

A NETWORK MODELING APPROACH WITH INTERDEPENDENT AGENTS FOR NETWORK COORDINATION

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ABSTRACT: A good coordination in supply chain network can achieve competitive advantages in terms of performance and customer satisfaction. In this paper, a supply chain is modeled as a network with higher visibility and better coordination among the supply chain entities. The approach is an integration of network modeling and agent-based framework, which considers the coordination problem in supply chain network with multiple entities. A supply chain is firstly modeled as a network with a set of nodes for supply chain entities and links for interdependent connection among entities, interdependent agents are then introduced to link and evaluate the output information from preceding entities to the input information for the succeeding entities in a supply chain network. The interdependent agents address problems of autonomy and complexity that cause changes and disruptions in supply chain network, so the proposed modeling approach can adjust any deviation as well as can maximize the coordinating performance in the network.

Keywords: Agent-based modeling, Network modeling, Supply chain management, Supply Chain Network

1. INTRODUCTION

In supply chain management, organizations tend to work closer to their partners, not only customers but also various types of logistics entities in the supply chain network, such as manufacturers, distributors, retailers. Establish valuable interdependencies among entities can achieve better coordination in supply chain network [1-5], which can help to maintain the overall performance of the network. Moreover, in studying the dynamic network interdependencies in supply chain, the characteristics of contemporary business situations and the internal functional structure of supply chain network can be revealed [6-10]. The importance of network interdependencies for enhancing the supply chain values in product or service delivery can also be found in the literatures [11-15].

In modeling the network interdependencies in supply chain network, most of the extant studies represent the supply chain network as a linear process flow, and capture the associated paths and tasks directly. However, supply chain network is a complex adaptive system [16-19] that involves a certain degree of autonomy among the entities in the network, such entities' autonomy can be effectively studied in an agent-based framework [20-23].

Agent-based framework is a distinctive modeling technique that emerged from a number of research disciplines including artificial intelligence [20], system design and analysis using object-oriented methodology and human interfaces [24-27]. Agent-based framework is a useful computational model for studying the coordination issues arising from the interaction of individual behaviors of a collection of

entities. Agents work through autonomous rule-based reasoning in response to their internal and external environment, and organize themselves to provide solutions by determining the structures, heterogeneity and hierarchy of the problems or environments in which they are participating [20,28]. In supply chain study, agent-based framework is used to utilize information to support multi-objective decision making [27], and to represent the interactive processes and the associated behaviors between interdependent and distributed entities [20,22,24]. The extant studies demonstrate the agent-based framework can realistically capture and simulate the dynamic autonomous and the inherent complexity of the entities in the supply chain network.

Although it is effective to apply the agent-based framework in modeling supply chain network, the potential of agents in coordinating the network has yet been exploited. This may due to the difficulties in practically fitting the agents to the problems, so many extant studies focused on modeling single entity application only. In addition, there is limited research addresses the use of interdependent agents in coordinating supply chain network. Therefore, in this paper, a network modeling approach with interdependent agents is proposed. The approach is an integration of network modeling and agent-based framework, which considers the coordination problem in supply chain network with multiple entities. The interdependencies and behaviors between agents are modelled in a network perspective, so a higher visibility and better coordination can be achieved in supply chain management.

The structure of this paper is as follows: the proposed network modeling with interdependent

