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Empirical study of manufacturing enterprise collaboration network: Formation and characteristics

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ABSTRACT

With the rapid development of society and economy, market competition is getting increasingly fierce. It is almost impossible for a single enterprise to respond promptly to the changing market. As a result, more and more enterprises tend to improve their competitiveness by means of collaboration. Specialization and cooperation arise between enterprises, forming manufacturing enterprise collaboration network (MECN). MECN is a complex network which comes into being by means of numerous enterprises selecting partners. Therefore, partner selection is a key issue in MECN. Considering that existing partner selection methods are subjective and theoretical to some extent, an objective and practical method called gray comprehensive evaluation is adopted in this paper. Besides, probability is introduced to simulate the preference and uncertainties. Correlations between each index and the optimal index are calculated according to which sort the possible partner enterprises, and the enterprises nearest to the optimal indexes are more likely to be selected. An MECN driven by an airplane as the final product is then studied as a case, and the statistical characteristics of the network are analyzed. Results show that probability-based gray comprehensive evaluation is an effective way to model MECN, and the network is of self-organization, complexity and localization.

1. Introduction

Nowadays, enterprises are faced with new challenges along with economic globalization and the rapid development of information technology. Market demands are getting diverse and customized with each passing day, and customers have growing requirements and expectations to products, which lead the competition between enterprises to become more and more fierce [1]. Moreover, the product life cycle gets shorter and the market opportunity is fleeting. Meeting the market demands and bringing products to market promptly is of crucial significance to an enterprise.

In response to these new challenges, a growing number of enterprises collaborate to enhance their competitiveness so as to meet the intensified competition. Modern industrial division is not only the comprehensive division on the national level, but the specialized division deep into the enterprise and department level. The most typical division is the division of process flow and the specialized product parts, which shape the manufacturing enterprise collaboration network (MECN). An MECN is a temporary enterprise alliance resulted from division of labor on the basis of specialization. In MECN, only the core business of an enterprise is maintained whereas other businesses (e.g., design, manufacture etc.)are outsourced, thus gaining higher profits via its core competence as well as meeting the market requirements of lower cost and quick response [2]. For instance, the Boeing 747 contains about 4 million parts manufactured by around 20,000 enterprises located in 65 countries; Bayer creates collaborative relationship with 35,000 enterprises which generate various final products using the intermediate products Bayer offers to them, etc.

MECN is a complex system. With the development of society and the specialization of manufacturing labor, the scale of MECN is getting larger and the collaboration among enterprises is getting closer. Consequently, the behavior of a single enterprise may affect its neighbors and the failure of a single enterprise may impact other enterprises, giving rise to cascading failures or even cause paralysis of the whole network [3]. Modeling, analyzing as well as controlling MECN is of great importance. Particularly, modeling and analyzing of an MECN is the foundation of controlling it. Therefore, in this paper, we focus on the study of MECN formation and its structural analysis.

Specifically, the life cycle of an MECN has the following three stages shown in Fig. 1 [4]:

During the life cycle of MECN, partner selection has attracted much attention since it is the first and most critical step in creating MECN. An MECN is a temporary enterprise alliance. When discovering

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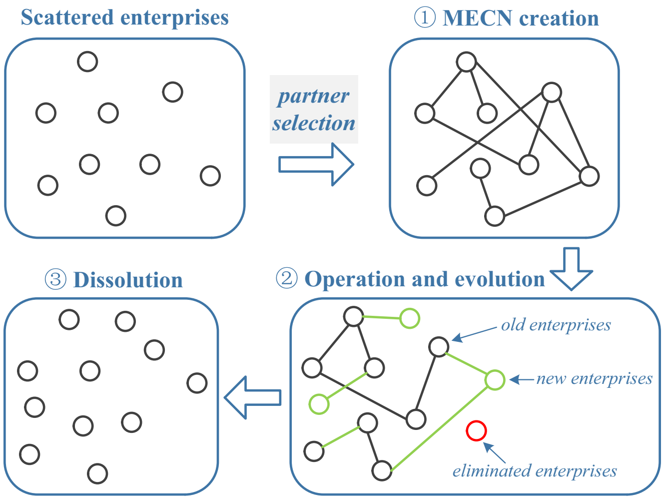

Fig. 1. Life cycle of an MECN.

