplier management for new product development in the lithium battery industry of new energy vehicles [29]. Scholars established a decision model by integrating QFD, AHP and TOPSIS method and applied it to lithium ion battery supplier selection [27]. Aiming at the research on evaluation and selection of suppliers from the perspective of risk, in China, scholars proposed an improved failure mode and consequence analysis (FMEA) method based on hesitation fuzzy set and grey correlation theory to conduct risk assessment on suppliers [8]. Scholars explored the supplier selection strategy of new energy vehicles based on the consideration of supply interruption risk in the two-stage supply chain of new energy vehicles [13]. Some scholars proposed a supplier risk selection method based on TODIM on the basis of considering market risk factors and decision-makers' risk attitudes [30]. Scholars studied the supplier selection decision support system in supply chain risk management based on the basic principle of CBR [7]. Scholars constructed a risk assessment system for aviation subcontract production suppliers based on the characteristics of aviation subcontract production projects, and used entropy weight TOPSIS to evaluate the risks of suppliers in order to obtain the optimal supplier selection decision [26]. Some scholars comprehensively applied factor analysis, cluster analysis and group multi-level analysis to construct Fa-Km-GAHP model to evaluate the group consensus consistency of supplier risk [25]. In foreign countries, scholars on the basis of considering the interaction of risk factors of supplier selection, comprehensively applied DEMATEL, FMEA and EDAS methods to construct a green supplier evaluation selection model [19]. Scholars used Delphi method and Lichter scale to construct a risk maturity assessment model to evaluate the risk management maturity of suppliers in the automotive industry [1]. Some scholars established a minimum risk model with budget and performance constraints with the goal of minimizing risks, and studied the group decision method for supplier selection [24]. Scholars combined fuzzy analytic hierarchy Process (AHP) with fuzzy multiplicative multi-objective optimization based on ratio analysis, and proposed a comprehensive method of risk assessment and supplier selection [14].

The existing literature has made a deep exploration on supplier evaluation and selection from the perspective of risk, however, few studies combine risk assessment with power battery supplier selection, the decision-making process of power battery supplier selection from the perspective of risk still needs to be improved. At the same time, although existing studies have carried out in-depth research on the decision-making method of power battery supplier selection, power battery supplier selection is a complex multi-link decision-making process, in addition to optimal decision-making, it also includes different stages such as preliminary screening and classification, construction of decision-making expert group, establishment of evaluation indexes system and determination of indexes weights. Existing researches mostly focus on how to design scientific and efficient selection and decision-making methods, while there are still limitations in other links. Therefore, in order to continuously optimize the decision-making process of lithium power battery supplier evalution and selection from the perspective of risk, in-depth research should be carried out in different stages combined with the impact of risk factors.

At present, the risk evaluation and selection process for lithium power battery suppliers still has the following shortcomings in different stages: The preliminary screening process from the risk perspective is not set, the candidate groups containing a large number of individuals are not screened at the initial stage, and the subsequent selection range is not narrowed; In the decision-making process, it is easy to appear that the opinions of various experts differ greatly and are highly subjective, which leads to an increase in the probability of the occurrence of risks within the decision-making group, insufficient attention is paid to the decision-making expert group, and in-depth research is not conducted on the consensus degree among experts. In the context of green development, ignoring the important impact of reverse logistics capability risk on the evaluation of enterprise's comprehensive risk resistance strength, the risk of reverse logistics capability is not included in the evaluation index system. When fuzzy interval number is used to express and process fuzzy information in evaluation decision method, there are problems such as method failure and heavy computation in some cases, which affect the work efficiency and accuracy. In addition, the final evaluation results of suppliers from the perspective of risk are prone to the problem of low credibility, the risk assessment process of supplier trustworthiness is not set up, the influence of trust risk factors on enterprise cooperation is not quantified.

In view of the above problems, this paper focuses on the risk evaluation and selection of lithium power battery suppliers. Firstly, the research questions are described and the main variables are explained. After that, the two-stage risk evaluation and selection process based on TRIT method is proposed. Then, the selection results are obtained by analyzing specific examples and the comparative analysis is conducted. And the last part is the summary and prospect of this paper.

2 Description and Variable Definition

In this paper, procurement enterprises and expert groups are considered to participate in different stages of risk evaluation and selection respectively, and combined with the current supplier selection process the two-stage risk evaluation and selection model is constructed, conduct in-depth research on preliminary selection, expert group construction and secondary selection. Explore how enterprises conduct preliminary screening of potential supplier groups under trust risk, how to establish a decision-making team with

Table 1. Main symbols and variable explanations.

Variate	Variable Explanations
A_i	Initial lithium power battery supplier individual
x_i	Influencing factors of supplier selection under trust risk
p_i	The weight of influencing factors under trust risk
Z_i	Initial evaluation index of lithium battery supplier risk evaluation
r_i	Decision expert individual
C_i	The final evaluation index of supplier risk evaluation
ω_i	The weight of the final evaluation index
M_i	Candidate lithium battery supplier individual after preliminary screening of trust risk
M_i^*	Lithium battery supplier individual after the second evaluation and selection
A^+	Positive ideal solution of TOPSIS method
A^-	Negative ideal solution of TOPSIS method
d_i^+	The distance between the solution and the positive ideal solution
d_i^-	The distance between the solution and the negative ideal solution

high consensus and low internal risk, and how expert groups efficiently and scientifically screen out suitable partners in the second risk evaluation. The main symbols and variables in this paper are explained in Table 1.

