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A flow-based three-dimensional collaborative decision-making model for supply-chain networks

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ABSTRACT

The inter-organizational collaboration of supply-chain networks is an important modern business model. This model involves the collaboration of different organizations and decentralized decision making to improve the overall performance of a supply-chain network. The current research on collaborative decision making lacks a clear and effective decision system, which leads to a series of problems, such as unclear decision positioning, vague decision processes and poor operability of decision solutions. To solve these problems, this paper studies the principles of inter-organizational collaboration and proposes a novel perspective for collaborative decision making based on material, information and time flows. A flow-based three-dimensional collaborative decision-making model for supply-chain networks is creatively advanced in this paper. The model is an efficient methodological tool for collaboration management in the following ways: (i) it clarifies both the domain and the space of collaborative decision making; (ii) it sets up mapping relationships of decision spaces in different decision domains and elaborates their formal descriptions systematically; (iii) it solves the issues related to the association and integration of inter-organizational collaboration in several decision domains; and (iv) it allows all members in all organizations to be involved in the decision making of a supply-chain network. A case is studied to elaborate and verify the efficiency of the collaborative decision-making model. Compared with previous collaborative decision-making research, this paper provides a more efficient solution for collaborative decision making. The outlined model has clearer decision-making positioning and a stronger actual operability, and it provides an effective methodological reference for operating the inter-organizational collaborative decision making of a supply-chain network.

1. Introduction

In the course of economic globalization, supply-chain networks are widely recognized as one of the most important modes of business cooperation and competition. Such networks are characterized by complex structural relationships [2,6], partial information sharing [7,20,21], and decentralized individual decision making [11,12]. The high operational performance of supply-chain networks cannot be realized without inter-organizational collaboration. Collaboration has played a significant role in improving and maintaining the performance of supply-chain networks, and it has become an inevitable choice for all organizations in a network. It requires that all organizations cross their boundaries to carry out collaborative decision making through such activities as planning, production, inventory and delivery to strengthen the competitiveness of the network [5]. Because organizations are selfish, completely centralized decision making cannot be reached for decentralized supply-chain networks. Therefore, collaborative decision making is much more difficult than centralized decision making, and it is characterized by lower precision, accuracy, and performance.

Supply-chain network collaborative decision making is a significant research topic in the field of operation management. A volume of literature has focused on issues related to this topic, such as centralized collaborative decision making and decentralized collaborative decision making.

Research on centralized collaborative decision making primarily makes use of operational research, control theory and game theory to identify the most optimal or satisfying decision solutions. Zhang et al. [24] proposed a modified multi-criterion optimization genetic algorithm for order distribution in a collaborative supply chain. The algorithm adopted a framework of a central coordination system. Che and Chiang [4] designed a collaborative supply chain plan using the analytic hierarchy process and a genetic algorithm with cycle-time estimation. Alemany et al. [1] developed an application that supports the integrated modeling and execution of the collaborative planning decision-making process in supply chains.

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The chains are comprised of several decisional centers that make decisions based on mathematical programming models under temporal and spatial integration. Zhang and Lu [25] proposed a fuzzy bi-level decision-making model for a general logistics-planning problem and developed a fuzzy number-based *K*th-best approach to find an optimal solution for the proposed fuzzy bi-level decision problem. Zhang et al. [27] applied the bi-level programming and swarm technique to address strategic bidding optimization in electricity markets. Bhattacharya et al. [3] proposed a collaborative decision-making approach using a fuzzy analytic network process (ANP)-based balanced scorecard to measure green supply-chain performance. Zhang et al. [26] proposed an integrated solution framework combining a scatter evolutionary algorithm, fuzzy programming and stochastic chance-constrained programming for the collaborative production planning of supply chains under price and demand uncertainty. Lu et al. [12] proposed a hybrid solution integrated Lagrangian relaxation and immunity-inspired coordination scheme to collaborative decision making in a decentralized supply chain. Zamarripa et al. [23] used the mathematical programming and game theory optimization-based tool for supply-chain planning in cooperative/competitive environments. Yan and Li [22] conducted a game analysis on the collaborative operation behavior in a logistics service-supply chain. Focusing primarily on complete information sharing, these studies attempt to exploit the optimization of supply-chain network collaboration by means of centralized decision making. Centralized decision making is separated from the actual operation features of supply-chain networks and limits the practical application of decision-making solutions.

In view of the shortcomings of centralized collaborative decision making, research on decentralized decision making has been conducted to improve the application value of decision solutions. These studies usually adopt the advantages of multi-agent systems in decentralized decision making. Hernández et al. [8] proposed a novel supply chain agent-based modeling methodology that supports a collaborative planning process within a collaborative planning environment. Hernández et al. [10] presented a novel collaborative planning model in multi-level supply chains that considers a multi-agent system modeling approach to carry out iterative negotiation processes, which support the decision making process from a decentralized perspective. Hernández et al. [9] used a multi-agent system to support the collaborative decision-making process in an automotive supply chain. Lin and Long [13], Long et al. [17,18], Long [14–16], and Long and Zhang [19] studied a series of multi-agent-based modeling and simulation methodologies and tools to support the collaborative decision-making process in decentralized supply chains with partial information sharing. Decentralized decision making based on incomplete information sharing has obvious advantages, but it does not consider the influences of cross-organization. The perspective of inter-organizational collaborative decision making must be employed in modern supply-chain network operation systems. Furthermore, the above-mentioned studies lack a clear and effective decision system, which leads to a series of problems, such as unclear decision positioning, vague decision-making processes and poor operability of decision solutions.

In a word, the current methods, models and technologies for collaborative decision making are less efficient, precise, and accurate in coping with inter-organizational supply-chain networks, and the decision solutions have less operability. Therefore, it is of great necessity to study a more effective inter-organizational collaborative decision-making model to improve its performance.

To solve the above-mentioned problems, this paper studies the principles of the inter-organizational collaborative operation of supply-chain networks and proposes a novel perspective of flow-based inter-organizational collaborative decision making. Then, a flow-based three-dimensional collaborative decision-making model for supply-chain networks is set up, and a systematical formal description of the model is provided. Finally, a case is studied to elaborate and verify the application of the model. The proposed model ascribes great importance to the context of inter-organizational collaboration, creatively puts forward a flow-based decision-making perspective, and improves the decision making and operability of decision-making solutions. The model defines both the domain and the space for decision making, clarifies the unified and standard process, reduces the difficulty of decision making, and improves the precision and accuracy of decision solutions. Additionally, the model provides an effective decision-making tool to allow all members in all organizations to participate in the decision-making process where their passions are motivated.

The rest of this paper is organized as follows: Section 2 exploits the flows in the inter-organizational collaboration of a supply-chain network. Section 3 elaborates the perspective of flow-based inter-organizational collaborative decision making. Section 4 puts forth a flow-based three-dimensional collaborative decision-making model for supply-chain network and provides a formal description of the model. Section 5 provides a case study on the application and verification of the model, and Section 6 presents conclusions and further study.

