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New Framework Based on a Multi-criteria Decision-making Model of Technology Transfer in the Auto-battery Manufacturing Industry under Uncertainty

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A B S T R A C T

This research builds a decision-based optimization model to evaluate and decide on the methods of technology transfer in the auto-battery industry under uncertainty. This research is conducted based on the needs of the country's battery industry and shows the impact of technology transfer on world-class manufacturing. At first, the effective indices in the assessment of a technology transfer method are singled out through reviewing the literature and the experts' judgment. The sample population in this research consists of experts from eight auto-battery manufacturing companies. Then, each of the approved indices is assessed via the best-worst method, and in continuation, the technology transfer methods are evaluated and prioritized using an MOORA method as multi-criteria decision-making under uncertainty. The gray theory is also used to deal with uncertainty. According to the results obtained from the best-worst method, the five significant indices (i.e., improving style management, business strategy, cost-effectiveness, how to communicate with the organization, and competitiveness) are considered to select the technology transfer methods in the auto-battery production industry. Finally, to implement the proposed framework in the state auto-battery manufacturing industries, a dual-purpose mathematical model is introduced for optimized world-class technology transfer methods. To solve the proposed model, the developed ε-constraint method is used. Finally, based on the results of the proposed method, the transfer method of joint investment is recognized as the most suitable technique for technology transfer in this industry.

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NOMENCLATURE

P_i	Cost of implementing the *i*-th method in manufacture *j*	L_{ij}	Reliability of the *i*-th method for implementation in manufacture *j*
W_{ij}	Weight of implementing the *i*-th method in manufacture *j*	D_j	Number of authorized methods that manufacturer *j* can choose
x_{ij}	Random numbers between 0 and 1		

1. INTRODUCTION

Globalization along with the development of technology has had a great impact on national competitiveness, improvements influence organizational strategies, tactics, and operative decisions. The applications of technology transfer and commercialization are vital issues in a highly competitive global market [1]. Due to the very low rate of technology products in developing countries, they are forced to import technology from pioneer countries to achieve the development and improvement of their products [2]. Technology management leads to everyday competition between companies, which results in increasing prices and complicating products and services [3, 4]. Global changes and processes mainly lead to the development and invention of new technologies and more than 50% new products and their processes have an important theoretical and practical background under the title of technology transfer.

Recent studies emphasize the importance of international research and development to increase domestic productivity as one of the global factors of increasing technology transfer between countries,

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especially among developed countries that help each other to develop. Today, only a handful of countries are independent in terms of technological needs, even the United States, which has long been at the forefront of technology development, is in many ways dependent on international resources. But developing countries are more dependent on external resources and technical know-how than other developed countries [5]. On the other hand, long-term prediction of technology and economic development is very important for Asian developing countries (e.g., Iran, Pakistan, and India) [6]. Technology transfer is a process that takes place to achieve the progress of companies or countries in various fields (e.g., competitiveness and financial profit) [7, 8]. It is about transferring technology from one place to another, for example, from one organization to another or from one country to another [9].

Technological pressure (through research) or market pull (through industry) leads to this transfer. The international scope of technology commercialization may include developed countries, developing countries, and other countries with economic transition [10].

The demand for batteries continues to grow worldwide, with the market for (rechargeable) batteries was 62 billion dollars in 2014[2] and reached 90 billion dollars in 2020 and by 2030, it is projected to increase to $150 billion[3]. Of this revenue in 2020, $35.5 billion came from automative battery sales[4], and as per a recent study by Global Market Insights INC, the global market for starter batteries is expected to exceed $47 billion by 2025.

Therefore, the purpose of this study is to present three-step mathematical modeling to evaluate and select transfer of technology methods in the automotive battery industry. It is based on multi-criteria decision-making (MCDM) techniques under conditions of information uncertainty. First, the best-worst method (BWM) is used to determine the optimal weight of the factors affecting technology transfer. Then a gray MOORA rating method is used to rank technology transfer methods, which are identified as the most important methods for managers. Then a multi-objective mathematical scheduling model is presented to select optimal methods aiming for world-class manufacturing. Finally, due to the multi-objective nature of the proposed model, the augmented ε-constraint method is used to solve the mathematical model. The following detailed objectives will be mainly considered in this research:

- Designing an optimal decision-based approach for technology transfer in the automotive battery industry under uncertain criteria.
- Identifying the factors affecting the evaluation of technology transfer methods
- Identifying appropriate technology transfer methods in the automotive battery industry, with a view to costs minimizing and maximizing reliability.

At the end of the first section (i.e., introduction), the structure of the research is divided as follows: the second section reviews the research literature, the third section describes the research method, the fourth section presents the research case study, and also the framework of proposed criteria, the fifth section discusses the computational results, the sixth part at the end presents a general conclusion and some suggestions for future researches.

2. LITERATURE REVIEW

In this section, the theoretical basis, research background, and research gaps are studied.

2. 1. World Class Manufacturing

In the dynamic and complex environment 21st-century environment, organizations, businesses, and industries compete internationally, and global production is a vital element of success in competing around the world [11]. As a result, a country's production & manufacturing capacity at a globally-competitive level as well as achieving high GDP growth rates are essential components of national identity and pride.

The world-class manufacturing (WCM) process focuses on deploying the following objectives:

- Gradual increase of quality and efficiency in industrial processes.
- Eliminating waste and losses.
- Improvement in data/information.
- Effective/efficient utilization of time resources.
- Increasing flexibility
- Development of customer service [12].

WCM refers to techniques/technologies enabling companies/businesses to correlate their performance with their leading competitors [13]. It creates a new paradigm consistent with rapidly-evolving customer requirements. Due to market changes (production diversity, quantity, etc.), by providing new and specific solutions, WCM possesses the ability to direct, guide, and organize businesses towards excellence with optimal flexibility [11].

One of the most significant requisite tools for accomplishing WCM accesses to the most up-to-date and advanced technologies in the world, providing the basis for producing products according to customer needs, highest quality achievable, cost-effectiveness, minimum waiting times, maximum flexibility, and optimal after-sales service. However, because access to new technologies is a time-consuming and costly process,

[2] https://www.grandview reserch .com/industry-analysis/battery-market/segmentation

[3] https://www.eurobat.org/

[4] https://batteryinnovation.org/

many countries use the technology transfer process.

2. 2. Technology Transfer Technology transfer is a method in which governmental research institutes transfer the technologies they have developed to private companies and try to stimulate and improve the commercialization of technology transfer. The main purpose of this method is to increase public awareness of such technologies to strengthen industrial and technological competition, which in turn leads to increased competitiveness at the national level [1]. This concept originates from the management of innovation and research and development and has become more prominent with the introduction of technology transfer between developed and developing countries and the design of its legal and contractual dimensions [14]. For an efficient and effective Technology transfer into the country, it is necessary to use appropriate routes and methods to the internal conditions of the country and the industry to achieve a competitive advantage in the market and industry. Advanced technologies of developed countries are essential for the industrialization of developing countries. Many of the countries that are now developed have benefited greatly from advanced imported technologies [15].

2. 3. Literature Review There are few empirical studies in the field of technology transfer and innovative performance in developing countries [1, 7]. Given that Iran is a developing country, technology transfer is a hot topic among domestic researchers, and various types of research have been done in this field, each of which has looked at the issue from one perspective. This section mentions some of the domestic and foreign research conducted in recent years.

Din Mohammadi and Shafiei [16] used a hybrid multi-criteria decision-making model based on Analytic Hierarchy Process (AHP) and TOPSIS method to rank the technology transfer factors in the wind turbine industry. This model is used to determine the most appropriate wind turbine transmission strategy from four options including reverse engineering, technical skills training, key contracts, and technology license for Iran's renewable energy sector. The results are compared with the outputs of classical decision-making models.

Arabzadeh [17] studied how organizations have maintained their growth through the use of technology transfer factors. In his study, some of the most important oil industry companies were evaluated using the fuzzy analytic hierarchy process (FAHP) and fuzzy TOPSIS (FTOPSIS). The results of both methods show that the oil pipeline and the telecommunication company are more important than the National Gas Company and the Petroleum Products Distribution Company. Also, the results of the FAHP technique show that the technological aspects of the oil industry are more prominent than its organizational, personnel, and industrial aspects. Lee et al. [1] studied the technology transfer of IT equipment and introduced a comprehensive framework for factors affecting the timely completion of technology transfer between suppliers and buyers according to technology transfer agreements. They used the Analytic Hierarchy Process (AHP) method to determine the factors affecting the timely completion of technology transfer.

