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Research on the Control Organization of Integrated Agile Supply Chain Based on Multi-agents

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Abstract

In the area of integrated agile supply chain system based on multi-agents (MASCM), the architecture and control of its organization are both important preconditions to ensure effective cooperation between multi-agents which are carried by MRPII/ERP. With the backgrounds of the automobile parts supply chain for Shanghai Volkswagen's Santana in China, the organization model and dynamic control model are designed according to the hierarchical system of SVW's supply chain and cooperative supply tasks. It is proved that the prototype system of MASCM can be developed using them, whose method and result have universal significance.

Keywords: Supply Chain Management, Agile Manufacture, Multi-agents System, MRPII/ERP

1. Introduction

The conflict between the changes of customers' demand and minimum utilization of operation resource is a forever topic for any enterprise. With the coming of global market and acceleration of technological transform, market competition becomes more and more intense. In order for survival, the enterprises are imposed on constant requirements such as shorter delivery time, higher quality, lower cost and better service than ever, which will definitely further the conflict between these two aspects. Agile supply chain management is a newly-initiated concept based on the above premise, which grasps the market opportunities and resists risks by means of the integration of enterprise's interior resources and dynamic exterior alliance so as to make full use of enterprise's interior and exterior resources efficiently to win the market competition --- so as to enhance the abilities to adapt to ever-changing customers' demand and optimize relevant resources on the supply chain.

At present, Manufacturing Resource Planning (MRPII) which integrates various operation activities, such as procurement, production, sales, logistics, human resource, finance and so on inside the enterprise, as well as Enterprise Resource Planning (ERP) which expands towards the enterprise's exterior resources have played a major role in assisting the enterprise to manage supply chain. As the original starting point of MRPII/ERP is limited inside the enterprise's interior, a new research subject of an agile supply chain information system between enterprises was proposed, which can dynamically configure and construct MRPII and ERP to manage the modern supply chain. Sponsored by the Chinese 863/CIMS fund,

with the background of the automobile part supply chain for Shanghai Volkswagen's Santana which have relatively stable supply relationship and regulated market environment with certain representation and complication, a Multi-agent Integrated Agile Supply Chain Model (MASCM) is suggested and researched to develop a prototype system.[1]。

MASCM's design concept is mainly based on the multi-agent technology in Distributed Artificial Intelligence (DAI) to establish a management system organized and coordinated hierarchically, which combines with communications system while coordination and management is distributed in the cooperation work between multi-agents on different network nodes. The research of MASCM is aimed at two key questions: ①Hierarchical control and dynamic organization structure of agile supply chain among MRPII/ERP subsystems under distributed isomerous environment; ②Constraint and conflict resolution management in the process of MRPII/ERP subsystem's cooperation on the supply chain. This article focuses on ①, and ② will follow in another article. Firstly, in section 1, the control and organization from of integrated supply chain based on multi-agents is presented, including the description of initialized organization structure, the description of hierarchical organization structure and how to create MASCM's control organization dynamically. Then, in section II, a detailed description about the creation of MASCM's organization model is given to demonstrate the definition of organization model and the organization structure. Finally, the creation of MASCM's dynamic hierarchical control model is discussed as well as the definition, the creating and operating process, evaluation etc.