3 Risk Evaluation and Selection Process of Lithium Power Battery Suppliers Based on TRIT Method

3.1 Preliminary Screening of Potential Suppliers Under Trust Risk

Trust is often regarded as the basis of transaction or exchange relationship, and transaction costs will be generated after the interaction between entities [12]. In actual production, enterprises are bound to interact with other links in the supply chain to obtain what they need, so the emergence of transactions indicates that the trust factor has begun to play a role. Quantitative research from the perspective of trust risk can not only enhance the credibility of results, but also eliminate unqualified objects, narrow the selection range and reduce the follow-up workload. Based on this, the preliminary screening process of potential suppliers under trust risk is designed in this paper, the steps are as follows:

Step 1: Summarize the initial supplier group, denoted as $A = \{A_1, A_2, A_3, ..., A_i, ..., A_n\}$, $(n \geq 2)$;
Step 2: Form the set of influencing factors, denoted as $X = \{x_1, x_2, x_3, ..., x_i, ..., x_m\}$, $(m \geq 2)$, and determine the corresponding weight, denoted as $P = \{p_1, p_2, p_3, ..., p_i, ..., p_m\}$, $(m \geq 2)$;
Step 3: Give the evaluation score x_{ij} according to the performance degree of $A_i(i = 1, 2, ..., n)$ under $x_j(j = 1, 2, ..., m)$;
Step 4: Establish the preliminary screening model of potential suppliers under trust risk:

$$f_i = \sum\nolimits_{j=1}^{m} p_j x_{ij} (i = 1, 2, ..., n, j = 1, 2, ..., m) \tag{1}$$

where f_i is the ith supplier evaluation total score under trust risk.
Step 5: Get the set f_i, denoted as $F = \{f_1, f_2, f_3, ..., f_i, ..., f_n\}$, $(n \geq 2)$; Then rank the suppliers according to the size of the evaluation score, determine the individual supplier that meet the requirements of trust risk, and the qualified suppliers enter the next stage.

3.2 Construction of Decision-Making Expert Group Based on Reciprocity Preference Network

In the decision-making process, different members of the group often have divergent opinions due to differences in interest appeal, professional background, work experience and personality, resulting in cracks in cooperation and affecting decision-making efficiency, therefore, it is necessary to explore the degree of unity of opinions among members and explore whether a higher degree of consensus can be reached. This problem can be solved by the reciprocity preference network theory, which combines the centrality index of social network and measures the distance between nodes representing members and all other nodes in the network by taking the similarity degree of preference among members of the group as the measure distance [11]. Based on this, this paper designs a selection and construction process of decision-making team, and the steps are as follows:

Step 1: Formulate requirements for the formation of the expert group and determine the number of experts in group k_0; Determine the initial supplier risk evaluation indexes system, denoted as $Z = \{z_1, z_2, z_3, ..., z_i, ..., z_n\} (n \geq 2)$;
Step 2: Invite k experts to form the candidate expert group $(k > k_0)$, denoted as $R = \{r_1, r_2, r_3, ..., r_i, ..., r_k\} (k \geq 3)$, let r_i score the importance of each indicator in Z by pairwise comparison, and take fuzzy binary relation $P_{ij} = (x_i, x_j)$ as the scoring result. Preference comparison is expressed as follows:

$$P_{ij} = \left\{ \begin{array}{l} 0 \; \textit{If} \;\; x_i \;\; \textit{is completely less important than} \;\; x_j \\ (0, 0.5) \; \textit{If} \;\; x_i \;\; \textit{is less important than} \;\; x_j \\ 0.5 \; \textit{If} \;\; x_i \;\; \textit{and} \;\; x_j \;\; \textit{are equally important} \\ (0.5, 1) \; \textit{If} \;\; x_i \;\; \textit{is more important than} \;\; x_j \\ 1 \; \textit{If} \;\; x_i \;\; \textit{is completely less important than} \;\; x_j \end{array} \right\}$$

Based on this, the reciprocity relationship preference matrix $P_{n \times n}$ between each expert r_i and each index z_i in the evaluation system Z is established:

$$P_{n \times n} = \left\{ \begin{matrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ P_{n1} & P_{n2} & \cdots & P_{nn} \end{matrix} \right\}$$

Determine the components of the intensity preference vector under the reciprocity condition, that is, the preference relation below the matrix P main diagonal is used:

$$V\left(p_{21}, p_{31}, \ldots, p_{n1}, p_{22}, p_{32}, \ldots, p_{n2}, \ldots, p_{n(n-1)}\right) \tag{2}$$

Step 3: The undirected weighted preference similarity network is constructed, and the intensity preference vector is used to represent the mutual preference relation between r_i and z_i [6]. On this basis, the decision experts network of similarity measurement is established, as shown in Fig. 1.

Experts preference similarity network is defined as $RG = [R_0, S_0]$, and r_i is taken as the network node. The edge set $S = \{S_{ij}, \ldots, S_{nn}\}$ in the network is represented by the cosine distance of similar preference vectors between r_i. The calculation formula is as follows:

$$S_{ij} = \frac{\sum_{i=1}^{n(n-1)/2} (v_i^p, v_i^q)}{\sqrt{\sum_{i=1}^{n(n-1)/2} (v_i^p)^2} \sqrt{\sum_{i=1}^{n(n-1)/2} (v_i^q)^2}} \tag{3}$$

Step 4: Use the proximity centrality index to judge the preference proximity between r_i, which is obtained by calculating the measure distance between points in the network. The closer the distance is, the closer the preference proximity between r_i is. The calculation formula is as follows:

$$CC^R = \sum_{j=1}^{k_0} d_{ij} / (k_0 - 1) \tag{4}$$

Where d_{ij} represents the shortcut distance between node v_i and node v_j. Rank according to the value of CC^R, and judge the members of the final decision-making expert group. The final decision experts set is $FR = \{r_1, r_2, r_3, \ldots, r_{k_0}\} (k_0 \geq 3)$.

