Air Materiel Supply Intelligent Collaborative Decision-making Mode Based on Ontology and Multi-Agent

Xiong Li[1], Chang-xin Liu[1], Fang Bing[1] and Xiongyi Li[2]
[1] *School of Management, Shanghai University, China*
[2] *Graziadio School of Business and Management, Pepperdine University, USA*

Abstract

To solve the complexity problem of each node and the diversity problem of decision-influencing factors in air materiel supply chain, an air materiel supply intelligent collaborative decision-making mode based on ontology theory and multi-agent has been proposed. To better organize the collaborative knowledge utilized by agents and facilitate agents' adaptive collaborative decision-making ability, an ontology-based approach is presented in this paper. The knowledge is separated into shared ontology and private ontology to ensure both the agent communicative interoperability and the privacy of strategic knowledge. Then, the collaborative mode and action planning of agents are analyzed, and the architecture of intelligent collaborative decision-making system of two-echelon air materiel supply chain has been designed. Thus a platform for the consultations and coordination of each agent has been provided, and an effective decision-making method has been proposed to decision-makers of air materiel supply.

Keywords intelligent collaborative decision, Ontology, multi-agent, action planning

1 Introduction

The decision-making mode of the air materiel supplying is actually one of the most important subjects in the field of air materiel management and engineering. In the decision-making process, the airline and air force mainly use the best analytical model available for the aircraft spares provisioning problem, which includes the order, transportation, storage and consumption of air materiel[1-3].In supply chain network, the complexity of each node and the diversity of decision-influencing factors are indispensable attributes, however, when making decisions, decision makers only consider a certain part or some key factors in the decision process. Usually, the actual decision authority and processes are distributed among the members in the supply chain, who are primarily concerned with optimizing their own objectives. As a result, making appropriate decisions to attain optimal performance in air materiel supply chain is a very challenging problem. Traditionally, contractual agreements and complex accounting schemes are used to ensure that the supply-chain works effectively during daily operations. And the centralized or hierarchical decision-making process in these supply chains results in losses of efficiency in a competitive and dynamic market environment. Members in a supply chain have to coordinate their individual decision-making closely and cooperatively to achieve optimal supply chain performance with balanced services level and inventory level, the each node of supply systems can no longer be viewed in isolation, they must be managed in the context of the total business and the associated key linkages of the business, and the collaboration is an attractive strategy in air materiel supply chain network. Due to the complexity of each node and the diversity of decision-influencing factors in the field of air materiel supply, it is worth to research the air materiel supply intelligent collaborative decision-making system to aid managers to make decisions.

Decision support systems (DSS) is the area of the information systems (IS) discipline that is focused on supporting and improving managerial decision-making[4]. The history of DSS reveals the evolution of a number of sub-groupings of research and practice. The major DSS sub-fields include Personal Decision Support Systems (PDSS), Group Support Systems (GSS), Organization Decision Support Systems(ODSS), Negotiation Support Systems (NSS), Intelligent Decision Support Systems (IDSS),Distributed Intelligent Decision Support Systems (DIDSS),Knowledge Management-Based DSS (KMDSS), Distributed Intelligent Cooperative Decision Support Systems(DICDSS) [5-8],etc. With the development of decision support systems, it has been applied in many areas, such as the application to support the temporal and spatial distributed decision-making process in supply chain collaborative planning[9].

A software agent is a program that performs a specific task on behalf of a user, independently or with little guidance, it is characterized with environment awareness, ongoing execution, autonomy, adaptiveness, mobility, intelligence, anthropomorphism, reproduction, independence, collaboration, distribution, etc. The software agent is crucial factor as DSS components to build Intelligent Collaborative Decision Support Systems characterized by cooperating agents, either human or non-human actors[9-11]. Ontology is a knowledge representation method with a philosophical concept as the branch of metaphysics which has been widely used in science and technology. From computer specialists perspective, ontology means a vocabulary and a set of terms and relations that define, with the needed accuracy, a set of entities enabling the definition of classes, hierarchies, and other relations among them [12], it has been established as a powerful paradigm to enable knowledge sharing, and became the foundation for many multi-agent system applications as a means to achieve semantic interoperability among heterogeneous agents systems. Many intelligent cooperative decision support systems based on ontology and multi-agent has been proposed by researchers[13-15]. For example, Chang-Shing Lee, etc. present an ontology-based intelligent decision support agent to apply to project monitoring and control to reduce the human efforts and the costs of the project [13]. In the study, the natural language processing agent, the fuzzy inference agent, the performance decision support agent, the capability maturity model integration ontology and project personal ontology are designed. Through the collaborative work of the agents and ontologies, the ontology-based intelligent decision support agent can work effectively for project monitoring and control of capability maturity model integration. Compared with the above articles, this paper has the following characteristics. At the first, the collaborative mode of agents based on ontologies has been designed, and according to the collaborative mode, the collaborative decision-making problem in agents located on the different nodes of supply chain network or between managements and agents can be resolved. Secondly, the approach of dynamic description logics(DDL) has been applied to planning the action sequences of agents in the instance of air material supply decisions. At last, the structure of air materiel supply intelligent collaborative decision support system based on the collaborative mode of ontologies and agents is designed. The details of this article are as follows.