market opportunity or developing new products, appropriate collaborative partners are needed for an enterprise to cope with the new business. Specifically, MECN is formed by multiple partner selections made by numerous enterprises. Partner selection determines to a large extent whether an enterprise can survive the fierce market competition. In essence, partner selection is a process of evaluation and optimization. Partner selection problem was studied by many scholars. Ho et al. [5] did a literature review of 78 articles between the year 2000 to 2008 in multi-criteria decision making approaches for supplier evaluation and selection. Govindan et al. [6] presented a literature review of the relative articles between the year 1996 to 2011 in multi criteria decision making approaches for green supplier evaluation and selection. Generally, existing partner selection methods include:

1) Mathematical programming approach. Wu and Su [7] took completion time as a constraint to model the partner selection problem by an integer programming formulation to minimize the manufacturing cost. Jarimo and Salo [8] used a mixed-integer linear programming model to select partners in a virtual organization.
2) Uncertainty theory, e.g., analytical hierarchy process (AHP), fuzzy set theory, grey systems theory, etc. Sari et al. [9] proposed an AHP model to contribute in the selection of partners in virtual enterprises. Mikhailov [10] presented a fuzzy programming method based on interval pairwise comparison judgement and approximate reasoning for the assessment of uncertain weights of partnership selection criteria and uncertain scores of alternative partners. Yue [11] introduced an approach to partner selection with linguistic values and intuitionistic fuzzy information under a group decision-making environment without aggregations to avoid information loss. Memon et al. [12] used combined grey systems theory and uncertainty theory for supplier selection and order allocation in order to achieve both quantitative and qualitative objectives associated with suppliers.
3) Swarm intelligence algorithm, e.g., genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), etc. Ip et al. [13] adopted a rule-based GA to find the optimal combination of partner enterprises for all subprojects to minimize the risk of the whole project, and it shows a good performance in both the computation speed and optimality. In order to reduce time complexity and avoid local best solution, Tao et al. [14] proposed a genetic algorithm method using binary heap and transitive reduction (GA-BHTR). Zhang et al. [15] designed a Pareto GA for partner selection problems which shows higher performance and shorter time than simulated annealing and PSO. Zhao et al. [16] adopted PSO with initialization expansion mechanism, variance mechanism, and local searching mechanism to solve partner selection problem with precedence and due date constraint. Niu et al. [17] presented an enhanced ACO for multiattribute partner selection in virtual enterprises and proved that it is of accuracy and rapidity.

Each of the above method has its own strengths, but there are still some defects:

1) There are parameters difficult to set. Judgment matrix used to describe the relative importance of two factors in AHP method is determined by the experience and intuition of a group of experts, giving rise to strong subjectivity. Fuzzy set theory cannot solve the repeated assessment problem brought by relevance of evaluation indexes and the membership function is sometimes hard to define. Judgment matrix, division of evaluation indexes, and membership function are all uncertain factors existed in the above methods which greatly influence the results, yet there is no objective or systematic rule to set these factors.
2) Strong in theory, difficult to apply. Swarm intelligence algorithms such as GA, PSO etc. are advantaged in optimization with large samples. However, in real MECN, it is impossible for a single enterprise to get the information of all the potential partners, i.e., knowing all the potential partners costs a lot. There are usually a small amount of enterprises involved when considering a specific partner selection problem. In that case, the advantage of swarm intelligence algorithms is not that obvious. Besides, enterprises may choose multiple partners whereas the above methods can only provide one. Additionally, how to jump out of partial optimization and achieve overall optimization is another problem requires consideration.
3) No mechanisms to reflect the decision-maker's subjective judgments. Uncertainty problems in the area of partner selection have been discussed by various researchers. The uncertainty of various decision parameters like uncertain demand, uncertain lead-time, etc. are mentioned, and the uncertainty of decision-maker's preferences are also taken into consideration by involving the decision-makers in determining the relative importance weights of the evaluation criteria. Generally, the existing literatures are trying to find the potential partner that is of the best quality (with the decision-makers determining the weights of criteria, and with different partner selection methods), and the potential partner of the best quality will finally be selected as the real partner by the decision-maker. However, since the final decision of partner selection is made by decision-makers, and humans are not machines, other special preference and emotion may exist when making the final decision. For instance, the decision-maker may consider other factors difficult to quantify, such as stability, loyalty, industrial espionage, etc. Given this, chances are that an enterprise is not selected as a partner though it is of good quality. Uncertainties that result from the decision-maker's subjective judgments of the final decision do exist in the partner selection problem, yet few partner selection methods deals with it.

Aiming at the defects above, a probability-based gray comprehensive evaluation method is proposed in this paper to solve the partner selection problem. Gray comprehensive evaluation is a part of gray system theory put forward by Deng in the year 1982 [18]. Evaluation objects are compared and ranked by the correlation between each index and the optimal index. In order to model the subjective uncertainties, probability is introduced. Compared