3.3 Establishment of Risk Evaluation Indexes System Based on Decision-Making Expert Group

After reviewing the literature, it is found that the construction principles of the index system used to evaluate the quality and effect of enterprises' social and economic activities include relative independence, scientific simplicity, flexibility and operability, scalability and the combination of qualitative and quantitative [2]. Therefore, on the basis of

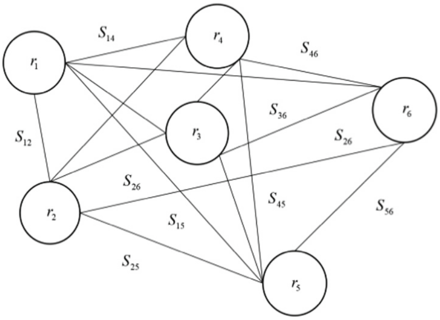

Fig. 1. Undirected weighted experts preference similarity network.

a high degree of consensus and internal low-risk expert group, combined with construction principles, industry characteristics and characteristics of lithium power battery enterprises, the final supplier risk evaluation index system is determined, which can be written as follows:

$$C = \{C_1, C_2, C_3, \ldots, C_i, \ldots, C_n\}(n \geq 2)$$

3.4 Determine the Weight of Risk Evaluation Indexes Based on Fuzzy AHP Method

AHP method is used as a tool to solve the problem of calculating index weight, at the same time, due to the uncertainty and incompleteness of partial information at the present stage, in order to minimize the influence caused by the subjectivity of expert judgment and the inaccuracy of original data, combining fuzzy mathematics with AHP method, fuzzy trigonometric number is used to replace the original fixed value, and fuzzy comprehensive processing is carried out on decision evaluation matrix [4]. AHP method is used to calculate the priority of each indicator, and fuzzy AHP method is comprehensively used to complete the determination process of the weight of risk evaluation indicators, the specific steps are as follows:

Step 1: Experts give scores to indicators C_i by pair-wise comparison, and the score value is represented by fuzzy trigonometric number, denoted as $M = (l, m, u)$, and the expert fuzzy evaluation matrix is established;
Step 2: According to the evaluation scoring results, calculate the fuzzy synthesis degree of C_i as follows:

$$F_i = \sum\nolimits_{j=1}^{m} N_{ij} [\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} N_{ij}]^{-1} \tag{5}$$

Where $\sum_{j=1}^{m} N_{ij} = (\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} n_j)$

$$[\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} N_{ij}]^{-1} = (\sum\nolimits_{i=1}^{n} l_i, \sum\nolimits_{i=1}^{n} m_i, \sum\nolimits_{i=1}^{n} n_i)^{-1};$$

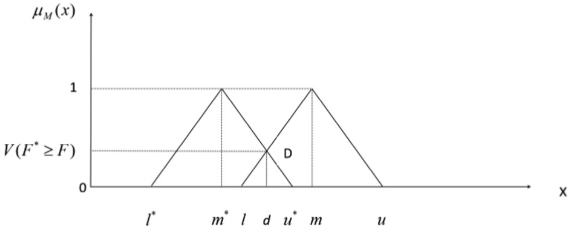

Fig. 2. Schematic diagram of probability degree.

Step 3: Defuzzize and standardize the weights, calculate the probability degree of $F \geq F_i$ and determine the minimum possibility degree that C_i is better than other indicators, where $F^* \geq F$ is shown in Fig. 2. The calculation method is as follows:

$$V(F_i \geq F_j) = sup_{x \geq y}[min(\mu_{s_i}(x), \mu_{s_j}(x))]$$

where $V(F_i \geq F_j) = hgt\left(F_j \cap F_i\right) = \mu_{s_j}(d)$

$$= \begin{cases} 1, m_i \geq m_j \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)}, m_i \leq m_j, u_i \geq l_j \\ 0, \text{other} \end{cases} \tag{6}$$

The probability degree that a certain fuzzy synthesis degree is better than k fuzzy synthesis degrees is calculated as:

$$V(F \geq F_1, F_2, ..., F_k) = minV(F \geq F_i), i = 1, 2, ..., k$$

Step 4: Calculate the weight vector and conduct standardized processing. The weight of C_i is:

$$\omega = (\omega_1, \omega_2, ..., \omega_n)^T, \omega_i = min(V(F_i \geq F_k)), i = 1, 2, ..., n$$

Step 5: Normalize weight ω, and get the final weight of C_i:

$$\begin{gathered} W = (W_1, W_2, \ldots, W_n)^T \\ W_i = \omega_i / \sum\nolimits_{h=1} \omega_h, i = 1, 2, ..., n \end{gathered} \tag{7}$$

3.5 Supplier Risk Evaluation and Selection Based on Improved Interval Number TOPSIS Method

TOPSIS method has the advantages that calculate accurately and can reflect the specific situation of suppliers [23], therefore, this paper chooses this method as the evaluation and selection tool. But TOPSIS method also has limitations. Although combined with fuzzy processing method, TOPSIS method can effectively reduce the influence of subjectivity and uncertainty, there are still defects in calculation, such as in some cases, if the number of interval centers is the same, the interval sizes cannot be compared, and the Euclidean distance measurement method fails, and the distances from the optimal solution to A^+ and A^- are all similar. Therefore, the improved A^+ and A^- representation method and the improved distance measurement method are comprehensively applied to improve the original method [16], and the supplier risk evaluation and selection process based on the improved TOPSIS method is designed, the specific steps are as follows:

Step 1: The candidate individual is denoted as $M = \{M_1, M_2, M_3,...,M_i,...,M_m\}(m \geq 2)$, r_i scores the performance of M_i under C_j, and is denoted as $[x_{ij}^L, x_{ij}^U]$; Interval number decision matrix is established, and is denoted as:

$$D([x_{ij}^L, x_{ij}^U])_{m\times n}(i = 1, 2, ..., m; j = 1, 2, ..., n)$$

Step 2: The evaluation interval number is standardized and the interval number standardization decision matrix is established. The standardization method is as follows:

$$n_{ij}^L = \frac{x_{ij}^L}{\sqrt{\sum_{i=1}^m (x_{ij}^L)^2 + (x_{ij}^U)^2}}$$

$$n_{ij}^U = \frac{x_{ij}^U}{\sqrt{\sum_{i=1}^m (x_{ij}^L)^2 + (x_{ij}^U)^2}}(i = 1, 2, ..., m; j = 1, 2, ..., n) \tag{8}$$

The interval number standardization decision matrix is denoted as:

$$N([n_{ij}^L, n_{ij}^U])_{m\times n}(i = 1, 2, ..., m; j = 1, 2, ..., n)$$

The standardized interval number is weighted and the interval number weighted standardization decision matrix is established, which is processed as follows:

$$v_{ij}^L = \omega_j n_{ij}^L, v_{ij}^U = \omega_j n_{ij}^U (i = 1, 2, ..., m; j = 1, 2, ..., n) \tag{9}$$

The interval number weighted standardization decision matrix is denoted as:

$$V([v_{ij}^L, v_{ij}^U])_{m\times n}(i = 1, 2, ..., m; j = 1, 2, ..., n)$$

Step 3: Calculate the improved A^+ and A^- in interval form.

$$A^{+} = \left(\left[\underset{i}{max} v_{ij}^{U}, 1\right]\middle| j \in I, \left[0, \underset{i}{min} v_{ij}^{L}\right]\middle| j \in J\right), j = 1, 2, \ldots, n$$

$$A^{-} = ([0, \underset{i}{min} v_{ij}^{L}] | j \in I, [\underset{i}{max} v_{ij}^{U}, 1] | j \in J), j = 1, 2, ..., n \tag{10}$$

Where $j \in I$ indicates that C_j is a positive indicator; $j \in J$ indicates that C_j is an inverse indicator.

Then the improved $d_i{}^{+}$, $d_i{}^{-}$ is calculated by using the improved measure distance method as follows:

$$d_i^{+} = \sum_{j \in I}\left(\left(v_j^{+L} + 1\right) - \left(v_{ij}^{L} + v_{ij}^{U}\right)\right) + \sum_{j \in J}(\left(v_{ij}^{L} + v_{ij}^{U}\right) - \left(0 + v_j^{+U}\right))$$

$$d_i{}^{-} = \sum\nolimits_{j \in I}((v_{ij}^{L} + v_{ij}^{U}) - (0 + v_j^{-U})) + \sum\nolimits_{j \in I}((v_j^{-L} + 1) - (v_{ij}^{L} + v_{ij}^{U})) \tag{11}$$

Step 4: Calculate the relative closeness R_i of scheme M_i.

$$R_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}, i = 1, 2, ..., m \tag{12}$$

Sort M_i based on the numerical size of R_i and establish set M^*, denoted as:

$$M^* = \{M_1^*, M_2^*, M_3^* ..., M_i^*, ..., M_m^*\} (m \geq 2)$$

Select suitable objects from the set M^*, and complete the risk evaluation and selection process.

4 Example Analysis

Company A is a large company committed to the scientific research and development, production and sales of new energy vehicles, has rich experience in enterprise cooperation, it is now necessary to select the appropriate lithium power battery supplier that meets the needs of the enterprise. According to the risk evaluation and selection model based on TRIT method established in this paper, company A will gradually complete the risk evaluation and selection of suppliers.

Table 2. Summary of influencing factors under trust risk.

Number	Influence Factors		Overall Impact	Weight
1	Supplier capability	x1	0.213	0.09
2	Supplier reputation	x2	0.407	0.17
3	Supplier products	x3	0.140	0.06
4	Trust in supplier personnel	x4	0.572	0.24
5	Experience in dealing with suppliers	x5	0.331	0.14
6	Communication with suppliers	x6	0.228	0.09
7	Dependency on suppliers	x7	0.262	0.11
8	The supplier's dependence on the enterprise	x8	0.270	0.11

4.1 Preliminary Screening of the Trust Risk for Potential Suppliers

First, set A (a total of 10 enterprises) was determined, and then eight items x_i were extracted according to the results of the research on the antecedents of trust and the influence of trust on cooperation in the research on supplier trust in literature [9]. According to the overall influence of x_i on cooperation, the weight was normalized to get p_i, as shown in Table 2.

Combined with Formula (1), the preliminary screening model of potential suppliers under trust risk is obtained:

$$f = 0.09x_1 + 0.17x_2 + 0.06x_3 + 0.24x_4$$

$$+0.14x_5 + 0.09x_6 + 0.11x_7 + 0.11x_8$$

The five-level scoring system was adopted for the evaluation and the score was x_{ij}. The situation is as follows:

$$x_{1j} = (3, 4, 2, 1, 5, 3, 5, 5), x_{2j} = (5, 1, 4, 4, 1, 3, 5, 5),$$

$$x_{3j} = (4, 2, 1, 2, 5, 5, 2, 1), x_{4j} = (5, 2, 3, 4, 3, 3, 1, 3),$$

$$x_{5j} = (5, 1, 3, 1, 3, 3, 4, 5), x_{6j} = (1, 4, 2, 1, 1, 4, 3, 5),$$

$$x_{7j} = (5, 3, 4, 4, 2, 3, 1, 1), x_{8j} = (3, 2, 3, 5, 1, 4, 4, 1)$$

Calculate f_i according to formula (1), as follows:

$$f_1 = 0.09 \times 3 + 0.17 \times 4 + 0.06 \times 2 + 0.24 \times 1$$

$$+0.14 \times 5 + 0.09 \times 3 + 0.11 \times 5 + 0.11 \times 5$$

$$F = \{f_1, f_2, ..., f_8\} = \{33.8, 33.3, 27.2, 30.6, 27.2, 25.1, 29.3, 30.4\}$$

was established and sorted according to numerical size, with the results as follows:

$$f_1 > f_2 > f_4 > f_8 > f_7 > f_3 > f_5 > f_6.$$

Taking the median "2.5" of the five-level scoring system as the screening basis, the screening criteria are determined as follows:

$$f = (0.09 + 0.17 + 0.06 + 0.24 + 0.14 + 0.09 + 0.11 + 0.11) \times 2.5 = 30.3$$

Finally, the candidate supplier group obtained after the preliminary screening under trust risk is determined as A_1, A_2, A_4, A_8.

4.2 Set up Internal Low-Risk Decision-Making Expert Group

Ten experts were invited to form an candidate group, and the set Z was established based on literature [15, 20] and enterprise demand, including five indexes: research and development capability risk, production capability risk, resource coordination capability risk, cooperation attitude risk and product quality risk. The comparative scoring of importance degree are as follows:

$$p^1 = \begin{pmatrix} 0 & 0.5 & 0.3 & 0.2 & 0.4 \\ & 0 & 0.9 & 0.5 & 0.9 \\ & & 0 & 0.9 & 0.5 \\ & & & 0 & 0.9 \\ & & & & 0 \end{pmatrix}, p^2 = \begin{pmatrix} 0 & 0.8 & 0.1 & 0.9 & 0.5 \\ & 0 & 0.9 & 0.5 & 0.5 \\ & & 0 & 0.9 & 0.5 \\ & & & 0 & 0.1 \\ & & & & 0 \end{pmatrix}, p^3 = \begin{pmatrix} 0 & 0.1 & 0.4 & 0.1 & 0.7 \\ & 0 & 0.5 & 0.6 & 0.2 \\ & & 0 & 0.8 & 0.7 \\ & & & 0 & 0.6 \\ & & & & 0 \end{pmatrix}$$

......

$$p^8 = \begin{pmatrix} 0 & 0.4 & 0.5 & 0.4 & 0.8 \\ & 0 & 0.8 & 0.9 & 0.8 \\ & & 0 & 0.8 & 0.2 \\ & & & 0 & 0.3 \\ & & & & 0 \end{pmatrix}, p^9 = \begin{pmatrix} 0 & 0.8 & 0.3 & 0.9 & 0.8 \\ & 0 & 0.1 & 0.5 & 0.5 \\ & & 0 & 0.8 & 0.8 \\ & & & 0 & 0.3 \\ & & & & 0 \end{pmatrix}, p^{10} = \begin{pmatrix} 0 & 0.5 & 0.2 & 0.1 & 0.7 \\ & 0 & 0.3 & 0.1 & 0.7 \\ & & 0 & 0.3 & 0.1 \\ & & & 0 & 0.9 \\ & & & & 0 \end{pmatrix}$$

According to Formula (2), each intensity preference vectors were extracted from the importance degree scoring matrix, as follows:

$$v_1 = (0.5, 0.3, 0.2, 0.4, 0.9, 0.5, 0.9, 0.9, 0.5, 0.9),$$

$$v_2 = (0.8, 0.1, 0.9, 0.5, 0.9, 0.5, 0.5, 0.9, 0.5, 0.1)$$

Establish RG, calculate the cosine distance according to formula (3), and take it as the network edge value.

$$S = \begin{pmatrix} 0 & 0.829 & 0.868 & 0.821 & 0.708 & 0.743 & 0.842 & 0.894 & 0.760 & 0.859 \\ & 0 & 0.749 & 0.703 & 0.562 & 0.757 & 0.772 & 0.870 & 0.888 & 0.634 \\ & & 0 & 0.743 & 0.828 & 0.753 & 0.756 & 0.858 & 0.793 & 0.721 \\ & & & 0 & 0.736 & 0.789 & 0.799 & 0.908 & 0.734 & 0.848 \\ & & & & 0 & 0.635 & 0.796 & 0.682 & 0.645 & 0.592 \\ & & & & & 0 & 0.835 & 0.822 & 0.793 & 0.625 \\ & & & & & & 0 & 0.825 & 0.662 & 0.643 \\ & & & & & & & 0 & 0.809 & 0.760 \\ & & & & & & & & 0 & 0.699 \\ & & & & & & & & & 0 \end{pmatrix}$$

Table 3. Fuzzy comparison matrix of risk evaluation indexes.

	C_1	C_2	C_3	C_4	C_5
C_1	(1.0,1.0,1.0)	(1.0,1.0,1.0)	(0.67,1.0,1.5)	(0.67,1.0,1.5)	(1.5,2.0,2.5)
C_2	(1.0,1.0,1.0)	(1.0,1.0,1.0)	(0.67,1.0,1.5)	(0.67,1.0,1.5)	(0.67,1.0,1.5)
C_3	(0.67,1.0,1.5)	(0.67,1.0,1.5)	(1.0,1.0,1.0)	(0.4,0.5,0.67)	(0.67,1.0,1.5)
C_4	(0.67,1.0,1.5)	(0.67,1.0,1.5)	(1.5,2.0,2.5)	(1.0,1.0,1.0)	(2.5,3.0,3.5)
C_5	(0.4,0.5,0.67)	(0.67,1.0,1.5)	(0.67,1.0,1.5)	(0.28,0.33,0.4)	(1.0,1.0,1.0)

According to Formula (4), each proximity centrality index is calculated, and the results are:

$$CC^R(v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10})$$

$= \{0.814, 0.752, 0.786, 0.787, 0.687, 0.750, 0.770, 0.825, 0.754, 0.709\}$

The order is as follows:

$v_8 > v_1 > v_4 > v_3 > v_7 > v_9 > v_2 > v_6 > v_{10} > v_5$.