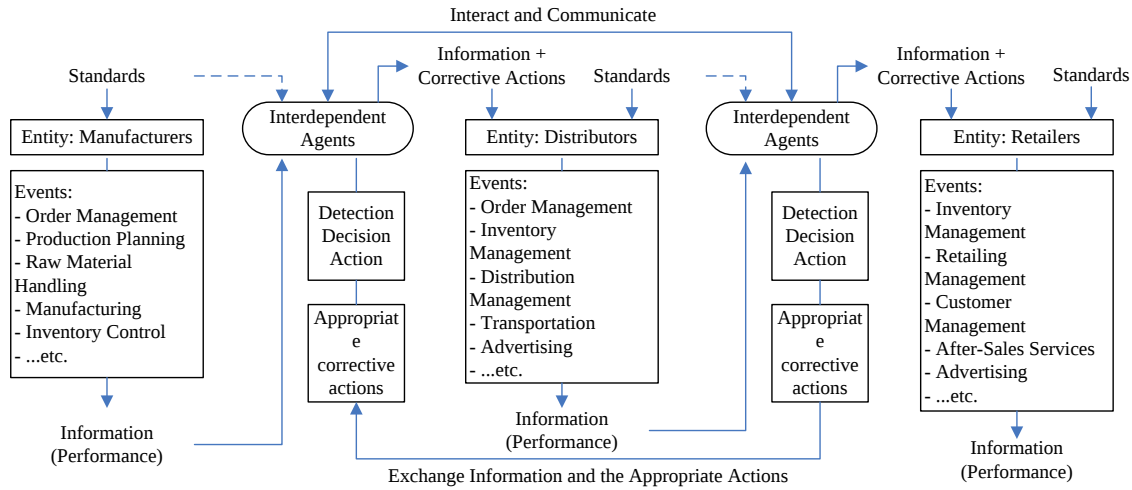


Fig.1 Framework of the network modelling approach with interdependent agents

agents is discussed in section 2. The interdependent agents' working environment, types, the adaptation and learning methods, and the communication methods are included in Section 2. A simulation study of the proposed approach is presented in section 3. Finally, a conclusion with suggestions for further development is given in section 4.

2. NETWORK MODELING WITH INTERDEPENDENT AGENTS

In the network modeling approach, a supply chain is modeled as a network of nodes (N) and links (L), in which $N = \{n_i | 1 \leq i \leq n\}$ as a set of supply chain entities while $L = \{l_j | 1 \leq j \leq l\}$ as a set of links between the supply chain entities. Because the performance of the supply chain network depends on the information transmits from one entity to other entities over the links, so interdependent agents are then introduced in the interdependent connection between the nodes. The interdependent agents need to address problems of autonomy and complexity that can cause changes and disruption in the supply chain network. Therefore, in this paper, a supply chain can be modeled as a network with higher visibility and better coordination among the entities. The major feature of the approach is the use of interdependent agents to link the output information from preceding entities to the input information for the succeeding entities in supply chain network. The information is related to the performance of the supply chain network, which is from the entities of manufacturers, distributors, retailers, etc. Fig. 1 presents the overall framework of the proposed modeling approach.

2.1 Working Environment

A supply chain network is a network that composes a parallel flow of products, materials, services, and information from the suppliers through

various intermediate entities to the customers, where all the entities are interrelated and connected together for the efficient and effective flow of information. In this paper, the interdependent agents respond and react to all the series or parallel flow performed by the entities in supply chain network, and these events can be denoted as a set of events E , i.e.

$$E = \{e_0, e_1, e_2, \dots, e_\infty\} \quad (1)$$

where e is the element of events E , and the events in the supply chain network can be distributed or continuous. For each recorded event in the supply chain network, there should be a related distinctive action responding to the event. These actions can be denoted as a set of actions ACT , i.e.

$$ACT = \{\alpha_0, \alpha_1, \alpha_2, \dots, \alpha_\infty\} \quad (2)$$

where α is the element of ACT , and the number of actions are limited to the number of events E in the supply chain network, i.e. $ACT \in E$. Each α in ACT carries a series of items of information from the previous event as an input action for the next event; meanwhile, each α in ACT also carries a series of items of information after each event is completed, and acts as an output action. Since interdependent agents are used in the supply chain, the actions α are then adaptive to the changes that occur in the event e .

In the proposed modeling approach, the supply chain network starts from an event e_0 of an entity. Next, the interdependent agents will decide on a set of actions α for the event e_1 that leads to the next event in the supply chain network. The interdependent agents will consider various appropriate actions for an event, but only one suitable action will be executed. This will lead to the start of the next event. The agent will continually execute suitable actions for each event in the supply chain