2. Supply-chain network flows

Complete/partial information sharing inside and outside organizations drives the inter-organizational collaboration of a supply-chain network. The collection of these information-sharing activities can be described as an information flow, as shown in Fig. 1. Outside the organization, throughout the supply-chain network—from the terminal customers to the upstream organizations—information flow drives all organizations to complete horizontal collaboration. Inside the organization, from the top strategic level to the bottom operational level, information flow drives all levels to complete vertical collaboration. Information flow is the key to guaranteeing the success of the inter-organizational collaboration of a supply-chain network. In a supply-chain network, activities such as purchasing, production, storage, sales and transportation are accompanied by another important flow—material flow. Driven by information flow, material flow moves step by step from upstream suppliers to downstream ones and finally to the terminal customers. It depicts both the property and space conversions from raw materials to the final products in the network structure. When space conversion occurs in information flow and material flow, time changes throughout the process. After a period of operation time, a specific track is left. As shown in Fig. 1, the track is described as a time axis, called time flow. Information, material and time flows should be considered together as a whole. The essence of inter-organizational collaboration is the collaboration among information, material and time flows. The success of the inter-organizational collaboration lies in the performance of collaboration among the three flows.

3. Flow-based collaborative decision making

Collaborative decision making is in pursuit of decentralized decision making, with the interests of each organization as its center. Simultaneously, it can achieve a performance similar to that of centralized decision making; that is to say, organization individuality should be maintained simultaneously with inter-organizational collaboration to the greatest degree. Material, information and time flows are the key objects and tools for inter-organizational collaboration for a supply-chain network. Correspondingly, collaborative decision making for a supply-chain network is doomed to rely on the three flows, which can cross organizational boundaries to promote their coordination. Hence, collaborative decision

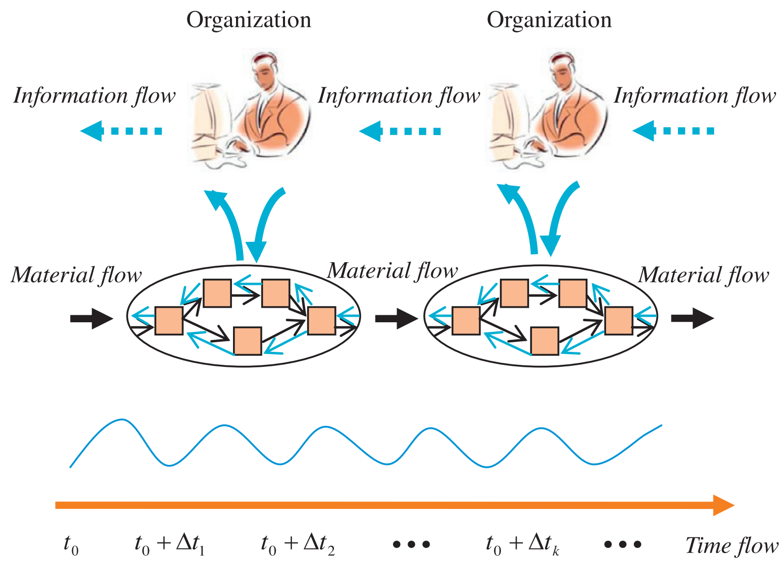


Fig. 1. Supply-chain network flows.

making for supply-chain networks is transformed into collaborative decision making for material, information and time flows. Information-flow-based collaborative decision making focuses on the collaborative collection, decomposition, transformation and transfer of customers' orders, the collaborative communication, drawing up and distribution of production plans, and the collaborative dynamic scheduling of production tasks. It aims to achieve optimal material and time flows. Material-flow-based collaborative decision making draws attention to the collaborative reconfiguration of a static network structure and the coordination of dynamic material flow driven by information flow. It aims for optimal network performance. Time-flow-based collaborative decision making concentrates on the time efficiency of supply-chain networks driven by information flow and supports decision analysis on the basis of time points and time series. It seeks optimal time-efficiency and time decision-making abilities. Differently from previous research on collaborative decision making, flow-based collaborative decision making not only maintains the independence of organizations in decentralized decision making but also crosses the boundaries of organizations to achieve integration with flows as the link. Furthermore, it promotes the emergence of macro overall performance from micro individual decision making.

4. Three-dimensional collaborative decision-making model

Based on the research perspective of flow-based collaborative decision making, this paper proposes a three-dimensional decision-making model to back up the flow-linked inter-organizational collaboration of a supply-chain network.

4.1. Collaborative decision-making framework

The three flows—information, material and time—were elaborated in the previous section. As the core objects and tools for inter-organizational collaboration, the three flows are naturally included in the following decision-making framework. In addition, the organizational structure can be refined according to its hierarchy. The hierarchy can be divided into the strategic level, the tactical level and the operational level. The hierarchy included in the decision-making framework is sure to enhance the clear positioning ability of the model. The current research on decision making is usually based on statistics, so it lacks the support of a complete framework. This paper puts forward a three-dimensional collaborative decision-making framework, as shown in Fig. 2. The framework consists of three dimensions—the level dimension, the flow dimension and the time dimension. The level dimension includes the strategic level, the tactical level and the operational level. The flow dimension can be divided into material flow, information flow and time flow. The time dimension is comprised of time points and time series. Time points can support decision analysis at a certain time; time series, as the ordered sequence of time points, can back up the trend analysis, mean and variance analysis in a period of time.

The specific value of the three dimensions defines the specific decision scope of decision making, for example, the decision scope defined by the tactical level, material flow and time points. This decision scope is called a decision domain, which determines the objects and boundaries of inter-organizational collaborative decision making. Unlike previous decision-making models, the decision domain subdivides and defines the objects of decision making, and it clarifies the attribution of decision issues and the choice of decision entities. It makes the decision-method choices more accurate, the decision process clearer, the decision evaluations more effective, and the decision performance evaluation more reliable. Decision solutions based on the three-dimensional collaborative decision-making framework have specific application domains and responsibility attributions, which enables stronger practical operability. This framework allows all members in all organizations to participate in the decision making, thus improving the decision-making performance with the help of collective wisdom.

Decision domains defined by the three dimensions have certain correlations, such as the relationship between aggregation and decomposition, the relationship between set and elements, and the relationship between nonlinear conversion among the three dimensions. Details about these correlations will be discussed in Section 4.2. These relationships depict the correlation among decision problems, decision objectives, decision actions, decision indexes and decision evaluation in different decision domains, which provides an effective logical reference to the comprehensive evaluation of decision quality and decision applications.