Considering that the final decision group consists of five people, the 8th, 1st, 4th, 3rd and 7th experts with high consensus among them are selected to form the final decision-making group.

4.3 Establish Supplier Risk Evaluation Index System

Based on the whole life cycle of products, combined with the "reverse recycling" mode of production enterprises proposed in The 14th Five-Year Plan and 2035 Vision Goal, the final risk evaluation index system determined by the expert group includes research and development capability risk (C_1), production capability risk (C_2), reverse logistics capability risk (C_3), lithium power battery product quality risk (C_4) and cooperate capability risk (C_5).

4.4 Determine the Weight of Risk Evaluation Indexes

The expert group established the fuzzy comparison matrix of risk evaluation indicators with the help of triangular fuzzy number, as shown in Table 3.

The value of fuzzy synthesis degree of C_i can be calculated according to Formula (5):

$$F_1 = (0.137, 0.220, 0.352), F_2 = (0.114, 0.183, 0.301),$$

$$F_3 = (0.097, 0.165, 0.285), F_4 = (0.180, 0.293, 0.463),$$

$$F_5 = (0.086, 0.140, 0.235)$$

Table 4. Probability degree values of evaluation indexes.

j	2	3	4	5
$i = 1$	1	1	0.680	1
j	1	3	4	5
$i = 2$	0.820	1	0.506	1
j	1	2	4	5
$i = 3$	0.740	0.920	0.441	1
j	1	2	3	5
$i = 4$	1	1	1	1
j	1	2	3	4
$i = 5$	0.527	0.703	0.793	0.246

Table 5. Summary of risk assessment indexs weights.

	C_1	C_2	C_3	C_4	C_5
ω_i	0.24	0.17	0.15	0.35	0.09

Table 6. Interval number decision matrix.

	C_1	C_2	C_3	C_4	C_5
M_1	[6, 20]	[10, 16]	[6, 11]	[8, 10]	[12, 22]
M_2	[12, 15]	[8, 11]	[10, 20]	[9, 18]	[8, 18]
M_3	[10, 13]	[12, 17]	[22, 28]	[20, 29]	[10, 16]
M_4	[12, 15]	[11, 15]	[12, 26]	[6, 12]	[10, 20]

The probability degree value of $F_i \geq F_j$ is calculated according to Formula (6) and summarized as shown in Table 4.

Normalization is performed according to Formula (7), the final weight values are obtained:$\omega = (0.680, 0.506, 0.441, 1.000, 0.246)$;$W = (0.24, 0.17, 0.15, 0.35, 0.09)$. Then, summarize the weights, as shown in Table 5.

4.5 Second Evaluation and Selection of Cooperative Suppliers

According to the candidate supplier group (4 suppliers in total) that has passed the preliminary trust risk screening and each evaluation index with determined weight, a decision matrix is established based on interval fuzzy number scoring, as shown in Table 6. Renumbering the supplier group, A_1, A_2, A_4, A_8 is denoted as M_1, M_2, M_3, M_4 respectively.

Table 7. Interval weighted normalized decision matrix.

	C_1	C_2	C_3	C_4	C_5
M_1	[0.0379,0.1264]	[0.0468,0.0749]	[0.0172,0.0315]	[0.0628,0.0785]	[0.0250,0.0458]
M_2	[0.0758,0.0948]	[0.0374,0.0515]	[0.0286,0.0573]	[0.0706,0.1412]	[0.0166,0.0374]
M_3	[0.0632,0.0821]	[0.0561,0.0795]	[0.0630,0.0802]	[0.1569,0.2275]	[0.0208,0.0333]
M_4	[0.0758,0.0948]	[0.0515,0.0702]	[0.0344,0.0744]	[0.0471,0.0942]	[0.0208,0.0416]

Table 8. Summary table of D_i^+, D_i^-, R_i.

	D_i^+	D_i^-	R_i	Sorting Result
M_1	5.0129	0.3903	0.0779	4
M_2	4.9481	0.4551	0.0920	2
M_3	4.6967	0.7065	0.1504	1
M_4	4.9547	0.4485	0.0905	3

According to formula (8) and (9), standardized and weighted processing is carried out, $V([v_{ij}^L, v_{ij}^U])_{m\times n}$ is obtained, as shown in Table 7.

According to formula (10), A^+, A^- of the improved interval form is determined:

$$A^+ = ([0.1264, 1], [0.0795, 1], [0.0802, 1], [0.2275, 1], [0.0458, 1])$$

$$A^- = ([0, 0.0379], [0, 0.0374], [0, 0.0172], [0, 0.0471], [0, 0.0166])$$

Calculate d_i^+, d_i^-, R_i according to formula (11) and (12), the summary is shown in Table 8.

4.6 Selection Results and Discussion

The final ranking of suppliers after evaluation is M_3, M_2, M_4, M_1, corresponding to A_4, A_2, A_8, A_1, that is, the fourth lithium power battery supplier is the best. In order to verify the effectiveness of the method in this paper, the interval TOPSIS method [10], which adopts Euclidean distance measure method, is applied to analyze the calculation example again. The calculation results and comparison are shown in Table 9.