Distanont et al. [18] investigated the factors affecting the technology transfer performance in the Thai petrochemical industry using exploratory factor analysis (EFA) and structural equation modeling (SEM). Research findings show important factors affecting the technology transfer performance are: 1) absorption capacity, 2) characteristics of partners, 3) complexity of technology and 4) inter-organizational relationships. Kraujalienė [19] studied appropriate tools for evaluating the efficiency of the technology transfer process in higher education institutions using TOPSIS, COPRAS, Multi-MOORA, and DEA methods. The results approved FARE to identify critical factors for the technology transfer process and their weights. Lavoie and Daim [20] introduced a methodology to evaluate an organization's technology transfer capabilities. Their proposed approach is a combination of practical research in the first stage. They used an analytic hierarchy process (AHP) method in the second stage, and instead of focusing on a single technology, project, or program, concentrates on the evaluation of the organization as a whole, i.e. this model provides an insight into the extent to which the organization is ready for successful technology transfer from the research phase to the operational phase.

Amini et al. [21] studied the factors affecting technology transfer at the University of Tehran. They used Analytic Hierarchy Process (AHP) to rank and evaluate the factors. Political, economic, and environmental conditions were identified as the most important factors in technology transfer. Amir-Ghodsi et al. [22] presented a new integrated method based on the Shannon-projection attribute function (PAF) using gray interval numbers, to analyze technology transfer methods in the construction industry. The results showed that reverse engineering and import of capital goods and machinery are the best methods of technology transfer, respectively. Naeeni Bonyadi et al. [23], in a study to select the best provider, best technology, and best transfer method, used the gray DEMATEL and the Best-Worst methods to determine the weights of the criteria, and the gray network analysis method to determine the priority of the options.

Nouri et al. [24] examined the impact of technology transfer on employment. Among the methods examined in this study, unity and joint ventures on ineffective employment and the effect of integration and acquisition methods, foreign direct investment, franchises, operating licenses, multinational enterprises, research and development, and reproducing enterprises on positive employment have been identified. In the second phase, the TOPSIS method was used to rank the technology transfer methods according to the criterion of impact on the employment of ordinary and skilled workers. Accordingly, the franchise method was identified as the most suitable method for creating employment among unskilled workers, and the research and development, foreign direct investment, and reproducing enterprise methods were identified as the most suitable method for creating employment among skilled workers. Iroegbu et al. [25] investigated the challenges affecting technology transfer between the two sides by creating a platform through which reliable solutions can be generated. Using the case study analysis and the Fuzzy AHP approach, several problems are identified in this study, including management and strategic issues, marketing concerns, technical issues, environmental difficulties, and regulatory concerns.

Durak et al. [26] identified the criteria that the companies in the technoparks in Istanbul take into consideration in their technopark preferences and then select the most appropriate technopark based on these criteria. The criteria used in the study are proposed for the first time for the selection of technoparks by authors. The sample studied is also used for the first time for the technopark selection. For this purpose, the current data obtained from the managers of the companies in the technoparks in Istanbul are used. In the application part, AHP and TOPSIS are used separately in the selection of the most appropriate facility location for the companies in Istanbul Technoparks. The result of the study shows that the most suitable facility location was the ITU by two different MCDM methods.

Mohammadi et al. [27] identified and prioritized the critical success factors in technology transfer projects by using an integrated approach based on the fuzzy Delphi method and the Additive Ratio Assessment (ARAS) method. The results show that experience in technology transfer in the transferee company, the existence of experienced technology transfer managers, sufficient organizational infrastructure, and documenting project problems, achievements, and experiences are four critical success factors of the technology transfer projects.

Ravi and Janodia [10] attempted to answer the research question of whether current dynamics within Indian universities create an environment for enabling knowledge transfer/commercialization and propose plausible suggestions to enable academia-industry technology transfer. They have tried to cover three key aspects: (1) the awareness and practice of patents and research commercialization among Indian academia, (2) comprehending strategies adapted to commercialize research activities, and (3) barriers in a university-industry technology transfer.

Dahooie et al. [28] considered selecting the most appropriate method of television technology acquirement for Irancell MTN Telecommunication Company using a combinational model consisting of MCDM methods. In the first phase of structuring the model, they defined the list of criteria and options based on a literature review. Then, in the evaluation phase, they used the fuzzy Delphi technique to finalize the list of criteria and options, and then they used a fuzzy group hierarchical best-worst method to determine the weights of the criteria and evaluate the options. Finally, in the ranking phase, the options were ranked using fuzzy multiple attribute decision-making (F-MADM) methods including ARAS-F, fuzzy TOPSIS, fuzzy WASPAS, fuzzy VIKOR, fuzzy MABAC, and fuzzy SAW. Then, the integer linear program (ILP) model was used to summarize the ranking. Based on the results, the main criteria in terms of importance are technological factors, environmental and market factors, organizational factors, and partner or vendor factors. The most important sub-criteria can also be considered in order: the rate of innovation in the industry, the degree of the strategic importance of technology, the need for access to technology, and the ability to divide assets. The final ranking results showed that turnkey contracts, stock ownership, and outsourcing are the top three options in order of priority.

Marznaki et al. [29] presented a study that delved into the dynamism of the variables impacting technology transfer capacities by following a system dynamics approach, examining similar studies, and interviewing experts in the downstream petrochemical industries in the polymer pipe and fittings domain. Then, causal loop diagrams are delineated and the causal relationships among variables are examined, and the VENSIM software is used for analyzing the causal loops.

2. 4. Research Gap Currently, 22 companies are operating in Iran that produce automotive batteries, of which 8 companies produce batteries and the rest are assemblers. The actual capacity of these companies in automotive battery production is about 15 million units and is increasing to about 18 million units. Considering the traffic volume of about 22 million vehicles in the country and the annual increase of about one million units and taking into account the average life of each battery of about 20 months, we need about 12 million batteries annually. In addition to all the above factors (the presence of excess capacity in relation to the country's needs), seasonal sales of batteries, the impossibility of battery maintenance, and factors (e.g., sanctions), the only way for companies to stay in the market is to switch to world-class manufacturing.

One of the most important tools for companies to globalize is the process of technology transfer, which can not only produce new products but also provide higher quality and lower prices to enter competitive markets (at home and abroad) and lead to:

- Improvement of the standard of living in developing countries, restructuring their industries, creating jobs, and improving their economies;

- Laying the foundation for eliminating the technological gap with the developed countries and reaching sustainable development by improving the level of technology in a country.

As can be seen in the literature review, the world-class manufacturing and technology transfer issue is one of the most important scientific challenges in Iran. Therefore, in this study, we intend to provide a new framework based on the best-worst, gray MOORA (G-MOORA) and Multi-Objective Optimization (MOO) to explore and select technology transfer methods in the automotive battery industry aiming to enter global markets.

3. FRAMEWORK OF THE PROPOSED APPROACH

In this section, the basic definitions related to the proposed decision-making approach are summarized. A mixed-integer bi-objective programming model is also being formulated. Based on these main concepts, a new approach consisting of fuzzy MCDM and mathematical optimization is proposed.

3. 1. Best-Worst Method The BWM is one of the powerful methods in solving MCDM problems used to obtain the weights of selected options and criteria [28, 30]. This method compensates the weaknesses of methods for based on couple comparison (e.g., AHP and ANP) and incompatibility. Also, it significantly decreases the number of couple comparisons, just by doing reference comparisons. In recent years, researchers in various fields used the BWM to define weights and rank options [31-33]. Generally, the BWM consists of the following steps:

Step 1: Establishing a decision benchmark system: The decision benchmark system composes of a set of criteria identified by assessing the comments and views of experts and calculated by $\{c_1,c_2,\ldots,c_n\}$. The values of the decision criteria can reflect the performance of various alternatives.

Step 2: Determining the best/worst from the primary criteria as well as the sub-criteria: Consistent with the decision criteria system, the best/worst criteria should be identified by the decision-makers. The best criterion is designated by the symbol c_B and the worst criterion is denominated by the symbol w_B.