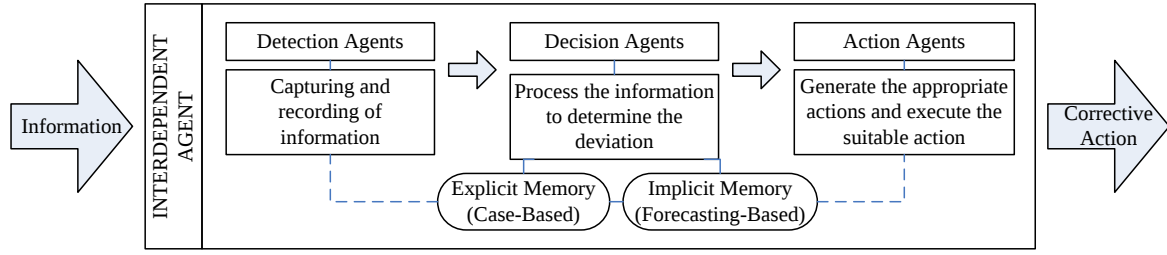


Fig. 2 Relationship between the detection, decision and action agents

network until the last event is reached.

Due to the dynamic variables in the supply chain network, the amount of information input for an event may be different from the output information from previous events. The interdependent agents are responsible for monitoring and controlling these variations. If the output information from an event is better than its input information, it means the performance of this particular event was good, and problems may not exist in this particular event. With this good information, the interdependent agents will then decide on what action is appropriate for the next event. In this way, performance can be maintained within the supply chain network. On the other hand, if the initial input information is better than the output information, which means problems may exist in this particular event. Investigation or corrective actions will be initiated by the interdependent agents on this particular event and will decide what action is appropriate for the next event to maintain the performance in the supply chain network. Variation between the input and output information can be determined by the following algorithm:

$$Q(e_{i+1}) = \tau \times Q(e_i) \frac{\sum x_i(e_i)}{\sum y_i(e_i)} \quad (3)$$

where $Q(e_{i+1})$ is the status of the information for the event e_{i+1} , $Q(e_i)$ is the status of the information of event prior to it, i.e. e_i . $\sum x_i(e_i)$ and $\sum y_i(e_i)$ are the input and output information of the event e_i , respectively. τ is a coefficient that represents the investigation or corrective actions of the interdependent agents in order to maintain the status of the information of an event.

For a completed supply chain network, a set of event-action routings R should be involved. The set of routings R for the interdependent agents in the supply chain network is induced by the interchanging sequence of the events and the executed actions. A general routing $r \in R$ can be illustrated as:

$$r: e_0 \xrightarrow{\alpha_0} e_1 \xrightarrow{\alpha_1} e_2 \xrightarrow{\alpha_2} \dots \xrightarrow{\alpha_{\infty-1}} e_{\infty} \quad (4)$$

where r is the element of routings R , i.e. $R = \{r_0, r_1, r_2, \dots, r_{\infty}\}$, and R can be considered as all the possible routings for each event and the appropriate actions based on reliable information.

Since the interdependent agents have to address problems of autonomy and complexity that lead to changes and disruptions with their intelligence, a coefficient for the interdependent agents' action is then added to each action. The coefficient represents the deviated action from the normal action as well as the adjustment from the original coordination. The set of agent-heuristic routings in Eq.(4) can then be further illustrated as:

$$R^{AG} = \{r_0^{AG}, r_1^{AG}, r_2^{AG}, \dots, r_{\infty}^{AG}\} \quad (5)$$

where R^{AG} is the agent-heuristic routing, and $r^{AG}: e_0 \xrightarrow{\tau\alpha_0} e_1 \xrightarrow{\tau\alpha_1} e_2 \xrightarrow{\tau\alpha_2} \dots \xrightarrow{\tau\alpha_{\infty-1}} e_{\infty}$. With the set of events E , action ACT , agent-heuristic routing R^{AG} and agent coefficient τ , the working environment for the interdependent agents can then be defined as:

$$Working\ Environment = \langle E, ACT, R^{AG}: \tau \rangle \quad (6)$$

Therefore, the interdependent agents can coordinate the supply chain network in terms of information from events, actions, and heuristic routings.