4.2. Collaborative decision-making methods

4.2.1. Decision space

In the decision process, the decision domain should usually be determined first to identify problems that need to be solved. According to the problems, decision objectives are defined for decision actions; these actions are defined in correspondence with the

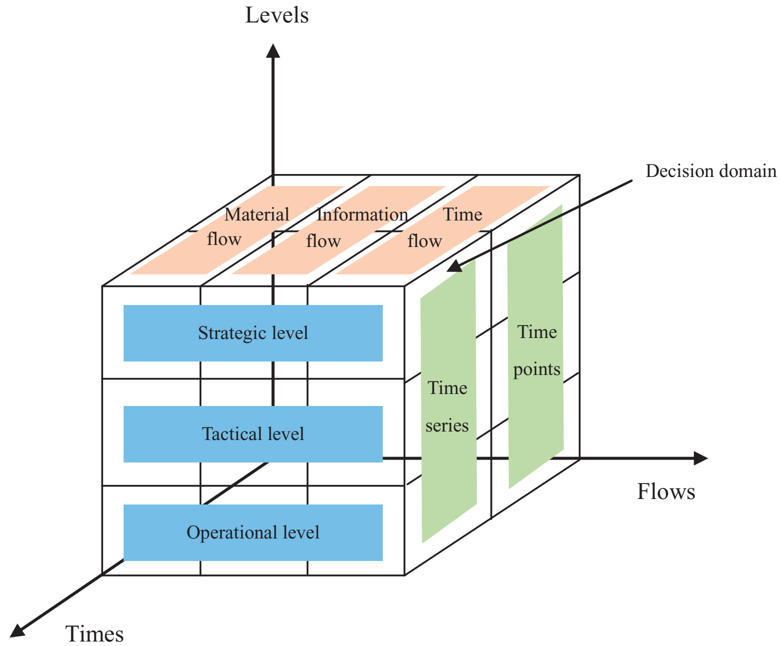


Fig. 2. Three-dimensional collaborative decision-making framework.

objectives. After decision indexes are set up, a decision evaluation is made according to the actions' results. Therefore, the decision space refers to the vector space comprised of the decision domain, problems, objectives, actions, indexes, and evaluations, as shown in the following:

$$D^{Space} = \{Domain, Problems, Objectives, Actions, Indexes, Evaluations\}$$

Let $Level_i$ refer to the ith level of the level dimension in the decision domain, $Flow_j$ refer to the jth flow in the flow dimension, and $Time_k$ refer to the kth time in the time dimension. Then, the decision domain of the ith level, the jth flow, and the kth time can be described as follows:

$$Domain_{ijk} = \{(Level_i, Flow_j, Time_k), E_{ijk}\}$$
$$E_{ijk} = \{element_t^{ijk}\}$$

The decision domain includes the three vectors—the level dimension, the flow dimension, and the time dimension. E_{ijk} is the set of decision factors in the decision domain of the ith level, the jth flow, and the kth time. $element_t^{ijk}$ is the tth decision factor in the decision domain of the ith level, the jth flow, and the kth time. It is the basic decision unit with an indecomposable structure in a specific decision domain. Different values of the three vectors define different decision domains, which in turn correspondingly determine the decision factors in the decision domains.

4.2.2. Analysis of decision space

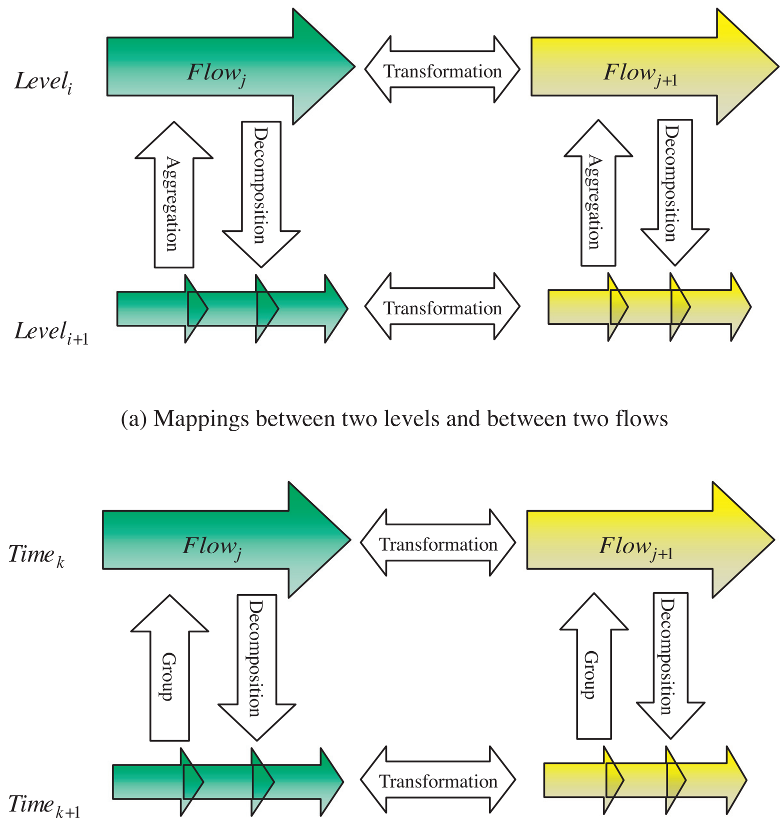
According to the definition of decision domain, the mappings of decision spaces can be realized between different levels, different flows and different times. Fig. 3 gives a conceptual model of the mappings of decision spaces among decision domains. Fig. 3(a) shows the mappings of the flows between two levels, including decomposition mapping and aggregation mapping. In general, the decision space of the strategic level can be decomposed into the decision space of the tactical level. Conversely, the decision space of tactical level can be aggregated into the decision space of the strategic level. Fig. 3(b) illustrates the mappings of the flows between two times, including decomposition mapping and group mapping. In general, the decision space of time series can be decomposed into the decision space of time points. Conversely, the decision space of time points can be grouped into the decision space of time series. Fig. 3 also shows the mapping of decision spaces between two flows, which is called transformation mapping. For example, information flow can be transformed into material flow, information flow can be transformed into time flow, and material flow and time flow can also be transformed into information flow through feedback mechanisms. Details on the formal descriptions of the mappings of decision spaces between levels, flows and times will be elaborated in the subsequent sections.

4.2.2.1. Analysis of the level dimension. Let $Level_1$, $Level_2$, and $Level_3$ represent the three levels in decision domain—the strategic level, the tactical level and the operational level. Let $Flow_1$, $Flow_2$, and $Flow_3$ represent the three flows—material flow, information flow and time flow. Let $Time_1$ and $Time_2$ represent the two types of time—time series and time points. Then, the decision space of the ith level $(1 \le i \le 3)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$ can be depicted as follows:

$$D_{ijk}^{Space} = \{Domain_{ijk}, Problems_{ijk}, Objectives_{ijk}, Actions_{ijk}, Indexes_{ijk}, Evaluations_{ijk}\}$$

Let $F_{i \to i+1} = \{f_{i \to i+1}^D, f_{i \to i+1}^P, f_{i \to i+1}^O, f_{i \to i+1}^A, f_{i \to i+1}^I, f_{i \to i+1}^V\}$ be the decomposition mapping of decision space from the ith level to the $i+1$th level.

