Fuzzy ELECTRE I in Sustainable Manufacturing

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The selectin of a demand forecasting method is critical for companies aiming to avoid manufacturing overproduction or shortages in pursuit of sustainable development. Various qualitative and quantitative criteria with different weights must be considered during the evaluation of a forecasting method; therefore, it is a fuzzy multiple criteria decision making (MCDM) problem. An extension of fuzzy ELECTRE I is used to evaluate demand forecasting methods in sustainable manufacturing.

demand forecasting methods | fuzzy ELECTRE I | Extended modified discordance matrix

1. Introduction

Manufacturing is a key driver of growth and global development and is a major contributor to the creation of prosperity and employment, especially in growing economies. However, industrial activities have a substantial environmental burden [1]. The key considerations in sustainable manufacturing (green manufacturing) are the efficient use of resources through the enhancement of resource productivity [2] and minimization of waste [3]. Therefore, to avoid overproduction or shortages during production, accurately forecasting demand is necessary to ensure the production of an adequate number of intermediate parts and final products. Manufacturing systems based on advanced forecasting subsystems play a key role in supply chains and can facilitate environmental protection and long-term sustainable development [3].

A forecasting method is a method of predicting the solution to a task to enable users to accurately predict outcomes [4]. A poor manufacturing forecast could cause a buildup of product stock, leading to increasing part ordering and holding costs [5]. Therefore, demand forecasting is a crucial element of the planning process for companies with the goal of sustainable development. More than 200 forecasting methods are described in the economic literature, and these methods can be classified on the basis of the following criteria: type of information, forecast time span, forecast object, and forecast goal [4]. Dweiri et al. [6] used the analytic hierarchy process (AHP) to select a production planning forecasting method in a supply chain. Dahooie et al. [7] provided a hybrid method of the fuzzy MULTIMOORA approach for multi-criteria decision making and the objective weighting method (CCSD) to select a forecasting method for technology. Various qualitative criteria, such as ease of use and data validity, and quantitative criteria, including implementation cost and forecast accuracy, must be considered when evaluating demand forecasting methods, as these criteria may differ in importance. Evaluating demand forecasting methods is thus a multiple criteria decision-making (MCDM) problem. Therefore, how to aggregate various criteria and their weights to select the most suitable demand forecasting method is a key challenge in forecasting research.

2. Sustainable Manufacturing

Since the 1980s, the core goal of sustainable manufacturing has been waste reduction, and the aim of cleaner manufacturing is to increase available resources and reduce energy usage in manufacturing (Seliger et al. [8]). Recently, sustainable manufacturing has been defined as "the ability to smartly use natural resources for manufacturing, by creating products and solutions that, thanks to new technology, regulatory measures and coherent social behaviours, are able to satisfy economical, environmental, and social objectives, thus preserving the environment while continuing to improve the quality of human life" (Garetti and Taisch [9]). The pursuit of sustainability affects operations and manufacturing activities in which input materials and energy are converted into commercial products (Haapala et al. [1]). Moreover, materials and equipment that are adaptable to various situations are required for flexible manufacturing, which is responsive to variations in material flows, and flexible manufacturing can enhance sustainability while maintaining competitiveness (Rosen and Kishawy [10]). Owing to the increased complexity and performance expectations in supply chains for high-tech products, forecasting product demands is now key for efficiently managing operations (Dweiri et al. [6]). Therefore, an accurate demand forecasting method that can avoid overproduction or shortages and facilitate sustainable manufacturing should be the cornerstone of a sustainable supply chain. Forecasting methods in sustainable manufacturing have drawn the attention of numerous scholars in various fields. Hart et al. [11] introduced effective manufacturing systems for supply chains based on demand forecasting. Rivera-Castro et al. [12] presented diagonal feeding, a useful technique for forecasting build-to-order lean manufacturing supply chains.