Step 3: Conducting reference comparisons for the best criterion: In this step, the best criterion is prioritized over other criteria by using numbers between 1 and 9. The results of this vector are shown as follows:

$$A_B=(a_{B1},a_{B2},\ \ldots,\ a_{Bn}) \quad (1)$$

where the a_{Bj} denotes the priority of the best-selected criterion of B over each j criterion. It is clear/obvious that $a_{BB}=1$

Step 4: Performing reference comparisons for the worst criteria: Similarly, via utilizing numbers between 1&9, the priority of all criteria over the worst selected criterion is calculated. The findings of this vector are demonstrated as follows:

$$A_w=(a_{1W},a_{2W},\ \ldots,\ a_{nW})^T \quad (2)$$

where a_{jW} denotes the priority of each j criterion over the worst selected W criterion. It is clear/obvious that $a_{WW}=1$.

Step 5: Determining the optimal eights $(W_1,W_2,\ldots,W_n)$. In this step, to achieve the optimal weights of the criteria, the maximum absolute difference $\{|w_B\text{-}a_{Bj}w_j|, |w_j\text{-}a_{jW}w_W|\}$ for all j must be minimized. It is formulated as the below-mentioned optimization problem.

$$\min \max_j \{|w_B\text{-}a_{Bj}w_j|, |w_j\text{-}a_{jW}w_W|\} \min \xi^L$$
$$\sum_j w_j=1 \quad (3)$$
$$w_j\geq 0, \text{ for all } j$$

Problem (3) can be converted to the following model:

$$\min \xi^L$$
$$\text{s.t.}$$
$$|w_B\text{-}a_{Bj}w_j|\leq\xi^L, \text{ for all } j$$
$$|w_j\text{-}a_{jW}w_W|\leq\xi^L, \text{ for all } j \quad (4)$$
$$\sum_j w_j=1$$
$$w_j\geq 0, \text{ for all } j$$

A 4-line model and the panswer is unique. Therefore, by solving this model, optimal weights $(w_1,w_2,\ldots,w_n)$, and quantities ξ^{L*} are obtained. Regarding the above model, the close to zero values of ξ^{L*} reveal a high level of compatibility [34].

3. 2. Gray MOORA Method A gray system theory is one of the most effective methods used to solve indeterminate problems in terms of discrete and incomplete information. As compared to other MADM methods, the MOORA method is very easy, simple, and comprehendible to use in any decision-making environment. These methods require less computing time because they require a minimum number of mathematical steps as well as being useful to the decision-makers who have less command in mathematics. For this reason, the MOORA method is very robust for different decision-making problems [36]. In general, a gray system theory is an algorithm that can analyze the uncertain relationships of members of a system with a reference member and also can be used in multi-criteria groups [35].

A gray number ($\otimes G$) is displayed as an $\otimes G = [\underline{a}, \overline{a}]$ an interval, in such a manner where a & a of real numbers are members of the (R) group, and possess the ability to have unlimited values.

If $\otimes G_1 = [\underline{a_1}, \overline{a_1}]$ & $\otimes G_2 = [\underline{a_2}, \overline{a_2}]$ are two gray numbers, henceforth the lgebraic calculations on $\otimes G_1$ & $\otimes G_2$ can be displayed as follows [37]:

$$\otimes G_1 + \otimes G_2 = [\underline{a_1} + \underline{a_2}, \overline{a_1} + \overline{a_2}] \quad (5)$$

$$-\otimes G_2 = [-\overline{a_2}, -\underline{a_2}] \quad (6)$$

$$\otimes G_1 - \otimes G_2 = \otimes G_1 + (-\otimes G_2) = [\underline{a_1} - \overline{a_2}, \overline{a_1} - \underline{a_2}] \quad (7)$$

$$\otimes G_1 \times \otimes G_2 = \begin{bmatrix} \min\left(\underline{a_1}\underline{a_2}, \underline{a_1}\overline{a_2}, \overline{a_1}\underline{a_2}, \overline{a_1}\overline{a_2}\right), \\ \max\left(\underline{a_1}\underline{a_2}, \underline{a_1}\overline{a_2}, \overline{a_1}\underline{a_2}, \overline{a_1}\overline{a_2}\right) \end{bmatrix} \quad (8)$$

$$\otimes G_2^{-1} = \left[\frac{1}{\overline{a_2}}, \frac{1}{\underline{a_2}}\right] \quad (9)$$

$$\otimes G_1 \div \otimes G_2 = [\underline{a_1}, \overline{a_1}] \times \left[\frac{1}{\overline{a_2}}, \frac{1}{\underline{a_2}}\right] = \left[\min\left(\frac{\overline{a_1}}{\overline{a_2}}, \frac{\overline{a_1}}{\underline{a_2}}, \frac{\underline{a_1}}{\overline{a_2}}, \frac{\underline{a_1}}{\underline{a_2}}\right), \max\left(\frac{\overline{a_1}}{\overline{a_2}}, \frac{\overline{a_1}}{\underline{a_2}}, \frac{\underline{a_1}}{\overline{a_2}}, \frac{\underline{a_1}}{\underline{a_2}}\right)\right] \quad (10)$$

$$k.\otimes G = [k\underline{a}, k\overline{a}],\ k>0 \quad (11)$$

The MOORA method is one of the multi-criteria decision-making methods developed by Brauers and Zavadskas [38]. In 2010, they made this method more stable and added the full multiplication form to it [39].

The MOORA method consists of two parts: the ratio system and the reference point approach to evaluate the options. In this study, gray numbers are integrated into the MOORA method and Table 1 is used as a Verbal scale evaluation of options based on the G-MOORA method.

Step 1: Forming the initial gray decision matrix X according to Equation (12) by using the verbal scale listed in Table 1.

$$X = \begin{bmatrix} [x_{11}, u_{11}] & [x_{12}, u_{12}] & \cdots & [x_{1n}, u_{1n}] \\ [x_{21}, u_{21}] & [x_{22}, u_{22}] & \cdots & [x_{2n}, u_{2n}] \\ \vdots & \vdots & \ddots & \vdots \\ [x_{m1}, u_{m1}] & [x_{m2}, u_{m2}] & \cdots & [x_{mn}, u_{mn}] \end{bmatrix}; \quad (12)$$

$i=1, \ldots, m; j=1, \ldots, n$

So that m represents the total number of options and n is equal to the total number of criteria. Each element $[x_{ij}, u_{ij}]$ of X that is consisted of two components x_{ij} as the lower limit and u_{mn} as the upper limit, indicates the importance of the ith option to the jth criterion.

TABLE 1. Verbal scale evaluation of options based on the G-MOORA method

Verbal expressions	Gray numbers
Very poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium poor (MP)	[3, 4]
Fair (F)	[4, 5]
Medium important (MI)	[5, 6]
Important (I)	[6, 9]
Very important (VI)	[9, 10]

Step 2: Obtaining the normal gray decision matrix $\bar{X}$ according to Equation (13). The elements of the matrix X are converted to scaleless numbers in the range of zero and one, using Equations (14) and (15).

$$\bar{X} = \begin{bmatrix} [\bar{x}_{11}, \bar{u}_{11}] & [\bar{x}_{12}, \bar{u}_{12}] & \cdots & [\bar{x}_{1n}, \bar{u}_{1n}] \\ [\bar{x}_{21}, \bar{u}_{21}] & [\bar{x}_{22}, \bar{u}_{22}] & \cdots & [\bar{x}_{2n}, \bar{u}_{2n}] \\ \vdots & \vdots & \ddots & \vdots \\ [\bar{x}_{m1}, \bar{u}_{m1}] & [\bar{x}_{m2}, \bar{u}_{m2}] & \cdots & [\bar{x}_{mn}, \bar{u}_{mn}] \end{bmatrix}; \quad (13)$$

$i=1, \ldots, m; j=1, \ldots, n$

$$[\bar{x}]_{m\times n} = \frac{2x_{ij}}{\left(\sum_{i=1}^{m} x_{ij} + \sum_{i=1}^{m} u_{ij}\right)} \quad (14)$$

$$[\bar{u}]_{m\times n} = \frac{2u_{ij}}{\left(\sum_{i=1}^{m} x_{ij} + \sum_{i=1}^{m} u_{ij}\right)} \quad (15)$$

Step 3: Calculating the weighted normal gray decision matrix $\hat{X}$ according to Equation (16). The weights obtained by the best-worst method are multiplied by each element of the normal gray decision matrix $\bar{X}$ according to Equations (17) and (18). So, the weighted normal gray decision matrix results as follows:

$$\hat{X} = \begin{bmatrix} [\hat{x}_{11}, \hat{u}_{11}] & [\hat{x}_{12}, \hat{u}_{12}] & \cdots & [\hat{x}_{1n}, \hat{u}_{1n}] \\ [\hat{x}_{21}, \hat{u}_{21}] & [\hat{x}_{22}, \hat{u}_{22}] & \cdots & [\hat{x}_{2n}, \hat{u}_{2n}] \\ \vdots & \vdots & \ddots & \vdots \\ [\hat{x}_{m1}, \hat{u}_{m1}] & [\hat{x}_{m2}, \hat{u}_{m2}] & \cdots & [\hat{x}_{mn}, \hat{u}_{mn}] \end{bmatrix}; \quad (16)$$

$i=1, \ldots, m; j=1, \ldots, n$

$$\hat{x}_{ij} = \bar{x}_{ij} \times w_j \quad (17)$$

$$\hat{u}_{ij} = \bar{u}_{ij} \times w_j \quad (18)$$

where w_j is the defuzzied weight of the jth criterion through the best-worst method.