In $f_{i \to i+1}^D : Domain_{ijk} \to Domain_{i+1jk} \cap element_t^{ijk} \to \{E_{i+1jk,t}, R_{i+1jk,t}^D, O_{i+1jk,t}^D\}$, $Domain_{i+1jk}$ is the decision domain of the $i+1$th level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $E_{i+1jk,t}$ is the set of sub-decision factors decomposed and mapped by $element_t^{ijk}$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R_{i+1jk,t}^D$ is the set of relationships of sub-decision factors; and $O_{i+1jk,t}^D$ is the content set of the relationships of sub-decision factors. In the level dimension, the relationships from the upper level to the lower level refer to decomposition mapping, which is the most basic method for analyzing and modeling a supply-chain network. When the decision



(a) Mappings between two levels and between two flows

(b) Mappings between two times and between two flows

Fig. 3. The mappings of decision spaces among decision domains.

domain of the strategic level referring to information flow and time points is mapped into the decision domain of the tactical level, its decision factors are correspondingly decomposed into the set of sub-decision factors of the tactical level. For example, the decision factor of customer satisfaction improvement can be decomposed into the set of sub-decision factors of product delivery time reduction, order fulfillment rate improvement and sales service improvement.

In $f^P_{i\to i+1}: problem^{ijk}_t \to \{P_{i+1jk,t}, R^P_{i+1jk,t}, O^P_{i+1jk,t}\}$, $problem^{ijk}_t$ is the tth decision problem in the decision domain of the ith level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $P_{i+1jk,t}$ is the set of sub-problems decomposed and mapped by $problem^{ijk}_t$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R^P_{i+1jk,t}$ is the set of dependent relationships of the sub-problems; and $O^P_{i+1jk,t}$ is the content set of the dependent relationships of the sub-problems. Generally speaking, a problem can be divided into several sub-problems and the structural relationships on which the sub-problems depend. Problem decomposition shows the actual needs, and sub-problems are easier to solve and match the context of division and cooperation in supply-chain networks. Additionally, sub-problems contribute to reaching a solution for the macro problem. For example, the decision problem of how to improve customer satisfaction on the strategic level can be decomposed into a set of sub-problems at the tactical level, including problems related to shortening the product delivery time, improving the order fulfillment rate and improving sales service. Dependent relationships exist among these sub-problems.

In $f^O_{i\to i+1}: objective^{ijk}_t \to \{O_{i+1jk,t}, R^O_{i+1jk,t}, O^O_{i+1jk,t}\}$, $objective^{ijk}_t$ is the tth decision objective in the decision domain of the ith level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $O_{i+1jk,t}$ is the set of sub-objectives decomposed and mapped by $objective^{ijk}_t$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R^O_{i+1jk,t}$ is the set of linear or nonlinear relationships of the sub-objectives; and $O^O_{i+1jk,t}$ is the content set of the linear or nonlinear relationships of the sub-objectives. The development and optimization of supply-chain networks have several objectives. For example, an objective at the strategic level can be decomposed into several sub-objectives at the tactical level. Sub-objectives back up objectives by means of a certain linear or nonlinear relationship. For example, the objective of supply-chain network performance improvement at the strategic level can be decomposed into the set of sub-objectives of profit growth, cost reduction and order fulfillment rate improvement at the tactical level. Linear or nonlinear relationships exist among these sub-objectives.

In $f^A_{i\to i+1}: action^{ijk}_t \to \{A_{i+1jk,t}, R^A_{i+1jk,t}, O^A_{i+1jk,t}\}$, : $action^{ijk}_t$ is the tth decision action in the decision domain of the ith level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $A_{i+1jk,t}$ is the set of sub-actions decomposed and mapped by $action^{ijk}_t$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R^A_{i+1jk,t}$ is the set of series relationships of the sub-actions; and $O^A_{i+1jk,t}$ is the content set of the series relationships of the sub-actions. In a supply-chain network, an action can be divided into several sub-actions that show series relationships, parallel relationships or no relationships. Series relationships must stay in sequence; parallel relationships can be executed in parallel, and no relationship can be executed without any constraints. For example, the action of supply-chain network structure optimization can be decomposed into the set of sub-actions of inventory, production and delivery layouts optimizations at the tactical level. Series or parallel relationships exist among these sub-actions.

In $f^I_{i\to i+1}: index^{ijk}_t \to \{I_{i+1jk,t}, R^I_{i+1jk,t}, O^I_{i+1jk,t}\}$, $index^{ijk}_t$ is the tth decision index in the decision domain of the ith level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $I_{i+1jk,t}$ is the set of the sub-indexes decomposed and mapped by $index^{ijk}_t$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R^I_{i+1jk,t}$ is the set of linear or nonlinear relationships of the sub-indexes; and $O^I_{i+1jk,t}$ is the content set of the linear or nonlinear relationships of the sub-indexes. In a supply-chain network, evaluation indexes can be divided according to the levels. They depend on the sub-indexes and their linear and nonlinear relationships. For example, the index of supply chain-network performance at the strategic level can be decomposed into the set of sub-indexes of profit, cost and service at the tactical level. Linear or nonlinear relationships exist among these sub-indexes.

In $f^V_{i\to i+1}: evaluation^{ijk}_t \to \{V_{i+1jk,t}, R^V_{i+1jk,t}, O^V_{i+1jk,t}\}$, $evaluation^{ijk}_t$ is the tth decision evaluation in the decision domain of the ith level $(1 \le i \le 2)$, the jth flow $(1 \le j \le 3)$, and the kth time $(1 \le k \le 2)$; $V_{i+1jk,t}$ is the set of sub-evaluations decomposed and mapped by $evaluation^{ijk}_t$ in the decision domain of the $i+1$th level, the jth flow, and the kth time; $R^V_{i+1jk,t}$ is the set of dependent relationships of the sub-evaluations; and $O^V_{i+1jk,t}$ is the content set of the dependent relationships of the sub-evaluations. Decision evaluations for a real supply-chain network can be conducted at different levels, which is helpful for organizations' performance assessment at any level. For example, the evaluation of supply-chain network performance at the strategic level can be decomposed into the set of sub-evaluations of profit, cost and service at the tactical level. Dependent relationships exist among these sub-evaluations.