The paper proposes a framework for building decision support systems using software agent technology and ontology to support organizations characterized by physically distributed, enterprise-wide, heterogeneous information systems. In Section 2, the structure and interoperability mode of ontology is presented, the multi-agents collaborative mode based on ontology is also analyzed, and a platform for the consultations and coordination of each agent has been provided. Section 3 analyzes the action planning of agent. In Section 4, the architecture of intelligent collaborative decision-making system of two-echelon air materiel supply chain is designed, and an effective decision-making method is presented to decision-makers of air materiel supply. Section5 presents conclusions of this paper.

2 The Multi-agents' Collaborative Mode Based on Ontology

2.1 Ontology based intelligent agent applications

An agent is defined as a software entity that is situated in some environment, and is capable of autonomous action in that environment in order to meet its design objectives[16]. A generic agent has a set of goals, certain capabilities to perform tasks and some knowledge about its environment. To achieve its goals, an agent needs to use its knowledge to reason about its environment and the behaviors of other agents, to generate plans and to execute these plans. A Multi-agent system(MAS) consists of a group of agents, interacting with one another to collectively achieve their goals. By absorbing other agents' knowledge and capabilities, agents can overcome their inherent bounds of intelligence. Air materiel supply intelligent collaborative decision-making system is the intelligent system based on air materiel supply knowledge. In the air materiel supply chain network, managers get consensus about some decision problems through the collaboration of intelligent agents or the intelligent agents and managers. Agent technology can provide flexible, distributed, and intelligent solutions for air materiel supply management. However, each agent is an independent entity, one agent needs to exchange the domain knowledge, related concepts with other agents in the internet, and the software agents need achieve the collaborative protocols regulating the set of rules that govern the interaction of agent.

Ontology as an explicit specification of a conceptualization, and the agreements about the conceptual frameworks for modeling domain knowledge, it is more than just a vocabulary and taxonomy of terms. It provides a set of well-founded constructs that can be leveraged to build meaningful higher level knowledge and relationships between terms[17]. By describing a set of concepts and the relationships between them, ontology can construct both the hierarchical architecture of the knowledge and the descriptive logics of regulations and activities. According to the ontology structure, inference rules can be defined to guide agents collaborative behaviors to adapt to various collaborative environments. As a novel knowledge organization concept, ontology is widely applied in the domain of information sharing, supply collaborative management, multi-agent systems, DSSs(Decision support systems) and rule-based reasoning systems to enable interoperable decision knowledge structures for knowledge sharing and utilization[18-20]. To effect the intelligent agent applications in the collaborative environment, ontology can help agents in representing and storing domain knowledge, enabling a semantic interoperable environment, reaching mutual understanding, reasoning and querying the knowledge repositories , maintaining a secure system access, etc.

In air materiel supply chain network, the members embrace mainly air materiel manufacturers, maintenance contractors, airlines, pooling providers of air materiel, etc. The pooling provider of air materiel is the air materiel warehouse or airline, manufacturer, maintenance contractor in essence which provides service of air materiel supply for the airlines, and the pooling provider charges the airlines in some calculation for the air materiel supply service in accordance with the agreement. In the decision-making analysis process of production, order and storage, generally the air materiel manufacturers, maintenance contractors and pooling providers are considered as the analysis object. Due to supply members needing to exchange the concept, domain knowledge and the agents' related activity specification in the collaborative decision process of air materiel manufacturers, maintenance contractors and pooling providers, two aspects have to be considered. The first is to solve the ontology interoperability problem in agent communication. The second is to build sophisticated private ontology and shared ontology to facilitate collaborative behavior deployment[15]. The private ontology abstracts the knowledge in supply chain collaborative decision which configures software agents computing and inference parameters. The shared ontology is developed in accordance with some criteria to ensure mutual understanding between agents developed by different air materiel supply chain members, and it is structured as the types of schemas: Concept and AgentAction, etc. The structure and interoperability mode of ontology are displayed by Fig.1.