Step 4: Calculating the normalized performance values by subtraction of the cost criteria (when the desired value of criteria is the maximum value) from the utility criteria (when the desired value of criteria is the minimum) as stated in Equation (19).

$$\hat{y}_i = \sum_{j=1}^{g} \hat{v}_{ij} - \sum_{j=g+1}^{n} \hat{v}_{ij} \quad (19)$$

where $\sum_{j=1}^{g} \hat{v}_{ij}$ is the sum of the total ascending criteria for $(1,\ldots,g)$ and $\sum_{j=g+1}^{n} \hat{v}_{ij}$ is the sum of the total descending criteria for $(g+1,\ldots,n)$. g is the number of utility criteria and n-g is the number of cost criteria.

Step 5: Attaining the best non-gray performance (BNGP) of the $\hat{y}_i$ characteristic by:

$$BNGP_i(\hat{y}_i) = \frac{\hat{x}_{ij}+\hat{u}_{ij}}{2} \quad (20)$$

Finally, the options are ranked according to the value of $\text{BNGP}_\text{i}(\hat{y}_\text{i})$, so that the option with a high value of $\text{BNGP}_\text{i}(\hat{y}_\text{i})$ is optimal and ranks first.

3. 3. Proposed Mathematical Model In this section, a two-objective mathematical model is proposed to allocate technology transfer methods considering cost and reliability objectives. Generally, implementing any of these methods is costly for the company. Therefore, only a part of them can be executed due to budget constraints. Reducing costs and increasing reliability are two of the main goals of this problem. As with other mathematical models, modeling the problem requires some hypotheses. The assumptions of this study are as follows:

- The number of technology transfer methods is specified and limited.
- The number of battery manufacturers is specified and limited.
- The cost of implementation and the degree of reliability of each method and the total budget for the methods are different and specific amounts.
- The order of implementation of methods is not desired.
- Several methods can be chosen for each manufacturer.
- The values of model parameters are definite.

Each method of the model has an importance coefficient which is a specific number between zero and one and is resulted in the gray MOORA method.

Indices:

$i=\{1, ..., m\}$	i technology transfer methods
$j=\{1, ..., n\}$	j battery producer

3. 3. 1. Mathematical Model

$$\min Z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} W_{ij} x_{ij} \quad (21)$$

$$\max Z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} P_i L_{ij} x_{ij} \quad (22)$$

s.t.

$$\sum_{i=1}^{n} x_{ij} \le D_j \qquad \forall j \quad (23)$$

$$\sum_{i=1}^{n} x_{ij} \ge 1 \qquad \forall j \quad (24)$$

$$x_{ij} \in \{0,1\} \qquad \forall i,j \quad (25)$$

The proposed model has two objectives under uncertain conditions (elucidated hereinafter). Objective function (21) minimizes the costs of implementing technology transfer methods. Objective function (22) maximizes the reliability of implementing technology transfer methods in manufacturing plants. The model also has three constraints. Constraint (23) guarantees that the number of methods assigned to each manufacturer does not exceed the limit. Constraint (24) ensures that at least one method is assigned to each manufacturer. Finally, Constraint (25) also determines the type of variables used in the problem.

3. 3. 2. Epsilon-constraint Method In multi-objective programming, evaluated problems are concerned with mathematical optimization involving more than one objective function, in which the objectives need to be optimized simultaneously or sequentially. In particular, in the literature, the Pareto or efficient frontier function has been used to illustrate the trade-offs among conflicts between multiple objectives. Various techniques concerning exact and heuristic procedures have been proposed to analyze the trade-offs among these conflicting objectives, one of which is ε-constraint programming. The advantages of ε-constraint programming include being able to obtain exact Pareto solutions, instead of approximated solutions, using a series of single-objective subproblems, in which all but one objective is transformed into constraints [40]. The formula of the ε-constraint method is as follows, wherein the first objective is introduced as the primary objective.

$$\min f_1(X) \quad (26)$$

$$x \in X \quad (27)$$

$$f_2(X) \le \varepsilon_2 \qquad f_n(X) \le \varepsilon_n \quad (28)$$

In the proposed query of this study, the initial objective is considered the primary objective, and other objectives are viewed as secondary objectives. Hence, according to the ε-constraint method, the new formula of the proposed model culminates in the following optimization problem.

$$\min \text{Obj}_1 \quad (29)$$

$$\text{Obj}_2 \ge \varepsilon_2 \quad (30)$$

Equation (9) represents the main objective function of the problem, and Equation (10) adds to the problem's set of constraints

4. CASE STUDY

Today, the battery industry has become one of the most important industries in the world, and one of the reasons is the use of portable electrical devices. On the other hand, the growth of the automotive industry has led to the growth of battery manufacturing. The studied population of this research consists of experts of battery companies, named 1. Saba Battery, 2. Borna Battery, 3. Pasarghad Battery, 4. Dorna Battery, 5. Sepahan Battery, 6. Azar Battery, 7. Niru Gostaran Khorasan Battery, and Vaya Battery. There are many indicators and criteria for evaluating technology transfer methods. The classification presented in this research has put together the indicators that were conceptually closer to the problem. This can help managers to have a more coherent view of the effective indicators while choosing the appropriate collaboration method. To this end, in this step, a list of relevant criteria for evaluating technology transfer methods is identified according to a review and revision of previous research and face-to-face interviews with experts, which is presented in Figure 1.

Technology transfer methods are defined as a set of activities in which the technology required by the applicant is provided for him, in exchange for the supplier's satisfaction. Technology transfer methods vary depending on the type of technology and transfer conditions and in some cases are very diverse. The transfer methods evaluated in this study are described in Table 2.

5. RESULTS

In this section, the results of using the proposed.

5. 1. Defining the Weights of Criteria: Best-Worst Method

In this section, the relative importance of the criteria presented in Figure 1 was obtained using the best-worst method. After defining criteria and sub-criteria, a committee of experts compared criteria and sub-criteria through numbers between 1 to 9.

The best and worst criteria for evaluating technology transfer methods were selected from all the main criteria, through a collective and mutual agreement. Accordingly, managerial factors and technical factors were selected as the best and the worst criteria, respectively. Then, the experts prioritized the best criterion over other criteria (BO) and also the priority of other criteria over the worst criterion (OW).

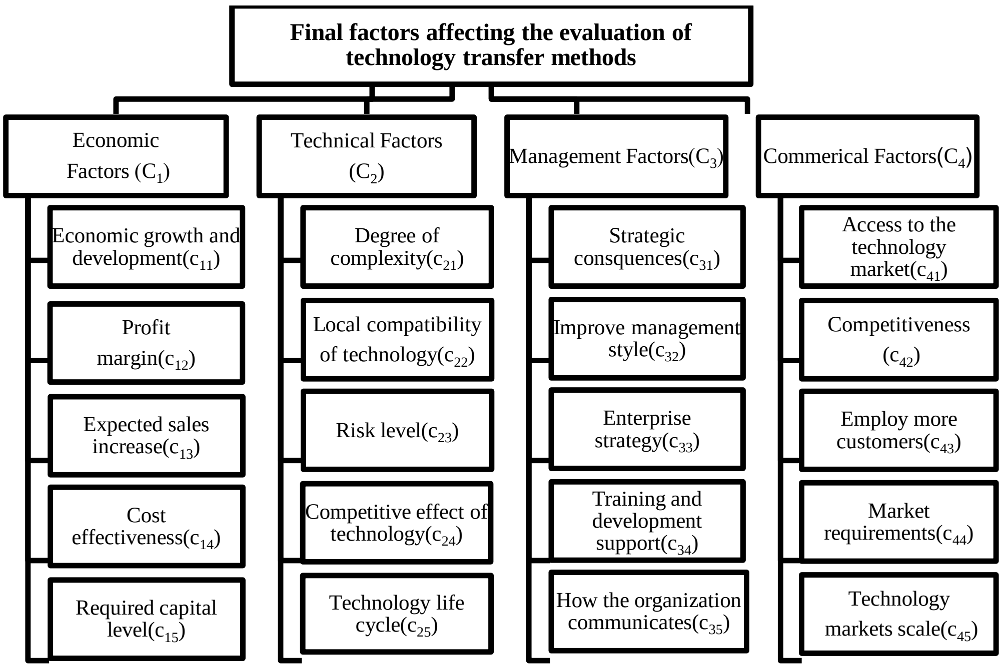

Figure 1. Factors influencing in evaluate the of technology methods in the automotive battery industry

Hence the vectors of best-other criteria and other criteria-worst obtained are presented in Table 3.