Let $F_{i+1\to i} = \{f^D_{i+1\to i}, f^P_{i+1\to i}, f^O_{i+1\to i}, f^A_{i+1\to i}, f^I_{i+1\to i}, f^V_{i+1\to i}\}$ represent the aggregation mapping of the decision space from the $i+1$th level to the ith level. In $f^D_{i+1\to i}: Domain_{i+1jk} \to Domain_{ijk} \cap \{E_{i+1jk,t}, R^D_{i+1jk,t}, O^D_{i+1jk,t}\} \to (element^{ijk}_t + e^D_{ijk,t})$, $element^{ijk}_t$ is the decision factor aggregated and mapped by the $E_{i+1jk,t}$ in the decision domain of the ith level, the jth flow, and the kth time; $R^D_{i+1jk,t}$ is the set of relationships of the sub-decision factors in the process of aggregation mapping; $O^D_{i+1jk,t}$ is the content set of the relationships of the sub-decision factors; and $e^D_{ijk,t}$ is the correction parameter of the decision factor after aggregation mapping, which can be negative, positive or zero. The macro phenomenon in the supply-chain network emerges along with the micro factors. Correspondingly, factors at the lower levels can emerge into a factor at the upper levels based on certain structural relationships. Deviation exists between the factors in decomposition mapping and the factors in aggregation mapping; thus, a corresponding correction parameter is needed. This methodology matches the research methodologies of top-bottom analysis and modeling and bottom-top emergence and appearance. For example, the sub-decision factors of product delivery time reduction, order fulfillment rate improvement and sales service improvement can be aggregated into the decision factor of customer satisfaction improvement based on a specific relationship by adding a correction parameter.

In $f^P_{i+1\to i}: \{P_{i+1jk,t}, R^P_{i+1jk,t}, O^P_{i+1jk,t}\} \to problem^{ijk}_t + e^P_{ijk,t}$, $problem^{ijk}_t$ is the decision problem aggregated and mapped by $P_{i+1jk,t}$ in the decision domain of the ith level, the jth flow, and the kth time; $R^P_{i+1jk,t}$ is the set of dependent relationships of the sub-problems in the process of aggregation mapping; $O^P_{i+1jk,t}$ is the content set of the relationships of the sub-problems; and $e^P_{ijk,t}$ is the correction parameter of the decision problem after aggregation, which can be negative, positive or zero. Generally speaking, several sub-problems can be aggregated as a problem in supply-chain network. That is to say, problems can emerge from sub-problems according to their structural relationships. However, deviation exists between these problems and those in the process of decomposition mapping. Therefore, a correction parameter is added. For example, the sub-problems at the tactical level, including the problems of how to shorten product delivery time, to improve the order fulfillment rate and to improve sales service, can be aggregated into the decision problem of how to improve customer satisfaction at the strategic level based on a specific dependent relationship by adding a correction parameter.

Formal descriptions of mapping functions such as $f^O_{i+1\to i}$, $f^A_{i+1\to i}$, $f^I_{i+1\to i}$, and $f^V_{i+1\to i}$ are similar to the formal description of $f^P_{i+1\to i}$; hence, they are not depicted in detail in this paper.

4.2.2.2. Analysis of the flow dimension. Let $F_{j\to j+1} = \{f^D_{j\to j+1}, f^P_{j\to j+1}, f^O_{j\to j+1}, f^A_{j\to j+1}, f^I_{j\to j+1}, f^V_{j\to j+1}\}$ be the transformation mapping of decision space from the jth flow to the $j+1$th flow.

In $f^D_{j\to j+1}: Domain_{ijk} \to Domain_{ij+1k} \cap element^{ijk}_t \to \{element^{ij+1k}_t, r^D_{ij+1k,t}, o^D_{ij+1k,t}\}$, $Domain_{ij+1k}$ is the decision domain of the ith level, the $j+1$th flow, and the kth time; $element^{ij+1k}_t$ is the decision factor transformed and mapped by $element^{ijk}_t$ in the decision domain of the ith level, the $j+1$th flow, and the kth time; $r^I_{ij+1k,t}$ is the mapping rules; and $o^I_{ij+1k,t}$ is the contents of the mapping rules. For example, the decision factor of inventory reduction, referring to material flow, can be transformed into the decision factor of production scheduling optimization, referring to information flow.

In $f^P_{j\to j+1}: problem^{ijk}_t \to \{problems^{ij+1k}_t, r^P_{ij+1k,t}, o^P_{ij+1k,t}\}$, $problem^{ijk}_t$ is the tth decision problem in the decision domain of the ith level, the jth flow, and the kth time; $problem^{ij+1k}_t$ is the decision problem transformed and mapped by $problem^{ijk}_t$ in the decision domain of the ith level, the $j+1$th flow, and the kth time; $r^P_{ij+1k,t}$ is the mapping rules; and $o^P_{ij+1k,t}$ is the contents of mapping rules. For example, the decision problem of how to shorten the product delivery time, referring to time flow, can be transformed into the decision problem of how to optimize delivery scheduling, referring to information flow.

Formal descriptions of mapping functions such as $f^O_{j\to j+1}$, $f^A_{j\to j+1}$, $f^I_{j\to j+1}$, and $f^V_{j\to j+1}$ are similar to the formal description of $f^P_{j\to j+1}$; hence, they are not depicted in detail in this paper.

Supposing $Flow_1$, $Flow_2$, and $Flow_3$ represent material flow, information flow and time flow, respectively, the following mapping relationships exists:

$$Flow_2 \to Flow_1$$
$$Flow_2 \to Flow_3$$
$$Flow_1 \cup Flow_3 \to Flow_2$$

As shown in the relationships, information flow can be mapped into material flow; for example, the production plan decides on the material flow in the enterprises. Information flow can also be mapped into time flow; for example, the production plan influences the production cycle. Conversely, material flow and time flow can give feedback to information flow; for example, the evaluation of material and time flows guides and corrects the production plan.

4.2.2.3. Analysis of the time dimension. Let $F_{k\to k+1} = \{f^D_{k\to k+1}, f^P_{k\to k+1}, f^O_{k\to k+1}, f^A_{k\to k+1}, f^I_{k\to k+1}, f^V_{k\to k+1}\}$ be the mapping of decision space from the kth time to the $k+1$th time.

In $f^D_{k\to k+1} : Domain_{ijk} \to Domain_{ijk+1} \cap element^{ijk}_t \to \{E^{ijk+1}_t, R^D_{ijk+1,t}, O^D_{ijk+1,t}\}$, E^{ijk+1}_t is the set of decision factors mapped by $element^{ijk}_t$ in the decision domain of the ith level, the jth flow, and the $k+1$th time; $R^D_{ijk+1,t}$ is the set of the relationships of the decision factors; and $O^D_{ijk+1,t}$ is the content set of the relationships of the decision factors. For example, the decision factor referring to the operation efficiency of production plans during a month can be decomposed into the set of sub-decision factors referring to the operation efficiency of production plans during a week. Time series relationships exist among these sub-decision factors.

In $f^P_{k\to k+1} : problem^{ijk}_t \to \{P_{ijk+1,t}, R^P_{ijk+1,t}, O^P_{ijk+1,t}\}$, $problem^{ijk}_t$ is the tth decision problem in the decision domain of the ith level, the jth flow, and the kth time; $P_{ijk+1,t}$ is the set of sub-problems decomposed and mapped by $problem^{ijk}_t$ in the decision domain of the ith level, the jth flow, and the $k+1$th time; $R^P_{ijk+1,t}$ is the set of the dependent relationships of the sub-problems; and $O^P_{ijk+1,t}$ is the content set of the dependent relationships of the sub-problems. Generally speaking, a certain problem related to time series in a supply-chain network can be divided into several sub-problems related to time points. It depends on these sub-problems and their structural relationships. For example, the decision problem of how to improve the average utilization of production equipment can be decomposed into a set of sub-problems of how to improve the utilization of production equipment at a specific time. Dependent relationships exist among these sub-problems.

