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Design optimization of resource combination for collaborative logistics network under uncertainty

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ABSTRACT

Collaborative logistics networks (CLNs) are considered to be an effective organizational form for business cooperation that provides high stability and low cost. One common key issue regarding CLN resource combination is the network design optimization problem under discrete uncertainty (DU-CLNDOP). Operational environment changes and information uncertainty in network designs, due to partner selection, resource constrains and network robustness, must be effectively controlled from the system perspective. Therefore, a general two-stage quantitative framework that enables decision makers to select the optimal network design scheme for CLNs under uncertainty is proposed in this paper. Phase 1 calculates the simulation result of each hypothetical scenario of CLN resource combination using the expected value model with robust constraints. Phase 2 selects the optimal network design scheme for DU-CLNDOP using the orthogonal experiment design method. The validity of the model and method are verified via an illustrative example.

1. Introduction

Collaborative logistics networks (CLNs) are an effective organizational form of supply chain management in the business intelligence era. They have broken the conventional rigid point-to-point cooperation model, recognized the rationality of contradiction and conflict, and emphasized the necessity of compromise and concession [1]. Through the integration of resource entities, that have different logistics functions, CLNs can realize synchronized coordination among many heterogeneous resources [2]. To provide customers with efficient personalized customized service, CLNs are mainly based on task orientation, perform resource matching between network task requirements and independent accounting logistics enterprises, design a service scheme of resource combination, and finally achieve excess returns by implementing the scheme [3]. The resource optimization process of CLNs consists of resource planning, resource discovery, resource evaluation, resource sharing and resource combination.

During the stage of resource combination in a CLN, the most important problem is how to determinate the best resource combination design scheme, which is the key to ensure the orderly operation of the CLN. The decision maker/leader should not only focus on the logistics efficiency improvement of resource nodes, but rather also complete a series of activities, such as demand decomposition, task packaging, resource allocation, cost control, and schedule monitoring [4]. In this stage, the decision maker/leader must first clearly define the risk preference regarding whether the CLN can stably operate, then determine a variety of constraints for network operation, and finally select suitable partners for the CLN from numerous candidates [5].

To effectively work with resource combination optimization problems, many previous studies have proposed different methods to design optimization schemes and minimize the impacts of uncertain factors on CLN operations [6,7]. In these studies, the researchers determine the key factors, that affect the resource combination of CLNs to be network robustness [8], resource constraints [9,10], and partner selection [11,12].

Network robustness is very important for CLNs, especially when operating under uncertainty. Uncertain changes in the business environment have negative effects on CLN operation, such changes include changes in customer demand, supplier replacement, process reengineering, and distribution networks [13,14]. Methods to maintain operational robustness have constituted a major research area regarding logistics networks. Some studies focus on uncertainty recognition and risk control, analyze the

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superior performance of robust model compared with deterministic models, and design compromise (between risk reduction and cost increases) schemes according to the impact of CLNs [8,15]. In addition, there is also some research concerned with robustness evaluation criteria and sustainable value creation [16,17].

Resource constraints are related to partner selection in CLNs. Considering the discrete and dynamic characteristics of business operations, resource supply and demand, especially supply have great uncertainty, this uncertainty causes difficulties in CLN resource combination [2,18]. According to business and supply factors, the optimization design of logistics networks has attracted significant attention in recent years [19–23]. For example, a bi-objective possibilistic mixed integer programming model has been developed to address uncertain and imprecise parameters caused by supply uncertainty and operation risk [24–27]. However, most of the proposed models related to this subject are based on case studies, and lack generality. Considering capacity limits, multi-resource management, demand uncertainty and value creation, a mixed integer programming model is proposed as a generalized model to overcome this limitation [6].

The partner selection process is critical in the formation of a CLN. This process refers to potential candidate evaluation, individual interest coordination and whole value creation. Multi-criteria decision making (MCDM) methods are often used to evaluate potential candidates by setting a series of indicators. Examples of MCDM methods used are AHP, TOPSIS, and DEA [28,29]. There are also some other methods proposed to solve this problem, such as the optimization method, empirical analysis, and model simulation [30–32]. Interest coordination is another key issue regarding partner selection. There are contradictions and conflicts amongst different individuals, and between the individual and the whole in a CLN, these conflicts require a compromise solution. To effectively select a group of efficient and compatible partners, a two-phase quantitative framework is proposed [10]. Phase 1 identifies efficient candidates using a CCR model, and phase 2 determines the best combination of efficient partners using an integer goal programming model. In addition, CLN operations cannot be at the expense of individual interests, a CLN should achieve a mutually beneficial outcome via value creation.