After obtaining the priorities of the main criteria, the relative weights were obtained using Model (4), which is presented in Table 4. According to the following table, the comparisons are very consistent because its value is 0.036 which is close to zero.

Similarly, pairwise comparisons of the sub-criteria of the main criteria are presented. Finally, the final weights of criteria affecting the evaluation of technology transfer methods in battery companies are presented in Table 5. As can be seen from the results, the criteria of management style improvement, the business strategy, cost-effectiveness, how to communicate with the organization, and competitiveness are the five primary criteria affecting the evaluation of technology transfer methods in battery companies.

5. 2. Evaluation of Technology Transfer Methods: Gray MOORA Method

After obtaining optimal weights of criteria, in the next step, the technology transfer methods are evaluated using the proposed gray MOORA method. All the experts were asked individually to evaluate the options based on criteria, using a verbal scale presented in Table 1. After obtaining the priority level of each expert, in the next step, the average of the degrees is calculated and the average gray decision matrix is obtained according to Table 6.

TABLE 2. Methods of technology transferrin auto-battery manufacturing industry

Technology Transfer Methods	Row
Buy royalties (A1)	1
Education and training (A2)	2
Foreign Direct Investment (A3)	3
Reverse Engineering (A4)	4
Recruitment and exchange of manpower (A5)	5
Franchise Method (A6)	6
Licensing (A7)	7
Joint R&D(A8)	8
External supply (A9)	9
Joint Venture(A10)	10

TABLE 3. Paired comparison between principal components

BO	Economic Factors (C1)	Technical Factors (C2)	Management Factors (C3)	Commercial Factors (C4)
Management Factors (C3)	2	8	1	4
OW	**Technical Factors (C2)**			
Economic Factors(C1)	3			
Technical Factors(C2)	1			
Management Factors(C3)	8			
Commercial Factors(C4)	2			

TABLE 4. Relative weight of the main dimension in evaluating technology transfer methods

Criterion	Relative normalized weight	ξ^{L^*}
Economic Factors (C1)	0.250	0.036
Technical Factors (C2)	0.071	
Management Factors(C3)	0.536	
Commercial Factors(C4)	0.143	

TABLE 5. Final weight of effective indicators in evaluating technology transfer methods

Final weight	Relative weight	Sub-criteria	Criterion
0.051	0.204	Economic growth and development (c11)	Economic factors (0.250)
0.042	0.166	Profit margin (c12)	
0.031	0.125	Expected sales increase (c13)	
0.113	0.453	Cost effectiveness (c14)	
0.013	0.053	Required capital level (c15)	
0.016	0.219	Degree of complexity (c21)	Technical factors (0.071)
0.012	0.164	Local compatibility of technology (c22)	
0.031	0.438	Risk level (c23)	
0.004	0.055	Competitive effect of technology (c24)	
0.009	0.123	Technology life cycle (c25)	
0.056	0.105	Strategic consequences (c31)	Management factors (0.536)
0.254	0.474	Improve management style (c32)	
0.113	0.211	Enterprise strategy (c33)	
0.028	0.053	Training and development support (c34)	
0.085	0.158	How the organization communicates (c35)	
0.016	0.111	Access to the technology market (c41)	Commercial factors (0.143)
0.032	0.222	Employ more customers (c43)	
0.008	0.056	Technology markets scale (c45)	

TABLE 6. Initial decision matrix gray option-criterion

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25
A1	[3.21, 6.7]	[3.5, 4.83]	[4.42, 5.92]	[2.75, 4.25]	[4.17, 5.83]	[3.67, 5.25]	[2.92, 4.42]	[2.5, 3.83]	[4.25, 5.83]	[3.67, 5]
A2	[4.83, 7.24]	[3.75, 5.25]	[3.17, 4.75]	[1.92, 3.33]	[3.08, 4.67]	[3.58, 4.75]	[4.17, 5.5]	[4.25, 5.83]	[4.75, 6]	[4.58, 6]
A3	[4.2, 7.61]	[3.92, 5.25]	[3.83, 5.33]	[4.67, 6.25]	[2.92, 4.17]	[4, 5.17]	[4.08, 5.33]	[2.58, 3.83]	[2.25, 3.92]	[4.58, 5.75]
A4	[3.71, 5.9]	[4.33, 5.83]	[3, 4.33]	[2.58, 4]	[4.08, 5.08]	[3.25, 4.58]	[2.83, 4.17]	[3.33, 4.75]	[2.75, 4.08]	[3.5, 4.83]
A5	[3.9, 7.27]	[4.33, 5.92]	[3.17, 4.33]	[4, 5.17]	[4.92, 6.67]	[4.17, 5.58]	[4.67, 6.08]	[2.75, 4.33]	[2.83, 4.25]	[3.17, 4.67]
A6	[4.18, 5.78]	[6.67, 8]	[4.08, 5.67]	[4.42, 6.17]	[4.17, 5.58]	[4.17, 5.83]	[4, 5.17]	[4.83, 6]	[3.33, 4.67]	[3.83, 5.33]
A7	[2.76, 5.68]	[4.17, 5.83]	[3.17, 4.67]	[3.92, 5.25]	[4.17, 5.33]	[4.42, 5.58]	[4.67, 6.25]	[5, 6.25]	[4.17, 5.25]	[3.42, 4.58]
A8	[3.66, 6.56]	[5.33, 6.5]	[3.5, 5.17]	[3.42, 5.08]	[4, 5.58]	[4, 5.33]	[3.83, 5.5]	[5.08, 6.75]	[4, 5.67]	[3.58, 4.92]
A9	[3.05, 7.05]	[4.33, 5.75]	[3.75, 5.08]	[6, 7]	[5.33, 6.5]	[4, 5.58]	[4.83, 6.42]	[3.25, 4.75]	[4.08, 5.83]	[3.83, 5.17]
A10	[3.86, 6.39]	[4.44, 6.86]	[3.05, 6.59]	[4.44, 5.6]	[4.55, 7.47]	[3.98, 5.6]	[4.34, 7.16]	[4.49, 5.93]	[4.09, 6.06]	[4.39, 7.56]
	C31	**C32**	**C33**	**C34**	**C35**	**C41**	**C42**	**C43**	**C44**	**C45**
A1	[3.5, 4.92]	[3.83, 5.33]	[3.67, 5.33]	[4.58, 6.33]	[5.17, 6.42]	[3.58, 4.92]	[2.33, 3.58]	[4.42, 5.83]	[3.33, 4.67]	[4.5, 5.83]
A2	[4.25, 5.5]	[4.08, 5.67]	[2.75, 4.33]	[3.75, 4.92]	[3, 4.25]	[4, 5.42]	[2.75, 4.25]	[3.67, 5.17]	[4.42, 5.75]	[5, 6.67]
A3	[3.58, 5.25]	[3.83, 5.08]	[4.5, 6.08]	[4.08, 5.42]	[4, 5.5]	[4.58, 6.17]	[4.67, 6.17]	[2.75, 4]	[4.25, 5.58]	[4.75, 6.5]
A4	[4.5, 6]	[4.33, 5.58]	[3.17, 4.33]	[4.08, 5.67]	[3.42, 4.67]	[5.25, 6.67]	[2.33, 3.5]	[3.75, 5.33]	[5.67, 6.83]	[5.5, 7.25]
A5	[4, 5.17]	[3.92, 5.33]	[3.92, 5.5]	[4.58, 6]	[3.75, 5.25]	[4, 5.17]	[3.33, 4.75]	[4, 5.08]	[3.25, 4.83]	[3.33, 4.75]
A6	[3.75, 5.25]	[4.5, 6.42]	[4.25, 5.58]	[4.33, 5.75]	[4.17, 6]	[4.58, 6.25]	[3.75, 5.25]	[3.75, 5.25]	[2.67, 4.25]	[3.33, 4.5]
A7	[4.92, 6.42]	[3.42, 4.58]	[4.25, 5.5]	[4.33, 6]	[2.42, 4]	[3.5, 5.08]	[5.25, 6.83]	[3.83, 5]	[4.17, 5.5]	[4.83, 5.92]
A8	[3.83, 5.17]	[3.25, 4.92]	[5.5, 6.5]	[4.42, 5.83]	[5.58, 6.92]	[4.67, 6.08]	[3.83, 5.5]	[3.33, 5]	[2.58, 3.67]	[2.33, 3.67]
A9	[4.42, 5.58]	[3.75, 5]	[4.58, 5.92]	[5.17, 6.83]	[3.42, 4.92]	[4, 5.5]	[3.75, 5.08]	[4.08, 5.33]	[3.17, 4.67]	[5.42, 7.25]
A10	[3.75, 6.9]	[3.93, 7.3]	[4.36, 5.8]	[3.86, 7.21]	[4.43, 7.08]	[3.7, 7.56]	[3.66, 5.97]	[3.63, 5.54]	[4.11, 6.26]	[3.64, 6.39]