Formal descriptions of mapping functions such as $f^O_{k\to k+1}$, $f^A_{k\to k+1}$, $f^I_{k\to k+1}$, and $f^V_{k\to k+1}$ are similar to the formal description of $f^P_{k\to k+1}$; hence, they are not depicted in detail in this paper.

Mapping relationships of $Time_1 \to Time_2$ and $Time_2 \to Time_1$ exist between time series $Time_1$ and time points $Time_2$. The two can be expressed by the relationship of set and elements, so they can be transformed into each other.

4.2.2.4. Comprehensive analysis of the three dimensions. Taking the three dimensions together, let

$$F_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}} = \{f^D_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}, f^P_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}, f^O_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}, f^A_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}, f^I_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}, f^V_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}\}$$

represent the mapping of decision space from the ith level to the $i+1$th level, from the jth flow to the $j+1$th flow, and from the kth time to the $k+1$th time.

The mapping function

$$f^D_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}} : Domain_{ijk} \to Domain_{i+1j+1k+1} \cap element^{ijk}_t \to \{E_{i+1jk,t}, R^D_{i+1jk,t}, O^D_{i+1jk,t}\} \cap element^{i+1jk}_t \to \{element^{i+1j+1k}_t, r^D_{i+1j+1k,t}, o^D_{i+1j+1k,t}\} \cap element^{i+1j+1k+1}_t \to \{E^{i+1j+1k+1}_t, R^D_{i=1j+1k+1,t}, O^D_{i+1j+1k+1,t}\}$$

can be achieved by level mapping, flow mapping and time mapping successively.

The mapping function

$$f^P_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}} : problem^{ijk}_t \to \{P_{i+1jk,t}, R^P_{i+1jk,t}, O^P_{i+1jk,t}\} \cap problem^{i+1jk}_t \to \{problem^{i+1j+1k}_t, r^P_{i+1j+1k,t}, o^P_{i+1j+1k,t}\} \cap problem^{i+1j+1k}_t \to \{P_{i+1j+1k+1,t}, R^P_{i+1j+1k+1,t}, O^P_{i+1j+1k+1,t}\}$$

can also be achieved by level mapping, flow mapping and time mapping successively.

Formal descriptions of mapping functions such as $f^O_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}$, $f^A_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}$, $f^I_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}$ and $f^V_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}$ are similar to the formal description of $f^P_{\substack{i\to i+1\\ j\to j+1\\ k\to k+1}}$; hence, they are not depicted in detail in this paper.

5. Case study

A case of a manufacturing supply-chain network is studied to illustrate the application of the proposed flow-based three-dimensional collaborative decision-making model. Because there are various decision domains in the proposed three-dimensional collaborative decision-making framework, the analysis of all domains is redundant. For brevity, two decision domains are chosen without a loss of generality for the analysis of the one-way mapping functions. The two decision domains are the decision domain $(Level_2, Flow_2, Time_1)$, positioned by the tactical level, information flow and time series, and the decision domain $(Level_3, Flow_1, Time_2)$, positioned by the operational level, material flow and time points. The decision space of the decision domain $(Level_2, Flow_2, Time_1)$ is shown in Table 1. It shows the vectors' values of the operation efficiency of the production plan in the decision domain $(Level_2, Flow_2, Time_1)$, including the definition of the decision domain, the recognition of decision problems, the determination of decision objectives, the drawing up of decision actions, the establishment of decision indexes, and the evaluation of actions' results. The vectors' values elaborate the decision-making process systematically and comprehensively. Taking advantage of the decision space function can support the clearing and transparency of the decision process. In a real supply-chain network, the final actions of decision focus primarily on the material flow at different time points at the operational level.

After the mapping of $F_{\substack{2\to 3\\ 2\to 1\\ 1\to 2}}$, the transformation of the decision space of the decision domain $(Level_2, Flow_2, Time_1)$ into the decision space of the decision domain $(Level_3, Flow_1, Time_2)$ is shown in Table 1, according to the mapping methods of decision space described in Section 4.2.2. The mapping realizes the vectors' decomposition of decision space from the tactical level to the operational level, the vectors' transformation from information flow to material flow, and the vectors' decomposition from the time series to the time point. By means of mapping, general decisions about the operation efficiency of production plans at the tactical level can be transformed into

Table 1
Mapping analysis of decision space from decision domain $(Level_2, Flow_2, Time_1)$ to decision domain $(Level_3, Flow_1, Time_2)$.

Vectors of decision space	Vectors' value before mapping	Mapping function	Vectors' value after mapping
$Domain_{2,2,1}$	Tactical level Information flow Time series	$F_{2\to3}$ $2\to1$ $1\to2$	Operation level Material flow Time points
$Problems_t^{2,2,1}$	Low average efficiency of the production plan in a certain period	$F_{2\to3}$ $2\to1$ $1\to2$	Redundancy of production processing nodes Unreasonable arrangement of production processing nodes Overloading of bottleneck nodes Incompatibility of production processing nodes Inadequacy of upstream material supply Low speed of material flow in production processing nodes Low efficiency of workers
$Objective_t^{2,2,1}$	Average efficiency improved more than preset threshold	$F_{2\to3}$ $2\to1$ $1\to2$	Reduction of node redundancy Optimization of node arrangement Elimination of bottleneck nodes' overloading Coordination of production processing nodes Optimization of upstream material supply Acceleration of material processing Workers' training for efficiency improvement
$Action_t^{2,2,1}$	Carry out research and create a detailed, careful, and scientific production plan	$F_{2\to3}$ $2\to1$ $1\to2$	Identify redundant nodes, make adjustments, combine or eliminate them According to the resource constraints, optimize the layout of production processing nodes by advanced scheduling tools Identify bottleneck nodes, update or extend their capacity Adopt advanced methods to coordinate production processing nodes Enhance the service of upstream material supply Adopt advanced methods to speed up material processing Carry out regular training for workers
$Index_t^{2,2,1}$	Average efficiency of the production plan	$F_{2\to3}$ $2\to1$ $1\to2$	Ratio of redundant production processing nodes Capacity and speed of production lines Number of bottleneck nodes and their overloading capacity Frequency of incompatibility among the production- processing nodes in unit time Grade of the service about upstream materials supply Time length for workers' training
$Evaluation_t^{2,2,1}$	Evaluate whether the efficiency matches the expected objective, and make adjustment in time	$F_{2\to3}$ $2\to1$ $1\to2$	Evaluate the ratio of node redundancy and make adjustments Evaluate the capacity and speed of material processing and make adjustments Evaluate the number of bottleneck nodes and their overloading capacity and make adjustments Evaluate the frequency of incompatibility among production processing nodes in unit time and make adjustments Evaluate the grade of the service of upstream materials supply and make adjustments Evaluate the time length for workers' training and make adjustments

the exact decisions about material flow (such as the production process, the production processing node, raw materials and labor force) at the operational level. These operation decisions can support the realization of decision making in the decision domain $(Level_2, Flow_2, Time_1)$. Members of different organizations can participate in collaborative decision making on the basis of material, information and time flows. Furthermore, flow-based collaborative decision making can effectively cross organizational boundaries and perform similarly to centralized decision making under the premise of satisfying the self-interests of organizations. Therefore, the proposed flow-based three-dimensional collaborative decision-making model has great significance in both theory and application.