It can be found that the results obtained by the two methods are consistent. In the process of calculating d_i^+, d_i^-, the improved measure distance method adopted in this paper is more convenient than the Euclidean measure distance method on the basis of guaranteeing accuracy and has more obvious advantages in reducing the amount of calculation. In addition to reducing the computational workload, the method in this paper also avoids the problem that A^+, A^- are invalidated and cannot be determined. Here, it is

Table 9. Comparison table of calculation results.

	Methods in literature		Methods of this paper	
	R_i	Sorting result	R_i	Sorting result
M_1	0.2255	4	0.0779	4
M_2	0.3542	2	0.0920	2
M_3	0.8537	1	0.1504	1
M_4	0.3410	3	0.0905	3

Table 10. Comparison of positive and negative ideal solutions.

	Methods in literature		Methods of this paper	
	A^+	A^-	A^+	A^-
C_1	[0.0758, 0.1264]	[0.0379, 0.0821]	[0.1264,1]	[0, 0.0379]
C_2	There are two intervals with the same number of centers, the ideal solution cannot be determined		[0.0795,1]	[0, 0.0374]
C_3	[0.0630, 0.0802]	[0.0172, 0.0315]	[0.0802,1]	[0, 0.0172]
C_4	There are two intervals with the same number of centers, the ideal solution cannot be determined		[0.2275,1]	[0, 0.0471]
C_5	[0.0250, 0.0458]	[0.0166, 0.0333]	[0.0458,1]	[0, 0.0166]

compared with the method of direct interval number ideal solution proposed in literature [3], and the results are shown in Table 10.

It is found that in $D([x_{ij}^L, x_{ij}^U])_{m\times n}$, there is $A_1 = [10, 16], A_3 = [11, 15]$ under C_2 index and $A_1 = [8, 10], A_3 = [6, 12]$ under C_4 index, the two places above have the same number of interval centers, that is, $\Delta_{A-B} = 0$, $\Delta_{B-A} = 0$. At this time, the size of the two intervals cannot be compared, that is, the ideal solution of the interval cannot be determined. Therefore, the method in literature (Dymova,2013) cannot be used, but the improved A^+, A^- representation method adopted in this paper effectively solves this problem by using 0 or 1 to represent the boundary of A^+, A^-.It should be noted here that there is no backward indicator set in this paper, so A^+, A^- are determined according to the requirements of forward indicator, it is found that the weighted normalized interval boundaries are closer to 0 and farther from 1, therefore, the interval range of A^+ is much larger than the interval range of A^-, making d_i^- being much smaller than d_i^+, resulting in the calculation result of R_i being smaller. So this paper only takes the numerical value of R_i as the sorting basis, and takes the scheme with the largest value as the final optimization result.

5 Conclusions

Aiming at the problem of risk evaluation and selection of lithium power battery suppliers for new energy vehicles, a two-stage evaluation and selection decision-making process was designed based on TRIT method. Firstly, the influence of trust risk is quantified and the preliminary screening model of supplier evaluation under trust risk is constructed; Secondly the reciprocity preference network is used to construct expert groups with high preference consensus and low internal risk; Thirdly, the risk evaluation index system is established in line with the characteristics of lithium battery enterprises, and the fuzzy AHP method is used to determine the weight of risk index; Then the improved TOPSIS method is used to carry on the second risk evaluation and selection of suppliers, and the final ranking results are obtained. The process method is verified by a specific example, the results show that the preliminary screening of suppliers' trust risk can eliminate the suppliers with low credibility, retain the potential partners with high credibility, narrow the selection range, reduce the follow-up workload and deepen the cooperative relationship of trust between enterprises and suppliers; reciprocity preference network theory can ensure that the disagreements among experts are as small as possible, improve the degree of internal solidarity and reduce the possibility of intra-group risk occurrence; The improved TOPSIS method can effectively avoid the limitation of the original measurement method, and at the same time reduce the work calculation of evaluation and selection to improve the efficiency, The method proposed in this paper is verified to be scientific and reasonable, which can provide reference for the risk evaluation and selection of lithium power battery suppliers in the future.

The risk evaluation and selection method proposed in this paper can better define the scope of potential suppliers with strength and screen out key suppliers more efficiently and scientifically to improve the selection efficiency. However, there are still shortcomings in this paper. Firstly, the evaluation index system is not comprehensive enough, and secondly, the established method cannot carry out dynamic evaluation and selection. Therefore, it will continue to be improved and supplemented in the subsequent research work.

Acknowledgement. This Research is Supported by National Natural Science Foundation of China (71571023), the Fundamental Research Funds for the Central Universities (No. 2020CDCGJX029), the Fundamental Research Funds for the Central Universities (No. 2021CDJSKJC17), and joint supported by the Fundamental Research Funds for the Central Universities (No. 2020CDJSK03PT08).