The contents of shared ontology developed by pooling providers embrace the air materiel category, air materiel name, payment method, order quantity, ordering price, shared price, unit cost of transportation , unit cost of inventory, unit cost of missing parts, agent name, agent address, AID (agent Identifier), etc. The contents of private ontology developed by pooling providers comprise order cycle, manufacturer's credibility, transportation methods, ordering price concessions degree, the way of ordering price concessions, agent negotiation strategies, etc. The contents of shared ontology developed by manufacturers embrace the air materiel category, air materiel name, sale price, delivery time, terms of service, unit operating costs, agent name, agent address, AID, etc. The contents of private ontology developed by manufacturers comprise pooling providers credibility, ordering price concessions degree, the way of ordering price concessions, agent negotiation strategies, etc.

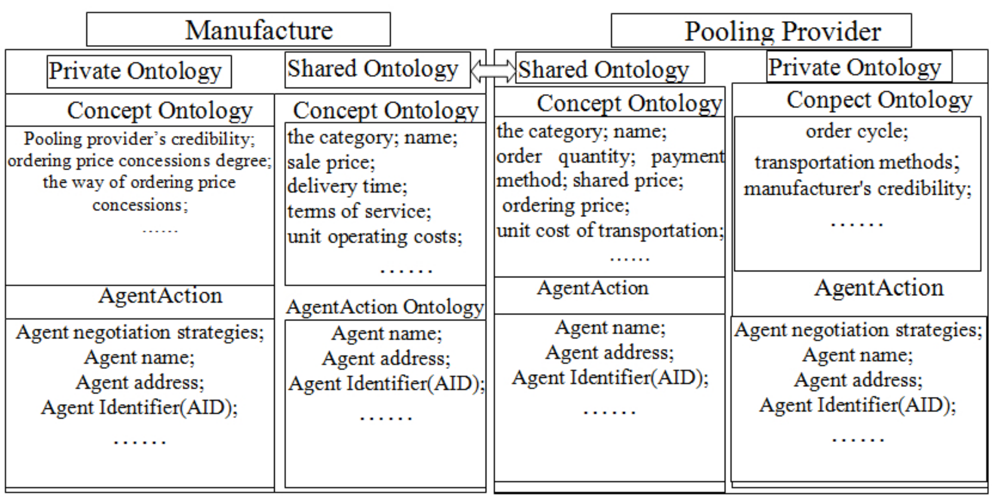

Fig.1 The Structure and Interoperability Mode of Ontology

2.2 The multi-agent collaborative mode

In the collaborative decision process of air materiel supply chain members, the members exchange the information and define the software agents collaborative mode through the ontology interoperability. The software agents solve the decision problem by interacting together. There is a set of intelligent agents defined as ordering decision agent, available inventory agent, manufacturer select agent, manufacturer production decisions agent, transport planning agent, etc. in the air materiel supply chain network. When the pooling providers make ordering decision, the ordering decision agent needs to choose adaptive agents from defined agents according to the task, and carry out manufacturer select agent to select possible manufacturers. Then the pooling provider sends information of order request to the possible manufacturers, exchanges shared ontology with them. According to the shared ontology exchanged and respective private ontology, the related parameters are calculated collaboratively by the ordering decision agent, available inventory agent and manufacturer production decision agent. At last, the order quantity and order price, etc. are negotiated repeatedly to determine the final order scheme by the ordering decision agent, manufacturer production decision agent and transport planning agent. The multi-agents collaborative mode is displayed by Fig.2.