To ensure consistency of the evaluation criteria, the initial gray decision matrix should be converted to a comparable scale. Hence the normal gray decision matrix is obtained using Equations (13) – (15) as shown in Table 7.

Then, the weights of each criterion are multiplied in the normalized gray decision matrix based on Equations (16) - (18), and the weighted gray matrix is created as shown in Table 8.

Finally, the normalized performance values are obtained by subtracting the cost criteria from the utility criteria, and also the best non-gray performance (i.e., the characteristic $BNGP_i(\hat{y}_i)$) is calculated (using Equations (12) (19) and (20), respectively), as shown in Table 9.

Studied input parameters are shown in Tables 10-12. Generally, the input Information used in the mathematical model can be divided into these three sections:

- Information such as the prioritization of appropriate methods of technology transfer in the automotive battery industry, which was reviewed and specified in the first part of the article;
- Information such as the cost of implementing different methods of technology transfer in companies (Table 10) and the number of methods allowed for allocation to manufacturers (Table 12). This part was collected from automotive battery companies that have generally carried out the technology transfer process in recent years; and
- Information such as the reliability of the implementation of each method of technology transfer in the companies obtained by creating a questionnaire and asking for expert opinions (Table 11).

5. 3. Optimal Allocation of Methods: Solve The Mathematical Model

In this section, a set of technology transfer methods is assigned to each manufacturer by solving a mathematical programming model. It should be noted that the set of manufacturers consists of 1. Saba Battery, 2. Borna Battery, 3. Pasarghad Battery, 4. Dorna Battery, 5. Sepahan Battery, 6. Azar Battery, 7. Niru Gostaran Khorasan Battery, and Vaya Battery. To solve the proposed mathematical model, the ε-constraint method is used in the GAMS software environment version 24.3 and CPLEX solver. In the following, the results of how the technology transfer methods are assigned to each manufacturer after solving the problem are reported.

TABLE 7. Normal gray decision matrix option-criteria

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25
A1	[0.06, 0.13]	[0.07, 0.09]	[0.1, 0.14]	[0.06, 0.09]	[0.08, 0.12]	[0.08, 0.11]	[0.06, 0.09]	[0.06, 0.08]	[0.1, 0.13]	[0.08, 0.11]
A2	[0.09, 0.14]	[0.07, 0.1]	[0.07, 0.11]	[0.04, 0.07]	[0.06, 0.1]	[0.08, 0.1]	[0.09, 0.11]	[0.09, 0.13]	[0.11, 0.14]	[0.1, 0.13]
A3	[0.08, 0.15]	[0.07, 0.1]	[0.09, 0.12]	[0.1, 0.14]	[0.06, 0.08]	[0.09, 0.11]	[0.08, 0.11]	[0.06, 0.08]	[0.05, 0.09]	[0.1, 0.12]
A4	[0.07, 0.11]	[0.08, 0.11]	[0.07, 0.1]	[0.06, 0.09]	[0.08, 0.1]	[0.07, 0.1]	[0.06, 0.09]	[0.07, 0.11]	[0.06, 0.09]	[0.08, 0.1]
A5	[0.08, 0.14]	[0.08, 0.11]	[0.07, 0.1]	[0.09, 0.11]	[0.1, 0.14]	[0.09, 0.12]	[0.1, 0.13]	[0.06, 0.1]	[0.06, 0.1]	[0.07, 0.1]
A6	[0.08, 0.11]	[0.13, 0.15]	[0.09, 0.13]	[0.1, 0.14]	[0.08, 0.11]	[0.09, 0.13]	[0.08, 0.11]	[0.11, 0.13]	[0.08, 0.11]	[0.08, 0.12]
A7	[0.05, 0.11]	[0.08, 0.11]	[0.07, 0.11]	[0.09, 0.12]	[0.08, 0.11]	[0.1, 0.12]	[0.1, 0.13]	[0.11, 0.14]	[0.09, 0.12]	[0.07, 0.1]
A8	[0.07, 0.13]	[0.1, 0.12]	[0.08, 0.12]	[0.08, 0.11]	[0.08, 0.11]	[0.09, 0.12]	[0.08, 0.11]	[0.11, 0.15]	[0.09, 0.13]	[0.08, 0.11]
A9	[0.06, 0.14]	[0.08, 0.11]	[0.09, 0.12]	[0.13, 0.16]	[0.11, 0.13]	[0.09, 0.12]	[0.1, 0.13]	[0.07, 0.11]	[0.09, 0.13]	[0.08, 0.11]
A10	[0.07, 0.12]	[0.08, 0.13]	[0.07, 0.15]	[0.1, 0.12]	[0.09, 0.15]	[0.09, 0.12]	[0.09, 0.15]	[0.1, 0.13]	[0.09, 0.14]	[0.1, 0.16]
	C31	**C32**	**C33**	**C34**	**C35**	**C41**	**C42**	**C43**	**C44**	**C45**
A1	[0.07, 0.1]	[0.08, 0.11]	[0.08, 0.11]	[0.09, 0.12]	[0.11, 0.14]	[0.07, 0.1]	[0.05, 0.08]	[0.1, 0.13]	[0.07, 0.1]	[0.09, 0.12]
A2	[0.09, 0.11]	[0.09, 0.12]	[0.06, 0.09]	[0.07, 0.1]	[0.06, 0.09]	[0.08, 0.11]	[0.06, 0.1]	[0.08, 0.12]	[0.1, 0.13]	[0.1, 0.13]
A3	[0.07, 0.11]	[0.08, 0.11]	[0.09, 0.13]	[0.08, 0.11]	[0.08, 0.12]	[0.09, 0.12]	[0.11, 0.14]	[0.06, 0.09]	[0.09, 0.12]	[0.09, 0.13]
A4	[0.09, 0.12]	[0.09, 0.12]	[0.07, 0.09]	[0.08, 0.11]	[0.07, 0.1]	[0.1, 0.13]	[0.05, 0.08]	[0.08, 0.12]	[0.13, 0.15]	[0.11, 0.14]
A5	[0.08, 0.11]	[0.08, 0.11]	[0.08, 0.11]	[0.09, 0.12]	[0.08, 0.11]	[0.08, 0.1]	[0.08, 0.11]	[0.09, 0.11]	[0.07, 0.11]	[0.07, 0.09]
A6	[0.08, 0.11]	[0.1, 0.14]	[0.09, 0.12]	[0.08, 0.11]	[0.09, 0.13]	[0.09, 0.12]	[0.09, 0.12]	[0.08, 0.12]	[0.06, 0.09]	[0.07, 0.09]
A7	[0.1, 0.13]	[0.07, 0.1]	[0.09, 0.11]	[0.08, 0.12]	[0.05, 0.08]	[0.07, 0.1]	[0.12, 0.16]	[0.09, 0.11]	[0.09, 0.12]	[0.1, 0.12]
A8	[0.08, 0.11]	[0.07, 0.1]	[0.11, 0.14]	[0.09, 0.11]	[0.12, 0.15]	[0.09, 0.12]	[0.09, 0.13]	[0.08, 0.11]	[0.06, 0.08]	[0.05, 0.07]
A9	[0.09, 0.12]	[0.08, 0.11]	[0.1, 0.12]	[0.1, 0.13]	[0.07, 0.1]	[0.08, 0.11]	[0.09, 0.12]	[0.09, 0.12]	[0.07, 0.1]	[0.11, 0.14]
A10	[0.08, 0.14]	[0.08, 0.16]	[0.09, 0.12]	[0.07, 0.14]	[0.09, 0.15]	[0.07, 0.15]	[0.08, 0.14]	[0.08, 0.12]	[0.09, 0.14]	[0.07, 0.13]