3. Fuzzy ELECTRE Method

The ELECTRE method was developed in 1965 and is suitable for selecting the best action from a given set of actions. The ELECTRE family is one of the most powerful MCDM techniques based on outranking relations. An introduction to ELECTRE and ELECTRE TRI can be seen in the work of Roy and Bouyssou [13]. Fundamentally, the ELECTRE method eliminates options that are worse than other options by a specified degree (Akram et al. [14]). Because ELECTRE allows combining qualitative and quantitative information, it is considered a flexible method that requires less complicated information (Tolga [15]). Moreover, the ELECTRE method enables rating the alternatives for each criterion independently without aggregating the score of the alternatives for all criteria (Çalı and Balaman [16]). Among the methods in the ELECTRE family, ELECTRE I is one of the most widely used versions. The ELECTRE I method is applied to selection problems (Adeel et al. [17]), and its complexity can be easily increased through combination with other methods (Govindan and Jepsen [18]). Furthermore, when considering a choice problem in which *a* is preferred to options *b* and *c*, analyzing the preference between *b* and *c* becomes irrelevant; these two actions can remain completely unmatched without degrading the decision procedure, and therefore, the basic idea of this series of methods is to emphasize the analysis of dominance relations (Basilio, et al. [19]). This is also the reason why ELECTRE I is used in the study instead of other existing methods. However, the ELECTRE method lacks precise measurements for producing criteria weights and performance ratings (Hatami-Marbini and Tavana [20]) because exact (or crisp) numbers are often inadequate for describing real-life situations. Fuzzy set theory (Zadeh [21]) is an ideal solution for overcoming this problem in that it resembles human reasoning in its use of approximate information and uncertainty to generate decisions (Belbag et al. [22]). The core advantages of the fuzzy ELECTRE method can be summarized as being highly applicable and non-compensatory when criteria are described in the ordinal scale (Chhipi-Shrestha et al. [23]). Belbag et al. [22] used fuzzy ELECTRE to rank four smart phone brands on the basis of a survey of 250 students. Akram et al. [24] indicated that the Pythagorean fuzzy set model can effectively capture the vagueness in human evaluations and thus proposed a Pythagorean fuzzy ELECTRE I method. Ayyildiz et al. [25] proposed integrating the AHP and ELECTRE methods using interval type2 trapezoidal fuzzy ELECTRE to evaluate individual credit. Chen [26] developed an extension of the ELECTRE method by using novel Chebyshev distance measures as Pythagorean membership grades and applied it to bridgesuperstructure construction methods for validating feasibility and applicability. Wang and Chen [27] used a T-spherical fuzzy ELECTRE approach to select potential companies for extending the scope of a business. Some recent fuzzy MCDM works can be seen in the work of Badi et al. [28], Martin and Edalatpanah [29], Puška and Stojanović [30], and Su et al. [31]. However, fuzzy ELECTRE I has yet to be applied to select demand forecasting methods for sustainable manufacturing. To fill this gap, the study proposes an extension of fuzzy ELECTRE I for selecting the most suitable demand forecasting method.

In fuzzy ELECTRE I, the division of two fuzzy numbers is needed to produce a discordance matrix. However, the membership function produced by this division has not been precisely defined. Thus, a proper defuzzification method is necessary to produce the discordance matrix. Numerous ranking and defuzzification methods have been investigated. Peddi [32] proposed a defuzzification method for ranking fuzzy numbers based on centroids and maximizing and minimizing sets. The literature on defuzzification methods has a long history which can be seen in the works of Kataria [33], Kumar [34], and Talon and Curt [35]. Recently published works are described in the articles by Arman et al. [36] and Menïz [37]. Each method has advantages and disadvantages. The signed distance (Yao and Wu [38]) method is used because it is simple and can be applied to both negative and positive fuzzy numbers. Moreover, the paper derives defuzzification formulas based on signed distance (Yao and Wu [38]) to derive an ELECTRE I model that can assist in decisionmaking. Zhang et al. [39] used the ELECTRE method to determine the ranking order of substrate nodes for resolving a virtual network embedding problem. They obtained the modified weighted summation matrix for ranking alternatives by using the Hadamard product to combine the concordance and modified discordance matrices. Despite the merits of the method proposed by Zhang et al. [39], it may have information loss that could lead to the production of an incorrect ranking order. Nghiem and Chu [40] suggested ranking sustainable conceptual designs by using a total net dominance value based on Nijkamp and Van Delft's [41] net concordance dominance value and net modified discordance dominance value in order to avoid information loss in the method of Zhang et al. [39]. Moreover, Ke and Chen [42] suggested an ELECTRE method for selecting e-services. The Hadamard product of the concordance matrix and modified discordance matrix was used to obtain the modified total matrix for ranking alternatives. Despite the merits of their method, it also can produce an incorrect ranking due to information loss resulting from zero values in the modified discordance matrix when the Hadamard product is used. To resolve this problem from Ke and Chen [42], Nghiem and Chu [43] proposed subtracting discordance values from concordance values to obtain the total dominance matrix and produce the Boolean matrix to obtain ranking results, and they further applied it to develop a BWM-based fuzzy ELECTRE I method and evaluate lean facility layout designs. Nevertheless, the two suggested methods still exhibit the problem of information loss when the Hadamard product is used. To resolve this problem, the present study adopts a closeness coefficient based on an extended modified discordance matrix. Herein, the proposed extension is compared with the methods of Ke and Chen [42] and Zhang et al. [39] to demonstrate its advantages. Finally, a numerical example is used to show the feasibility of the proposed method. Furthermore, a numerical comparison is conducted with some other methods to display the advantages of the proposed fuzzy ELECTRE I method.

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