To further verify the proposed collaborative decision-making model, comparative simulation experiments are designed and implemented using a supply-chain network. This network has five levels, including a level of suppliers, two levels of manufacturers, a level of distributors and a level of customers. The network provides three types of productions for three types of customers. The production processes in suppliers are not discussed in the network. The parameters of the network are defined at the operational level, including the three aspects of material, information and time flows. The parameters of material flow refer to the static types and layouts of nodes (production, inventory and delivery) and dynamical material transformation rules. The parameters of information flow care about the scheduling policies of production and deliver tasks. The parameters of time flow are related to time attributes of material and information flows and time collaboration schemes for distributed simulation. The parameter definitions can be found in [14]. A multi-agent system is adopted to build the simulation model of the network. This paper uses agent-based distributed simulation technology [18] to implement the designed simulation model for collaborative decision-making analysis. In the network, (i) materials from suppliers are unlimited; (ii) the stochastic production failure of manufacturers is not considered because the case primarily focuses on enterprises' collaborative decision making; (iii) resource (e.g., materials and delivery) competition exists among enterprises; (iv) stockout decreases, competitive resource coordination, task scheduling optimization and customer customer-demand priorities are considered in the collaborative decision-making process; and (v) the objective of the decision making is the overall optimization of the network. The experiment processes are described as follows: First, the model before decision making is simulated to obtain the operation efficiency of the production plans of manufacturers and the overall supply-chain network. Second, the operation efficiency is evaluated according to the preset objectives. According to the evaluation results, the collaborative decision-making model is used to conduct the mapping analysis of decision spaces similarly to Table 1, and the parameters of the network are adjusted according

Table 2
Comparison of operation efficiency of production plans before and after decision making.

	First (%)	Second (%)	Third (%)	Average (%)
Before decision making				
Manufacturer 1	83.69	82.80	80.25	82.25
Manufacturer 2	93.75	92.11	93.75	93.21
Manufacturer 3	100	100	100	100
Manufacturer 4	77.35	77.13	75.07	76.52
Manufacturer 5	93.14	90.76	95.32	93.07
Supply-chain network	89.59	88.56	88.88	89.01
After decision making				
Manufacturer 1	100	100	100	100
Manufacturer 2	100	100	100	100
Manufacturer 3	100	100	100	100
Manufacturer 4	71.07	70.18	71.79	71.01
Manufacturer 5	99.30	99.30	99.30	99.30
Supply-chain network	94.07	93.90	94.21	94.06

to the analysis results. Third, the adjusted model after decision making is simulated to obtain the operation efficiency of the production plans of manufacturers and the overall supply-chain network. Finally, the simulation results of the two models are compared to verify the proposed decision-making model.

The operation efficiency of the production plans of manufacturers and the overall supply-chain network are calculated using the following equations:

$$E_{Manufacturer_i}^{Production\quad plan} = \frac{\frac{Sum\quad of\quad time}{Number\quad of\quad tasks}}{Unit\quad time\quad of\quad task}$$

$$E_{Supply\quad network}^{Production\quad plan} = \frac{\sum_i E_{Manufacturer_i}^{Production\quad plan}}{Number\quad of\quad manufacturers}$$

To consider the stochastic factors in the simulation process, each model is simulated three times. The average value of the three times is used. Table 2 shows the comparison of the operation efficiency of production plans before and after decision making.

First, the operation efficiency of the production plans of the overall supply-chain network before and after decision making are compared. Before decision making, the operation efficiency of the production plans of the overall supply-chain network is 89.01%. After decision making, the value is 94.06%, representing a 5.05% increase. The operation efficiency promotion is due to resource coordination and task scheduling optimization using the proposed decision-making model. The results demonstrate that the proposed decision-making model can effectively support decision making for the overall optimization of a supply chain-network in a specific decision space.

Second, the operation efficiency of the production plans of manufacturers before and after decision making are compared. This supply-chain network has five manufacturers. Before decision making, the operation efficiency of the production plans of manufacturers 1–5 is 82.25%, 93.21%, 100%, 76.52% and 93.07%, respectively; after decision making, these values are 100%, 100%, 100%, 71.01% and 99.30%, respectively. As mentioned above, unlimited materials from suppliers, sufficient delivery resources among suppliers and manufacturers and the lack of failure of manufacturers' production cause the operation efficiency of the production plans of manufacturers 1, 2 and 3 to approach 100%. However, the stockouts, resource competition and task incoordination lead to the lower operation efficiency of the production plans of downstream manufacturers. In the comparative experiments, the operation efficiency of manufacturers 1, 2 and 5 increases by 17.75%, 6.79% and 6.23%, respectively. Manufacturer 2 maintains a value of 100%. Only the value of manufacturer 4 reduces by 5.51%. The reason is that the overall optimization of the supply-chain network may lead to the efficiency reduction of some manufacturers. Nonetheless, the results clearly illustrate that the proposed decision-making model can effectively support decision making for the individual optimization of supply chain-network members in a specific decision space.

6. Conclusions and further study

The inter-organizational collaboration of supply-chain networks is an important modern mode that requires organizations to collaborate with each other on important operational processes to promote overall performance. In such a context, the decentralized decision making of each organization needs to be included in the collaborative framework. Inter-organizational collaborative decision making should solve several problems related to technology, particularly problems related to crossing the boundaries of organizations and maintaining the interests of each organization. Material, information and time flows are analyzed as the key ways to support inter-organizational collaboration and to affect the performance of a supply-chain network. Based on the inter-organizational principles of the three flows, a perspective of flow-based inter-organizational collaborative decision making is proposed. Additionally, an important collaborative methodological tool—a flow-based three-dimensional collaborative decision-making model—is proposed. The model shows the content vectors and process specifications in the collaborative decision making for supply-chain networks, creatively puts forward the concepts of the decision domain and the decision space, and studies the mappings of decision space among different decision domains. It defines a clear decision scope and allows all organizations and their members to participate in collaborative decision making. In application, the model contributes to determining decision problems both inside and outside organizations, setting up reasonable decision objectives, creating effective decision actions, establishing perfect decision indexes and evaluating itself and the overall performance based on the actions' results. Differently from previous models, it is an efficient collaborative decision solution in promoting the accuracy and precision of collaborative decision making, and it serves as an effective reference for the actual operation of collaborative decision making for real supply-chain networks. The model represents a powerful tool for managers and staff in all organizations to be involved in organizational decision making and the improvement of supply chain-network performance.