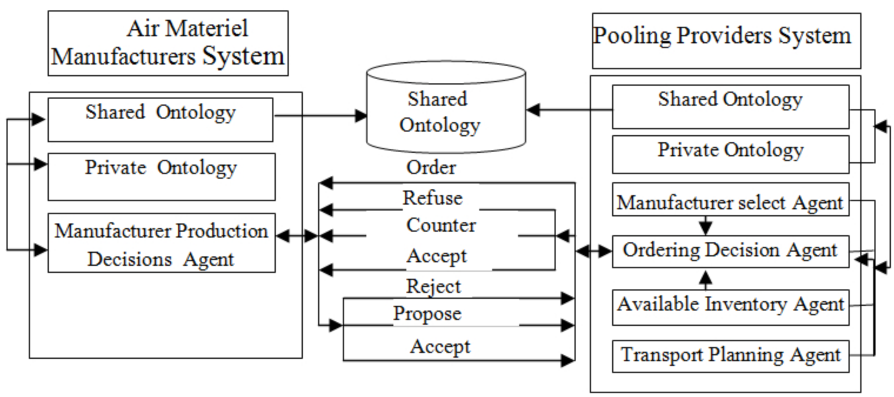

Fig.2 The Multi-agent Collaborative Mode

3 Agents action plan

An agent is a tuple, and concrete agents have the same architecture. The components of task agent is defined as follows: W=<Act, Belief, Desire, Intent>, Act is the act ability component, and represents available behaviours, as well as the situations in which these plans are applicable. Its action derive from collaborative mode of agent. Beliefs comprise information known by the agent, and regularly updated as a result of perception. Desire represents situations that the agent reacts to by adopting plans, corresponding to desired states. Intention structures comprise the set of partially instantiated plans currently adopted by the agent[21-23].

When the members of air materiel supply chain make ordering decision, the ordering decision agent embrace the order information of a certain air materiel. The content of its belief as follows:

$$\begin{aligned}Belief = \{&AVI(avi), Equal(avi, \text{``}Agent5\text{``}),\\ &PRC(prc), Equal(prc, \text{``}Agent7\text{``}),\\ &MPD(mpd), Equal(mpd, \text{``}Agent8\text{``}),\\ &M(m), Equal(m, \text{``}materiel6\text{``}),\\ &P(p_j), Equal(p_j, \text{``}Producer-1, Producer-2, ..., Producer-n\text{``}),\\ &MA_1(m, a_1), Equal(a_1, v_1), ...,\\ &MA_n(m, a_n), Equal(a_n, v_n), ...,\\ &PB_1(p_1, b_{11}), Equal(b_{11}, x_1), ...,\\ &PB_n(p_j, b_{jn}), Equal(b_{jn}, x_n), ...\}\end{aligned}$$

Concept AVI represents the collection of available inventory agent. Concept PRC represents the collection of manufacturer select agent. Concept MPD represents the collection of manufacturer production decisions agent. Concept TP represents the collection of transport planning agent. Concept M represents the collection of air materiel category. Concept P represents the collection of manufacturer.MA_k(m,a_K) represents the kth attribute of an item air materiel named M is a_K. Relation of Equal(a,v_k) represents that the value of a is v_k.PB_K(p_j,b_{jk}) represents the kth attribute of a manufacturer named p_j is b_{jk}. Relation of Equal (b_{jk}, x_k) represents that the value of b_{jk} is x_k.

The collection of belief represents that it knows an available inventory agent named Agent5, an manufacturer select agent named Agent7, an manufacturer production decision agent named Agent8, an item air materiel named materiel6 and n attributes of the air materiel, a set of manufacturers named Producer-j and n attributes of every manufacturer. The attributes of the air materiel may be the index of price, performance specifications and transport conditions, etc.

In the decision process, ordering decision agent receives the ordering instructions from upper layer agent to formulate an order scheme of an air materiel. According to collaborative mode of agent, the ordering decision agent sets the Desire as follows:

$$\{AI(m, q_0) \wedge HR(q_0) \wedge PC(m, p) \wedge HR(p) \wedge OQ(m, q) \wedge HR(q) \wedge OP(m, \omega) \wedge HR(\omega) \wedge AP(m, \phi) \wedge HR(\phi) \wedge EP(m, e) \wedge HR(x)\} \quad .$$

Relation of AI(m,q_0) represents the available inventory of air materiel named m is q_0. Relation of PC(m, p) represents manufacturer of air materiel named m is p. Relation of OQ(m, q) represents order quantity of air materiel named m is q. Relation OP(m, ω) represents the collaboration price of air materiel named m is ω. Relation AP(m, ϕ) represents profit distribution parameters of air materiel named m is ϕ.Relation EP(m, e) represents optimal expected profit is e in the collaborative ordering decision process. Concept $HR(x)$ represents returning to the upper layer agent. Ordering decision agent determines the order quantity, collaboration price, profit distribution parameters and optimal expected profit, then the order scheme is returned to upper layer agent.