References

1. Cech, Marek. & Januska, Martin. (2020). Evaluation of risk management maturity in the Czech automotive industry: Model and methodology. J. Amfiteatru Economic. 22(55), 824–845.
2. Cheng Chen. (2020). Research on supplier efficiency evaluation of intelligent manufacturing enterprise based on DPMPSO-BP neural network. Huaibei: Huaibei Normal University.
3. Dymova, L., Sevastjanov, P., Tikhonenko, A. (2013). A direct interval extension of TOPSIS method. J. Expert Systems with Applications. 40(12), 4841–4847.
4. Fangxiang Sun. (2019). Research on evaluation of outsourcing suppliers in high-end equipment manufacturing industry based on product life cycle management. Hefei: Hefei University of Technology.
5. Feng Li, Chia-Huei Wu, Li Zhou, Guangshu Xu, Yongsheng Liu, Sang-Bing Tsai. (2020). A model integrating environmental concerns and supply risks for dynamic sustainable supplier selection and order allocation.J. Soft Computing. 25, 1–15.
6. Gonzalez-Arteaga, T., Calle, R.D., Chiclana, F.(2016). A new measure of consensus with reciprocal preference relations: The correlation consensus degree.J. Knowledge-Based Systems. 107(sep. 1), 104–116.
7. Hengbo Jiang, Jian Zhang, Wanqing Ouyang, Yujie Luo, Xiaoyu Lu.(2020).Research on supplier selection decision support system based on supply chain risk management. J. China Management Informationization. 23(06), 79–81.
8. Jianxin You, Wei Liu, Miying Yang. (2017). An improved FMEA for supplier risk assessment.J.Journal of Tongji University (Natural Science). 47(01), 130–135.
9. Jing Wang. (2009).The study of interfirm turst and default risk in supply chain. Xi'an: Chang'an University.
10. Kai Zhang, Jianhua Dai, Jianming Zhan. (2021). A new classification and ranking decision method based on three-way decision theory and TOPSIS models.J. Information Sciences. 568, 54–85.
11. Kamis, N.H., Chiclana, F., Levesley, J. (2018). Preference similarity network structural equivalence clustering based consensus group decision making model.J. Applied Soft Computing. 67:706–720.
12. Kwon, M., Berry, F.S., Feiock, R.C. (2009). Understanding the adoption and timing of economic development strategies in US cities using innovation and institutional analysis. J. Journal of Public Administration Research and Theory: J-PART. 19(4), 967–988.
13. Lining Jiang, Gongzhi Luo, Ruiyi Chen. (2019). Selection of new energy vehicle suppliers with considering supply disruptions. J. Science and Management. 39(01), 80–86.
14. Madjid, Tavana., Akram, Shaabani., Soleyman, Mansouri Mohammadabadi., Nilofar, Varzgani. (2021). An integrated fuzzy AHP- fuzzy MULTIMOORA model for supply chain risk-benefit assessment and supplier selection. J. International Journal of Systems Science-Operations & Logistics. 8(3), 238–261.
15. Mary, Vayaliparampil., Frank, Page., Eric, Wolterstorff. (2021). The missing ingredient for successful multi-stakeholder partnerships: Cooperative capacity. J. Societies. 11(2), 37.
16. Meijuan Li, Yuxin Pan, Linming Xu, Jincheng Lu. (2021).Improved dynamic TOPSIS evaluation method of interval numbers. J. Journal of Systems Science and Mathematical Sciences. 41(07), 1891–1904.
17. Meiqin Wu, Zhuoyu Li, Jianping Fan. (2021). Selection of new energy vehicles using hybrid approach: A case study of China. J. Intelligent & Fuzzy Systems. 40(6), 11967–11980.
18. Min Hu, Heng Wang, Qi Chen. (2020). Development status and trend of lithium-ion power batteries for electric vehicles. J. Automobile Applied Technology. 9, 8–10.
19. Morteza, Yazdani., Prasenjit, Chatterjee., Dragan, Pamucar., Doval, Abad Manuel. (2020). A risk-based integrated decision-making model for green supplier selection:A case study of a construction company in Spain. J. Kybernetes. 49(4), 1229–1252.

20. Naqvi, Mohammad Abbas. &Amin, Saman Hassanzadeh. (2021). Supplier selection and order allocation: A literature review. J. Journal of Data, Information and Management.prepublish, 1–15.
21. Qianzhan Industrial Research Institute. (2021). Foresee 2021: China lithium battery industry panorama map.J.China Electrical Equipment Industry. 4, 4–28.
22. Qin Chen. & Qixiang Zeng. (2013). Supplier evaluation and selection analysis of lithium battery package S enterprise. J. Modern Business Trade Industry. 25(12), 18.
23. Qingqing Lu.(2020). Research on WL enterprise supplier selection and management optimization based on DANP and fuzzy TOPSIS. Zhengzhou: Zhengzhou University.
24. Radulescu, Constanta Zoie. & Radulescu, Marius. (2020). A group decision approach for supplier selection problem based on a multi-criteria model. J. Studies in Informatics and Control. 29(1), 35–44.
25. Siqin Yu. & Zhongmin Liu. (2022). Risk consensus assessment of credit suppliers base on the FA-KM-GAHP model. J/OL. Journal of Shanghai University (Natural Science Edition). 1–16.
26. Sijia Zhu. & Wanhua Qiu. (2020). Risk assessment for suppliers in the air subcontracting production based on the entropy weight and TOPSIS. J. Systems Engineering. 38(01), 154–158.
27. Tusnial, Anirudh., Sharma, Satyendra Kumar., Dhingra, Parth., Routroy, Srikanta. (2020). Supplier selection using hybrid multi-criteria decision-making methods. J. International Journal of Productivity and Performance Management.Ahead-of-print, 1393–1418.
28. Wei Zhang. (2021).Analyze of the new energy vehicles battery technology bottleneck and the research of countermeasures. J. Metallic Functional Materials. 28(01), 78–84.
29. Xiaofan Hu. & Binghai Zhou. (2015). Application of new product development supplier management in lithium battery industry of new energy vehicles.J. Machinery. 53(08), 73–78.
30. Yongzheng Zhang, Chunming Ye, Xiuli Geng. (2019). A risky supplier selection approach based on hesitant fuzzy generalized choquet integral. J. Industrial Engineering and Management. 24(04), 47–54.