Although the issues of resource combination are discussed to a great extent in the literature, most of these studies focus on specific issues or single scenarios, these are the remarkable characteristics of the classical CLN design optimization problem (CLNDOP). The general design optimization issue of resource combination under discrete uncertainty has received very little attention [33,34]. In the actual CLN operation process, decision makers need a proposed scheme that can help them make the best decisions or provide a variety of planning options for the final decision, rather than a strict mathematical optimization solution or analytical solution.

In this paper, we focus on the development of a new solution for resource combination in CLNDOP under discrete uncertainty (DU-CLNDOP). This problem is actually an extension of the classical CLNDOP, a design comprised of multiple concurrent uncertain factors is considered to replace specific uncertain factors, and the interaction effect of uncertainty is considered to protect resource combination design schemes against data distortion, which may compromise the reliability and validity of schemes. Moreover, multiple hypothetical scenarios are also used to describe the dynamic environment. To obtain an acceptable design scheme while meeting the task requirements for the DU-CLNDOP, a general two-stage decision framework is proposed and designed for such cases. Phase 1 is a scenario simulation based on the uncertain decision variables in the design of a CLN. This simulation results in various possible resource combinations that are considered in Phase 2 of the analysis. Numerical experiments are conducted to demonstrate the effectiveness and efficiency of the two-stage decision model, and to explore the various impacts of CLN discrete uncertainty on resource combination design.

The rest of this paper is organized as follows. In Section 2, following the description of the CLN optimization design problem under discrete uncertainty, the solution framework is proposed. In Section 3, the expected value model with robust constraints is proposed, and the orthogonal experiment design that is used to select the optimal design scheme is introduced in Section 4. In Section 5, an illustrative example is provided. Finally, conclusions are given in Section 6.

2. Problem statement and solution framework

2.1. CLN optimization design problem under discrete uncertainty

As discussed above, the key issues encountered in resource combination in CLNs are partner selection, resource constraints, and network robustness. For example, consider a scenario in which a CLN with these three types of uncertain factors is to be formed. If there are 3 potential candidates for the CLN demand, 3 possible supply–demand relationships (i.e., supply uncertainty, demand uncertainty, and uncertainty in both), and 3 robustness requirements for CLN operation (i.e., high, medium and low), then the total number of resource combination design schemes considered is 27. All of these design schemes must be evaluated and the most desirable one should be identified. The evaluation of a design scheme is based on CLN resource combination tasks generated by requirements, the evaluation function is formulated in the following equation:

$$N_T = f(P, C, R, S) \tag{1}$$

where N_T is the CLN operating cost at time T, P is the number of potential candidates that meet the requirements, C is the constraint condition regarding resource combination, R is the robustness level of the CLN operation, and S is the scenario of under which the resource combination scheme is designed. Parameters P, C, R, and S are interrelated, and they are expressed in the form of Eq. (2). The relationship between the parameters and N_T is shown in Fig. 1.

The relationships between P, C, R, S and N_T are mutually dependent, N_T can reach the maximum value only if the parameters are balanced in the appropriate environment. Therefore, the optimization design of CLN resource combination can be an extremely trivial and time-consuming process. Moreover, it is very difficult to incorporate into one decision model both the uncertain variables for CLN

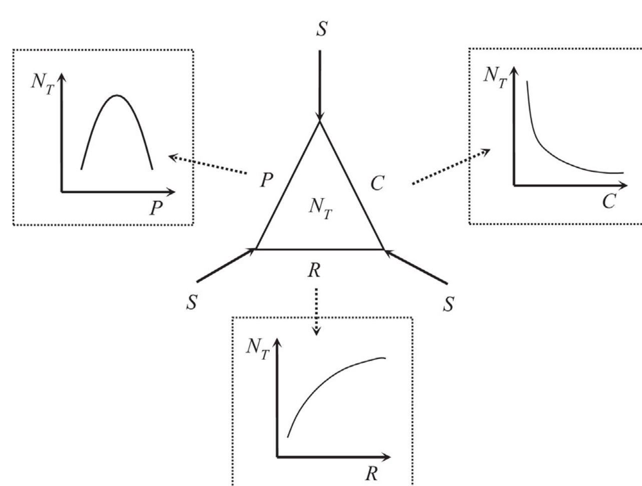

Fig. 1. Analysis of the relationship between parameters and N_T.