TABLE 8. Normalized gray decision weight matrix option-criteria

	C11	C12	C13	C14	C15	C21	C22	C23	C24	C25
A1	[0.003, 0.007]	[0.003, 0.004]	[0.003, 0.004]	[0.007, 0.011]	[0.001, 0.002]	[0.001, 0.002]	[0.001, 0.001]	[0.002, 0.003]	[0, 0.001]	[0.001, 0.001]
A2	[0.005, 0.007]	[0.003, 0.004]	[0.002, 0.003]	[0.005, 0.008]	[0.001, 0.001]	[0.001, 0.002]	[0.001, 0.001]	[0.003, 0.004]	[0, 0.001]	[0.001, 0.001]
A3	[0.004, 0.007]	[0.003, 0.004]	[0.003, 0.004]	[0.012, 0.016]	[0.001, 0.001]	[0.001, 0.002]	[0.001, 0.001]	[0.002, 0.003]	[0, 0]	[0.001, 0.001]
A4	[0.004, 0.006]	[0.003, 0.005]	[0.002, 0.003]	[0.006, 0.01]	[0.001, 0.001]	[0.001, 0.002]	[0.001, 0.001]	[0.002, 0.003]	[0, 0]	[0.001, 0.001]
A5	[0.004, 0.007]	[0.003, 0.005]	[0.002, 0.003]	[0.01, 0.013]	[0.001, 0.002]	[0.001, 0.002]	[0.001, 0.002]	[0.002, 0.003]	[0, 0]	[0.001, 0.001]
A6	[0.004, 0.006]	[0.005, 0.006]	[0.003, 0.004]	[0.011, 0.015]	[0.001, 0.001]	[0.001, 0.002]	[0.001, 0.001]	[0.003, 0.004]	[0, 0]	[0.001, 0.001]
A7	[0.003, 0.006]	[0.003, 0.005]	[0.002, 0.003]	[0.01, 0.013]	[0.001, 0.001]	[0.002, 0.002]	[0.001, 0.002]	[0.003, 0.004]	[0, 0]	[0.001, 0.001]
A8	[0.004, 0.006]	[0.004, 0.005]	[0.002, 0.004]	[0.009, 0.013]	[0.001, 0.001]	[0.001, 0.002]	[0.001, 0.001]	[0.003, 0.005]	[0, 0.001]	[0.001, 0.001]
A9	[0.003, 0.007]	[0.003, 0.005]	[0.003, 0.004]	[0.015, 0.018]	[0.001, 0.002]	[0.001, 0.002]	[0.001, 0.002]	[0.002, 0.003]	[0, 0.001]	[0.001, 0.001]
A10	[0.004, 0.006]	[0.004, 0.006]	[0.002, 0.005]	[0.011, 0.014]	[0.001, 0.002]	[0.001, 0.002]	[0.001, 0.002]	[0.003, 0.004]	[0, 0.001]	[0.001, 0.001]

	C31	C32	C33	C34	C35	C41	C42	C43	C44	C45
A1	[0.004, 0.006]	[0.021, 0.029]	[0.009, 0.013]	[0.002, 0.003]	[0.009, 0.012]	[0.001, 0.002]	[0.004, 0.006]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]
A2	[0.005, 0.006]	[0.022, 0.031]	[0.006, 0.01]	[0.002, 0.003]	[0.005, 0.008]	[0.001, 0.002]	[0.005, 0.007]	[0.003, 0.004]	[0.002, 0.002]	[0.001, 0.001]
A3	[0.004, 0.006]	[0.021, 0.027]	[0.011, 0.014]	[0.002, 0.003]	[0.007, 0.01]	[0.001, 0.002]	[0.008, 0.01]	[0.002, 0.003]	[0.002, 0.002]	[0.001, 0.001]
A4	[0.005, 0.007]	[0.023, 0.03]	[0.007, 0.01]	[0.002, 0.003]	[0.006, 0.008]	[0.002, 0.002]	[0.004, 0.006]	[0.003, 0.004]	[0.002, 0.002]	[0.001, 0.001]
A5	[0.005, 0.006]	[0.021, 0.029]	[0.009, 0.013]	[0.002, 0.003]	[0.007, 0.009]	[0.001, 0.002]	[0.006, 0.008]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]
A6	[0.004, 0.006]	[0.024, 0.035]	[0.01, 0.013]	[0.002, 0.003]	[0.008, 0.011]	[0.001, 0.002]	[0.006, 0.009]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]
A7	[0.006, 0.007]	[0.018, 0.025]	[0.01, 0.013]	[0.002, 0.003]	[0.004, 0.007]	[0.001, 0.002]	[0.009, 0.011]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]
A8	[0.004, 0.006]	[0.018, 0.027]	[0.013, 0.015]	[0.002, 0.003]	[0.01, 0.012]	[0.001, 0.002]	[0.006, 0.009]	[0.002, 0.004]	[0.001, 0.001]	[0, 0.001]
A9	[0.005, 0.006]	[0.02, 0.027]	[0.011, 0.014]	[0.003, 0.004]	[0.006, 0.009]	[0.001, 0.002]	[0.006, 0.008]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]
A10	[0.004, 0.008]	[0.021, 0.039]	[0.01, 0.014]	[0.002, 0.004]	[0.008, 0.013]	[0.001, 0.002]	[0.006, 0.01]	[0.003, 0.004]	[0.001, 0.002]	[0.001, 0.001]

TABLE 9. Best non-gray performance in technology transfer methods

Technology transfer method	$\hat{v}_{ij}^{+}$	$\hat{v}_{ij}^{-}$	$\hat{y}_i$	$BNGP_i(\hat{y}_i)$	RANK
Buy royalties (A1)	[0.073, 0.104]	[0.004, 0.006]	[0.069, 0.098]	0.084	7
Education and training (A2)	[0.069, 0.099]	[0.005, 0.007]	[0.064, 0.092]	0.078	10
Foreign Direct Investment (A3)	[0.082, 0.113]	[0.004, 0.006]	[0.078, 0.107]	0.093	3
Reverse Engineering (A4)	[0.073, 0.1]	[0.004, 0.006]	[0.068, 0.094]	0.081	9
Recruitment and exchange of manpower (A5)	[0.077, 0.107]	[0.005, 0.007]	[0.073, 0.1]	0.086	6
Franchise Method (A6)	[0.086, 0.119]	[0.006, 0.008]	[0.08, 0.111]	0.096	2
Licensing (A7)	[0.076, 0.105]	[0.006, 0.008]	[0.07, 0.097]	0.084	8
Joint R&D (A8)	[0.08, 0.111]	[0.006, 0.008]	[0.074, 0.103]	0.089	5
External supply (A9)	[0.084, 0.113]	[0.005, 0.007]	[0.079, 0.106]	0.092	4
Joint Venture (A10)	[0.081, 0.132]	[0.006, 0.008]	[0.075, 0.124]	0.099	1

TABLE 10. Cost of implementing technology transfer method *i* in company *j*

W_{ij}	M1	M2	M3	M4	M5	M6	M7	M8
A1	2,089	2,574	2,063	3,429	1,932	3,383	2,179	3,162
A2	2,987	2,862	2,168	3,345	2,177	3,199	3,316	1,971
A3	2,194	1,853	3,148	3,172	2,062	2,558	2,604	2,696
A4	2,169	2,178	1,817	2,780	1,844	2,523	3,138	2,536
A5	3,245	3,236	1,995	2,279	2,376	2,510	2,973	1,845
A6	3,043	2,331	2,532	1,925	2,965	2,797	2,742	3,332
A7	2,165	3,076	2,716	3,224	3,300	3,061	2,375	2,115
A8	2,173	2,028	2,251	3,300	3,280	2,000	2,687	2,838
A9	2,792	3,300	2,098	3,244	2,661	2,665	2,999	1,824
A10	1,909	2,046	2,212	2,531	3,450	3,172	2,518	2,584