After the objective of agents determined, it searches the act ability base according to the collaborative mode, and plan the sequence action for achieving the goals. The act of ordering decision agent comprises the action as follows:

RequestAvailableInventory(availableinventory Agent5,materiel, attribute$_1$, ..., attribute$_n$, availablequantity)=
$<$ { AI(availableinventory Agent5), K(availableinventory Agent5),
M (materiel), K(materiel),
MA$_1$(materiel, attribute$_1$) , K(attribute$_1$),...,
MA$_n$ (materiel, aattribute$_n$) , K(attribute$_n$),
- AI(materiel, availablequantity)} ,
{ K(availablequantity), AI(materie1, availablequantity)} $>$

RequestProducersChoose(producerschoose Agent7, producer-j, attribute$_j$1, ..., attribute$_j n$, producer)=
$<$ { PC(producerschoose Agent7), K(producerschoose Agent7),
P (producer-j), K(producer-j),
PB$_1$(producer-1, attribute$_1$1) , K(attribute$_1$1),...,
PB$_n$ (materiel, aattribute$_j n$) , K(attribute$_j n$),...,
- PC(materiel, producer-j)} ,
{ K(producer-j), AI(materie1, producer-j)} $>$

RequestDecisionsPlan(manufacturerproductiondecision Agent8, quantity, price, assigning parameters, optimalexpectedprofit)=
$<$ { MPD(manufacturerproductiondecision), K(manufacturerproductiondecision),
M (materiel), K(materiel),
P (producer-j), K(producer-j),
AI (materiel, availablequantity) , K(availablequantity),
PC (materiel, producer-j) , K(producer-j),
- (OQ(materiel,quantity)$\wedge$OP(materiel, price)$\wedge$AP(materiel, assigning parameters) $\wedge$EP(materiel, optimalexpectedprofit))} ,
{ K(quantity), OQ(materiel,quantity),
K(price), OP(materiel, price),
K(assigning parameters), AP(materiel, assigning parameters),

K(optimalexpectedprofit), EP(materiel, optimalexpectedprofit) } >

ReturnOrdersPlan(producer, quantity, price, assigning parameters, optimalexpectedprofit)=
< { MPD(manufacturerproductiondecision), K(manufacturerproductiondecision),
M (materiel), K(materiel),
PC(materiel, producer-j), K(producer-j),
OQ(materiel,quantity), K(quantity),
OP(materiel, price), K(price),
AP(materiel, assigning parameters), K(assigning parameters),
EP(materiel, optimalexpectedprofit), K(optimalexpectedprofit),
-(HR(producer-j)∧HR(quantity)∧HR(price)∧HR(assigning parameters)∧
HR(optimalexpectedprofit))},
{ HR (producer-j), HR(quantity), HR (price), HR (assigning parameters),
HR(optimalexpectedprofit) } >

The concept K represents the value of an element has been determined. The RequestAvailableInventory indicates if the attribute of surplus stock, repairing parts and parts waiting for repair of an air materiel and an available inventory agent are known, then the number of available stock can be obtained through the available inventory agent. The RequestProducersChoose indicates if the attribute of quality, order price, reliability, maintainability of an air materiel produced by different manufacturers and a manufacturer select agent are known, then the manufacturers can be obtained through the manufacturer select agent. The RequestDecisionsPlan indicates if the number of available inventory and manufacturer of an air materiel and a manufacturer production decisions agent are known, then order quantity, collaborative price, profit distribution parameters and optimal expected profit can be determined through the manufacturer production decisions agent. The appropriate ordering scheme of an air materiel can be formulate. The ReturnOrdersPlan indicates if manufacturer, the number of available inventory, order quantity, collaborative price, profit distribution parameters and optimal expected profit are known, then it can be considered as an order scheme returned to upper layer agent. The action achieving decision objective as follows:

$$\text{RequestAvailableInventory } (avi, m, a_1, \ldots, a_n, q_0)$$
$$\text{RequestProducersChoose } (prc, p_j, a_{j1}, \ldots, a_{jn}, p)$$
$$\text{RequestDecisionsPlan } (mpd, q, \omega, \phi, e)$$
$$\text{ReturnOrdersPlan } (p, q, \omega, \phi, e)$$

The sequence action represents firstly the available stock and manufacturer can be obtained through available inventory agent and manufacturer selection agent, then the request of ordering is sent to manufacturer production decision agent for obtaining the collaborative price, profit distribution parameters and optimal expected profit of an air materiel, at last the order scheme is returned to upper layer agent.