2.2 Types of Interdependent Agents

In the modeling approach, three types of interdependent agents are proposed, i.e. detection agent, decision agent, and action agent. All these agents are subject to the properties of the working environment for interdependent agents, i.e.

$$AGENT \text{ def } \langle DETECTION_{AGENT}, DECISION_{AGENT}, ACTION_{AGENT} \rangle \\ s.t. \langle E, ACT, R^{AG}: \tau \rangle \quad (7)$$

Detection agents are the interdependent agents that responsible for capturing and recording the status of all information within the supply chain network. In order to obtain the information $Q(e_i)$ from an event e_i , the detection agents will capture and record the status of it in terms of a set of information in the working environment for interdependent agents, i.e.

$$Q(e_i) \rightarrow DETECTION_{AGENT}: Q(e_i) = \{q_0, q_1, q_2, \dots, q_{\infty}\} \quad (8)$$

After the information is captured and recorded, decision agents will process the information. Decision agents possess a certain level of skill and is knowledgeable about how to process the designated information and has considerable skill in handling scientific algorithms and computations to determine any changes needed in the information, i.e.

$$\begin{aligned} DETECTION_{AGENT}: Q(e_i) = \{q_0, q_1, q_2, \dots, q_\infty\} \rightarrow \\ DECISION_{AGENT}: Q^*(e_i) \end{aligned} \quad (9)$$

where $Q^*(e_i)$ is the designated information with 3 situations, i.e. $Q^*(e_i) = 1$: the output information is better than the input information; $Q^*(e_i) = 0$: the output information is the same as the input information; and $Q^*(e_i) = -1$: the output information is worse than the input information. If changes occur in the information and have been detected by the decision agents, the action agents will then generate a set of appropriate actions. Action agents are adaptable and can generate and store the appropriate actions for every events, and will select one suitable action for the event to execute, i.e.

$$\begin{aligned} DECISION_{AGENT}: Q^*(e_i) = \{1; 0; -1 \rightarrow \\ ACTION_{AGENT}: ACT^{AG} = \{\alpha_0^{AG}, \alpha_1^{AG}, \alpha_2^{AG}, \dots, \alpha_\infty^{AG}\} \end{aligned} \quad (10)$$

where ACT^{AG} is the set of appropriate actions for an event, but only one suitable action α_{i+1}^{AG} will be executed by the action agents for the next event, i.e.

$$ACTION_{AGENT}: ACT^{AG} = \{\alpha_{i+1}^{AG*} \rightarrow Q(e_{i+1})\} \quad (11)$$

where α_{i+1}^{AG*} is the most suitable action for the next event, in which appropriate corrective action is carried out to maintain the information $Q(e_{i+1})$ for the next event in the supply chain network. The relationships among the three types of interdependent agents in the supply chain network are illustrated in Fig. 2.

2.3 Adaptation and Learning

Two adaptation and learning memory mechanisms are adopted by the interdependent agents to enhance the monitoring and controlling of the information. The two memory mechanisms are “explicit memory” and “implicit memory”. “Explicit memory” allows the interdependent agents to learn from historical actions so they can react quickly to any significant changes in the information, while “implicit memory” allows the interdependent agents to propagate the action in response to changes of the information.

The “explicit memory” mechanism is based on the distributed case-based learning approach that was developed from the former agents’ action and

behavioral patterns on information, and is stored in its knowledge base. Such knowledge is then reused for future cases that possess similar information. This knowledge is retrieved through an extended case-based reasoning mechanism. On the other hand, the “implicit memory” mechanism is to modify any deviation in the promissory information. The forecasting-based learning approach simulates the action and behavioral patterns regarding unforeseen perturbations and changes in the information from the events of the entities. By revealing these unpredictable behaviors, the interdependent agents are able to generate appropriate action to correct any deviation in the information.

2.4 Communication between Agents

In the working environment for interdependent agents, the agents communicate and interact with each other to maximize internal utility functions and maintain the stability in the supply chain network. There are two main kinds of communication information between agents, i.e. input information for action and output information for process. Fig. 3 illustrates the communication cycle of interdependent agents for an event in the supply chain network.

In the communication, there are two rule-based methods for transmitting communication signals, i.e. through public broadcasting or one-to-one communication. In communication through public broadcasting, all interdependent agents in the working environment can receive communication signals despite the position of the event or of the entity in the supply chain network, and then the target agents can respond to the signals. On the other hand, the communication signal for one-to-one communication sent to the target interdependent agents only.