TABLE 11. Reliability of implementing technology transfer method *i* in company *j*

L_{ij}	M1	M2	M3	M4	M5	M6	M7	M8
A1	0.895	0.973	0.895	0.974	0.905	0.981	0.851	0.887
A2	0.940	0.959	0.892	0.942	0.933	0.873	0.933	0.851
A3	0.905	0.976	0.911	0.871	0.979	0.936	0.943	0.932
A4	0.907	0.984	0.870	0.931	0.882	0.914	0.850	0.983
A5	0.983	0.897	0.896	0.892	0.903	0.963	0.938	0.854
A6	0.857	0.956	0.962	0.965	0.903	0.852	0.901	0.875
A7	0.885	0.904	0.878	0.862	0.864	0.968	0.934	0.862
A8	0.919	0.884	0.959	0.938	0.864	0.984	0.876	0.913
A9	0.916	0.879	0.976	0.878	0.925	0.864	0.925	0.983
A10	0.855	0.900	0.977	0.875	0.897	0.949	0.854	0.948

TABLE 12. Number of methods allowed for allocation to manufacturer *j*

	M1	M2	M3	M4	M5	M6	M7	M8
D_j	3	4	2	3	2	2	3	2

Based on this information, the mathematical problem designed for 100 iterations of the ε-Constraint Method was solved and the Pareto front was obtained from two objective functions.

The results are shown in Figure 2. The results were presented to the experts. They agreed on choosing the best answer from the 101 points on the Pareto front, based on the values obtained for the objective functions. The results are shown in Table 13. Also, how the technology transfer methods are assigned to each manufacturer is described in Table 14.

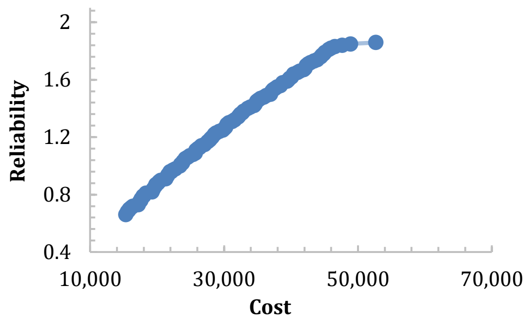

Figure 2. Pareto front created based on target functions

TABLE 13. Optimal goal function based on expert opinion

Cost (Z1)	Reliability (Z2)
30,756	1.3

TABLE 14. How to assign the technology transfer method to each company

Technology transfer method	Company							
	1	2	3	4	5	6	7	8
A1					✓			
A2								
A3		✓			✓			
A4								
A5								✓
A6		✓		✓				
A7								
A8	✓	✓				✓		
A9			✓					✓
A10	✓	✓	✓				✓	

6. CONCLUSION

One of the key success factors for international competition in companies is the accumulation of technology-based advantages. Enterprises use different ways to access technology. Technology transfer is known as one of the main shortcuts for developing countries to reduce the technology gap with developed countries. However, companies and countries face different challenges in this journey. In this regard, the development of intelligent and facilitating laws that are appropriate to the characteristics and challenges of each country can help improve the level of technology transfer.

In this study, we attempted to follow theoretical and research principles and frameworks to provide a model to identify the factors affecting technology transfer methods to improve company performance. For this purpose, at first, we reviewed domestic and foreign research and proposed a set of 20 factors in four categories of economic, technical, managerial, and commercial factors which were localized according to the judgments of an expert committee composed of expertise from battery companies. Then the best-worst method (BWM)was used to determine the effective weight of each factor and prioritize technology transfer methods. The conclusion of best-worst showed that the indicators of “improving management style”, “firm strategy”, “cost effectiveness” “how to communicate with the organization” and “competitiveness” are among the effective indicators in the evaluation of technology transfer methods, considering the company's performance improvement.

Also, the “joint venture” approach achieved the best performance in three indicators of “risk level”, "management style improvement” and “competitiveness”, which indicates that if the company intends to compete in the world-class and take a step in the development and progress direction, the joint venture method is of the most importance. Because the company can benefit from the direct and continuous help and cooperation of large companies to improve its business, move towards modernization of production methods, increase efficiency and productivity, and as a result increase the capacity and production rate of its business. The other notable result of this study mentions the low rank of the training and teaching method. This indicates that the experts of the relevant companies believe that a technology transfer method such as training and teaching is time-consuming and the results do not greatly improve the company's competitive position and production capacity. They were not sure about the efficiency of methods like training and teaching, hiring, or exchanging of human forces. Finally, a two-objective mathematical model (zero and one type) was presented and solved to assign each method to the most important battery manufacturers in the country. According to the obtained results, the technology transfer method of "joint venture" had the most frequency in companies.

Research limitations include access to company experts, intrinsic limitations of the questionnaire, the possibility of a conservative response from the experts, the time-consuming distribution, completion, and collection of the questionnaires due to administrative barriers, and the wide variation in the experts' views on factors affecting technology transfer. In future research, the following can be considered:

- To cover all aspects of the problem more comprehensively and to avoid conservative responses from experts, it is recommended that a combination of interview and questionnaire be used at all stages of future research; because more useful information can usually be obtained during the interview due to two-way communication.
- Using a heuristic algorithm or other MCDM models, such as VICOR, TOPSIS, VASPAS, etc. to analyze the sensitivity of the results obtained from the Best-Worst method is effective in prioritizing options.
- Evaluating and ranking technology transfer methods based on the variables of transfer speed, transfer cost, adaptability, and self-sufficiency;

More activity of the company's research and development department not only in terms of technology adoption but also in terms of development activities.

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Persian Abstract

چکیده

هدف از این پژوهش طراحی یک مدل مبتنی بر تصمیم‌گیری-بهینه‌سازی به‌منظور ارزیابی و تخصیص شیوه‌های انتقال تکنولوژی در صنایع باتری‌سازی خودرو تحت شرایط عدم قطعیت است. این تحقیق بر مبنای نیاز صنعت باتری کشور انجام گرفته و نشان دهنده تاثیر به سزای انتقال تکنولوژی بر تولید در کلاس جهانی است. ابتدا شاخص‌های مؤثر در ارزیابی شیوه‌های انتقال تکنولوژی از طریق بررسی مرور ادبیات و همچنین نظرات خبرگان شناسایی می‌شوند. جامعه آماری این پژوهش را خبرگان هشت شرکت تولیدکننده باتری خودرو تشکیل می‌دهند. سپس هر یک از شاخص‌های تأییدشده از طریق به‌کارگیری روش بهترین-بدترین وزن دهی می‌گردند و در ادامه شیوه‌های انتقال تکنولوژی با استفاده از روش تصمیم‌گیری چندمعیاره مورا تحت شرایط عدم قطعیت مورد ارزیابی و اولویت‌بندی واقع شدند. بمنظور در نظر گرفتن عدم قطعیت نیز از تئوری خاکستری بهره گرفته شد. مطابق نتایج به‌دست‌آمده از روش بهترین-بدترین شاخص‌های "بهبود سبک مدیریتی"، "استراتژی بنگاه"، "اثربخشی هزینه‌ای"، "نحوه ارتباط با سازمان" و "رقابت‌پذیری" پنج شاخص اولیه مؤثر در ارزیابی روش‌های انتقال تکنولوژی در صنعت باتری‌سازی هستند. در نهایت به منظور پیاده‌سازی چارچوب پیشنهادی در صنایع باتری‌سازی کشور از طریق حل یک مدل ریاضی دوهدفه بهینه‌سازی شیوه‌های بهینه انتقال تکنولوژی با هدف تولید در سطح جهانی، برای هر یک از تولیدکنندگان مشخص گردید. جهت حل مدل پیشنهادی از رویکرد اپسیلون-محدودیت تکامل یافته بهره گرفته شد، مطابق نتایج به دست آمده از رویکرد پیشنهادی، شیوه انتقال "سرمایه‌گذاری مشترک" مناسب‌ترین روش جهت انتقال فناوری در صنایع باتری سازی است.