4 The structure of the intelligence collaborative decision-making support system

Owing to the distribution of the geographical location of the air materiel supply chain members, the heterogeneity of the network and internal business data resources, and the dynamic of decision support activities, the problem of mistakes and misunderstandings among the supply chain members are easy caused. To facilitate the collaborative decision support activities in the air materiel supply chain members, it is essential to integrate and filter the information of inventory, distribution, production and logistics, and to provide a shared domain knowledge structure to enable the members to reach mutual understanding with each other. At the same time, collaborative mechanism of the members and collaborative mode of agent need to be designed, and the interaction between man and computer is realized based on web.

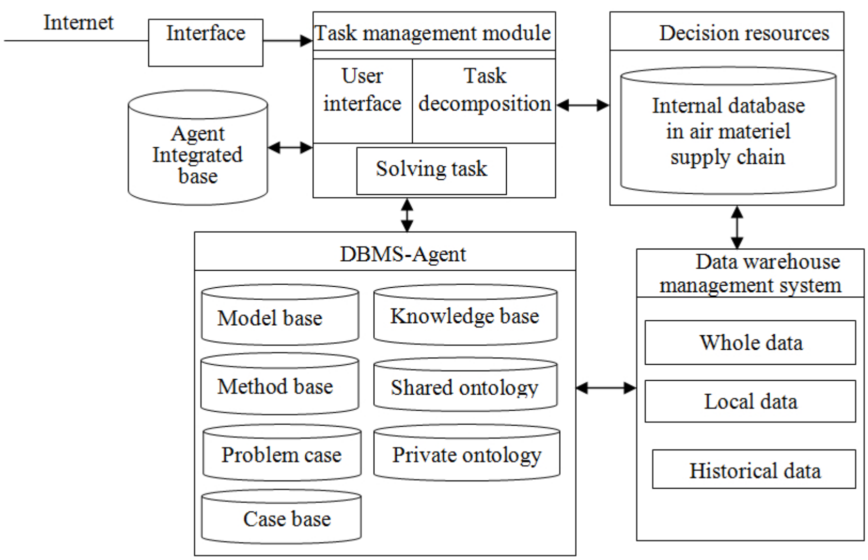

Fig.3 The System Architecture

There are many types of decision agents owned by the members of air materiel supply chain. In the every decisions process, each decision agent calls on the corresponding agent in supply chain network according to the decision tasks, and they complete the decision task through the collaborative mode. The system architecture shows as Fig.3. It mainly comprises the interface, task management module, internal database and management system of each node in air materiel supply chain, data warehouse and management system, the agents integrated base, model base, knowledge base, method base, problem base, case base, shared ontology base, private ontology base, the management systems, etc.

When the members of air materiel supply chain submit decision problems to the system through interface, the task management module calls on the corresponding agent to resolve and deal with the decision problems, and the shared ontologies are exchanged to guarantee the mutual understanding of agents through the interface agent and ontology agent. Then the collaborative decision-making model is established, and decision problems are solved by calculation and reasoning through calling on the database, model base, knowledge base, method base and case base. The subsequent collaborative processes between the members involve iterative exchanges of proposals and counter-proposals until the final result is achieved.

5 Conclusions

In this paper, an intelligence collaborative decision-making mode based on the ontology and multi-agent technology has been proposed. A generic structure and interoperability mode of ontology has been developed. It involves the knowledge representation method and collaborative protocol. The collaborative scheme of multi-agent has also been presented. Then, the collaborative mode and action planning of agent are analyzed, and the architecture of intelligent collaborative decision-making system of two-echelon air materiel supply chain has been designed. A platform for the consultations and coordination of each agent has been provided, and an effective decision-making method has been proposed to decision-makers of air materiel supply. The proposed decision-making mode is still in the development stage, in the future, the model can be extended to encompass more collaboration considerations in air materiel supply chains.

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Corresponding Author

Author can be contacted at: liuchangxin5128@msn.com.