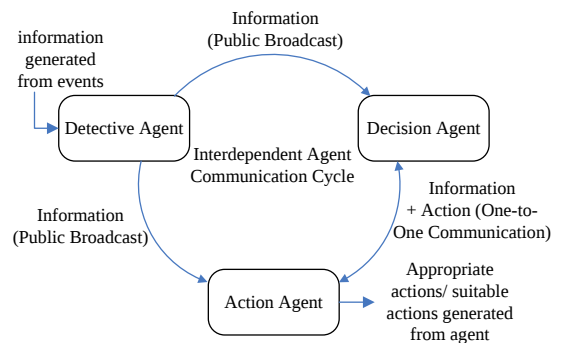


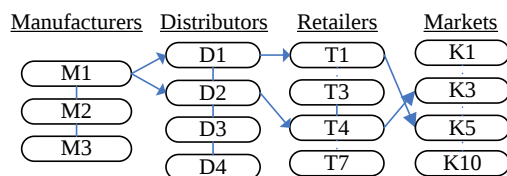
Fig. 3 Communication cycle among the interdependent agents.

3. A SIMULATION STUDY

For illustrating the proposed modeling approach, a simulation study on a supply chain network is conducted. The simulation involves a supply chain

network with three manufacturers, four distributors, and seven retailers. The supply chain network is targeted for ten markets.

Since there are three manufacturers $M = \{1,2,3\}$, four distributors $D = \{1,2,3,4\}$, seven retailers $T = \{1,2,3,\dots,7\}$, and ten markets $K = \{1,2,3,\dots,10\}$, there are totally 840 possible heuristic routings with a minimum of 2520 interdependent agents, coefficient and corrective action for each product. In this simulation, the data are quantified by the synthetic analytical methods so the data can be used as the performance data. The product demand, the quantified standard for each entity, and the quantified information from entity to entity are predefined in the interdependent agents' working environment. For the quantified standard, there are upper and lower limits for the data so that flexibility can be induced for the coefficient τ . If any deviation occurs between the information and standard, interdependent agents will carry out the corrective action α . The coefficient τ and the corrective actions α are heuristics that are determined by the interdependent agents in the simulation. For this repeated monitoring and controlling of the information and the interdependent agents' actions, the best heuristic routings with case-based and forecasting-based set of $\tau\alpha_{MDT}^1(e_i)$ and $\tau\alpha_{MDT}^2(e_i)$ are thus defined as $M_1 \rightarrow D_1 \rightarrow T_1 \rightarrow K_5$, and $M_1 \rightarrow D_2 \rightarrow T_4 \rightarrow K_3$ (Fig.4). According to these simulation result, the performance are maximized: $Q_{MDT}^* = 490$ and $Q_{MDT}^{2*} = 114$. In addition, using the proposed approach, interdependent agents can identify the worst routings as well as the entities with relatively poor performance, i.e. manufacturer M_2 , distributor D_3 , and retailers T_3 , T_6 , T_7 , in the simulation study. Therefore, by maximizing and performance in the supply chain network, the entities can closely interact with each other and achieve higher visibility and better coordination.



4. CONCLUSION

In this paper, a network modeling approach with interdependent agents is proposed. The approach is an integration approach that considers the coordination problem in supply chain network with multiple entities. The interdependent agents are used to monitor and control the input and output information that generated by the supply chain entities. The major feature of this approach is the modeling adopts the

features of agent for network coordination. The proposed interdependent agents can thus autonomously and adaptively to generate appropriate and suitable corrective actions for adjusting any deviation in the network. In this way, performance can be assured in the supply chain network. Moreover, the modeling approach can help to maximum the performance in the supply chain network, so the entities can closely interact with each other and achieve higher visibility and better coordination; in turn, a higher customer satisfaction can be achieved in the supply chain network.

The modeling approach proposed in this paper can be further improved in several ways. In the working environment for the interdependent agents, sub-agents can be used to assist the coordination within the events of the entities to enhance the autonomy and adaptively of the supply chain network. Moreover, for the interdependent agents, the definition of information can further be elaborated and equipped with other elements, such as the cost of taking corrective actions. To further elaborate these elements, the agent-based modeling approach can balance the objectives between the information and the cost of the supply chain network. Therefore, if any problem arises in the supply chain network, the corrective action taken by the interdependent agents can maximize the performance as well as minimize the cost of the whole operation.

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