However, the collaborative decision-making model has some limitations. First, the model is comprehensive. The mappings of the decision space among different decision domains make the model difficult to understand and use. Second, although the paper provides effective formal descriptions of the mappings of decision space, it does not consider an automatic function for the mappings. Obviously, this function is of great important to reduce the difficulty of using the model and to improve decision-making efficiency. In addition, more in-depth application research on the proposed model should be conducted. These limitations create great opportunities for future research. Therefore, future research should focus on the model improvement, automatic function development and more in-depth case studies of supply-chain networks based on this model.

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References

[1] M.M.E. Alemany, F. Alarcon, F.C. Lario, J.J. Boj, An application to support the temporal and spatial distributed decision-making process in supply chain collaborative planning, Comput. Ind. 62 (5) (2011) 519–540.
[2] A. Arkhipov, D. Ivanov, An entropy-based approach to simultaneous analysis of supply chain structural complexity and adaptation potential, Int. J. Shipp. Transp. Logist. 3 (2) (2011) 180–197.
[3] A. Bhattacharya, P. Mohapatra, V. Kumar, P.K. Dey, M. Brady, M.K. Tiwari, S.S. Nudurupati, Green supply chain performance measurement using fuzzy ANP-based balanced scorecard: a collaborative decision-making approach, Prod. Plan. Control 25 (8) (2014) 698–714.
[4] Z.H. Che, T.A. Chiang, Designing a collaborative supply-chain plan using the analytic hierarchy process and genetic algorithm with cycle-time estimation, Int. J. Prod. Res. 50 (16) (2012) 4426–4443.
[5] J.H. Cheng, Inter-organizational relationships and information sharing in supply chains, Int. J. Inf. Manag. 31 (4) (2011) 374–384.
[6] C.Y. Cheng, T.L. Chen, Y.Y. Chen, An analysis of the structural complexity of supply chain networks, Appl. Math. Model. 38 (9–10) (2014) 2328–2344.
[7] M. Ganesh, S. Raghunathan, C. Rajendran, The value of information sharing in a multi-product, multi-level supply chain: Impact of product substitution, demand correlation, and partial information sharing, Decis. Support Syst. 58 (2014) 79–94.
[8] J.E. Hernandez, M.M.E. Alemany, F.C. Lario, R. Poler, SCAMM-CPA: a supply chain agent-based modelling methodology that supports a collaborative planning process, Innovar-Rev. Cinecias Adm. Soc. 19 (34) (2009) 99–120.
[9] J.E. Hernandez, A.C. Lyons, J. Mula, R. Poler, H. Ismail, Supporting the collaborative decision-making process in an automotive supply chain with a multi-agent system, Prod. Plan. Control 25 (8) (2014) 662–678.
[10] J.E. Hernandez, R. Poler, J. Mula, D. de La Fuente, Collaborative tactical planning in multi-level supply chains supported by multiagent systems, IFIP Adv. Inf. Commun. Technol. 322 (2010) 260–267.
[11] I.H. Hong, J.C. Ammons, M.J. Realff, Decentralized decision-making and protocol design for recycled material flows, Int. J. Prod. Econ. 116 (2) (2008) 325–337.
[12] S.Y.P. Lu, H.Y.K. Lau, C.K.F. Yiu, A hybrid solution to collaborative decision-making in a decentralized supply-chain, J. Eng. Technol. Manag. 29 (1) (2012) 95–111.
[13] J. Lin, Q.Q. Long, Development of a multi-agent-based distributed simulation platform for semiconductor manufacturing, Expert Syst. Appl. 38 (5) (2011) 5231–5239.
[14] Q.Q. Long, An agent-based distributed computational experiment framework for virtual supply chain network development, Expert Syst. Appl. 41 (9) (2014) 4094–4112.
[15] Q.Q. Long, Distributed supply chain network modelling and simulation: Integration of agent-based distributed simulation and improved SCOR model, Int. J. Prod. Res. 52 (23) (2014) 6899–6917.
[16] Q.Q. Long, Three-dimensional-flow model of agent-based computational experiment for complex supply network evolution, Expert Syst. Appl. 42 (5) (2015) 2525–2537.
[17] Q.Q. Long, J. Lin, Z.X. Sun, Agent scheduling model for adaptive dynamic load balancing in agent-based distributed simulations, Simul. Model. Pract. Theory 19 (4) (2011) 1021–1034.
[18] Q.Q. Long, J. Lin, Z.X. Sun, Modeling and distributed simulation of supply chain with a multi-agent platform, Int. J. Adv. Manuf. Technol. 55 (9–12) (2011) 1241–1252.
[19] Q.Q. Long, W.Y. Zhang, An integrated framework for agent based inventory-production-transportation modeling and distributed simulation of supply chains, Inf. Sci. 277 (2014) 567–581.
[20] H.J. Shin, Collaborative production planning in a supply-chain network with partial information sharing, Int. J. Adv. Manuf. Technol. 34 (9–10) (2007) 981–987.
[21] M. Shnaiderman, F. El Ouardighi, The impact of partial information sharing in a two-echelon supply chain, Oper. Res. Lett. 42 (3) (2014) 234–237.
[22] F. Yan, M. Li, Game analysis on the collaborative operation behavior in logistics service supply chain, in: Proceedings of 3rd International Conference on Consumer Electronics, Communications and Networks (CECNet), 2013, pp. 324–327.
[23] M.A. Zamarripa, A.M. Aguirre, C.A. Mendez, A. Espuna, Mathematical programming and game theory optimization-based tool for supply chain planning in cooperative/competitive environments, Chem. Eng. Res. Des. 91 (8) (2013) 1588–1600.
[24] H.X. Zhang, Y. Deng, F.T.S. Chan, X.G. Zhang, A modified multi-criterion optimization genetic algorithm for order distribution in collaborative supply chain, Appl. Math. Model. 37 (14–15) (2013) 7855–7864.
[25] G.Q. Zhang, J. Lu, Model and approach of fuzzy bilevel decision making for logistics planning problem, J. Enterp. Inf. Manag. 20 (2) (2007) 178–197.
[26] G.Q. Zhang, J. Shang, W.L. Li, Collaborative production planning of supply chain under price and demand uncertainty, Eur. J. Oper. Res. 215 (3) (2011) 590–603.
[27] G.Q. Zhang, G.L. Zhang, Y. Gao, J. Lu, Competitive strategic bidding optimization in electricity markets using bilevel programming and swarm technique, IEEE Trans. Ind. Electron. 58 (6) (2011) 2138–2146.