2. Control and Organization Form of Integrated Agile Supply Chain Based on Multi-agents

The control and organization of MASCM refers to the responsibilities (the role) of agent in various activities and definitions of their inter-relationship (association method, control authority and communication protocol) in order to establish a close and cooperative relationship between agents, guide the disassembly and distribution of the supply task, integrate and evaluate the share and result of the processing data. Central control and distributed control are the two extremes in multi-agents cooperative process control between which hierarchical control is. Broadly speaking, the upper and lower node relationship on the supply chain can be any multi-to-multi relationship, which shows an overall irregular network structure. Therefore, many current literatures focus on the framework structure[3,4,5] of either central integrated control based on star pattern with high coupling degree or distributed control with low coupling degree, etc. However, in practice, the structure of supply chain normally takes on some rules. Take Santana for example, the car assembly factory disassembles the car into several major part groups(such as chassis system, power system, shift system, transmission system and brake system, etc.) which are purchased from each backbone professional part factories; and each backbone part manufacturer will purchase from more suppliers. This current situation is shown in an obvious hierarchy (see fig. 1).
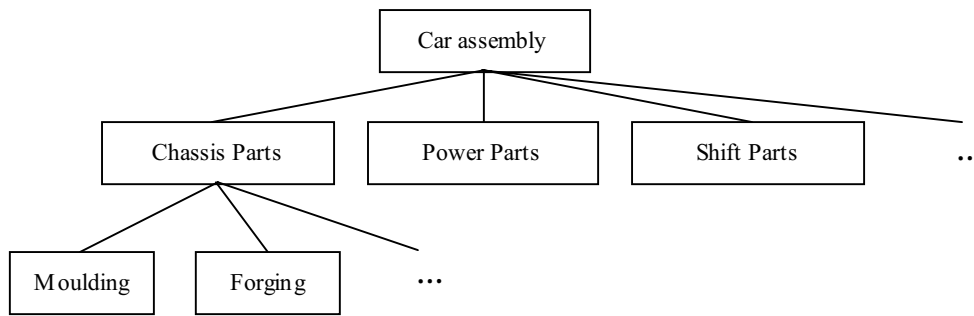
Fig.1 Supply Chain Hierarchical Structure Model of Automotive Parts

Hierarchical control is linked by several partial centers level by level. Although the control nodes are distributed, they have many advantages of central control. The following three traits that MASCM has are the main reasons to adopt hierarchical control and dynamic organization:

（1）Supply task in fig. 1 has a natural subtask hierarchical structure. It is natural and effective to complete the organization task according to the task's hierarchical structure. Considering that plenty of different node negotiations and data transmissions exist among upper and lower nodes, system's communication volume can be greatly reduced.

（2）Agent receiving the task from the higher level becomes the control center in this level, whose position enables it to know the overall situation of the controlled and supervised agents, then efficiently instructs the coordination and distribution of the supply task to avoid and solve potential conflict sin time to promote the close cooperation between controlled agents.

（3）In practice, the responsibilities and inter-relationship of agents may vary according to different supply tasks and need be dynamically refreshed and changed in coordination. Therefore, it is more efficient to dynamically establish the organization controlled by MASCM.

In MASCM's hierarchical control organization, the number of control center should be limited into one in each level, thus some distributed controlled functions can be reserved in each level to allow the control center to organize cooperation of agents in the same level dynamically according to the accepted task ---- which is flexible (there are multiple options to the organized agents), adaptable (adaptable to some specialty) and effective (similar to fixed hierarchical system).

2.1 Description of Initialized Organization Structure

MASCM is composed of five-level agent groups (car assembly factory, backbone parts factory, core parts factory, peripheral parts factory and raw material supply factory)（see fig. $2(a)$）. Each level includes a MAgent with coordination and management abilities as well as several members SAgent (see fig. 2(b)) carried by MRPII/ERP. This structure belongs to

parallel structure catalogue. The initialized organization structure of MASCM is described as：

$$\text{Init\_Stru} = (L, M, S, F_1, F_2)$$

In which：

(1) L is the collection of agents in all levels；

(2) M is the collection of all Magents；

(3) S is the collection of all SAgents；

(4) F_1 is the map，$F_1: L \rightarrow M$，describing the distributed situation of MAgent in each level；

(5) F_2 is the map，$F_2: L \rightarrow S$，describing the distributed situation of SAgent in each level.

Level No. 1 Car Assembly Factory
2 Backbone Parts Factory
3 Core Parts Factory
4 Peripheral Parts Factory
5 Raw Material Facotry

T_{i-1}_Packet
Magent_i / GM_i
$i^{\#}$
T_i_Packet
$\text{MAgent}_{i+1}/GM_{i+1}$
$(i+1)^{\#}$
T_{i+1}_Packet
$i=2\sim4$

Fig: ⬭ Group Member Team ● Group Manager ○ Group Member
→ Task Transmission Relation ⟶ Affiliation

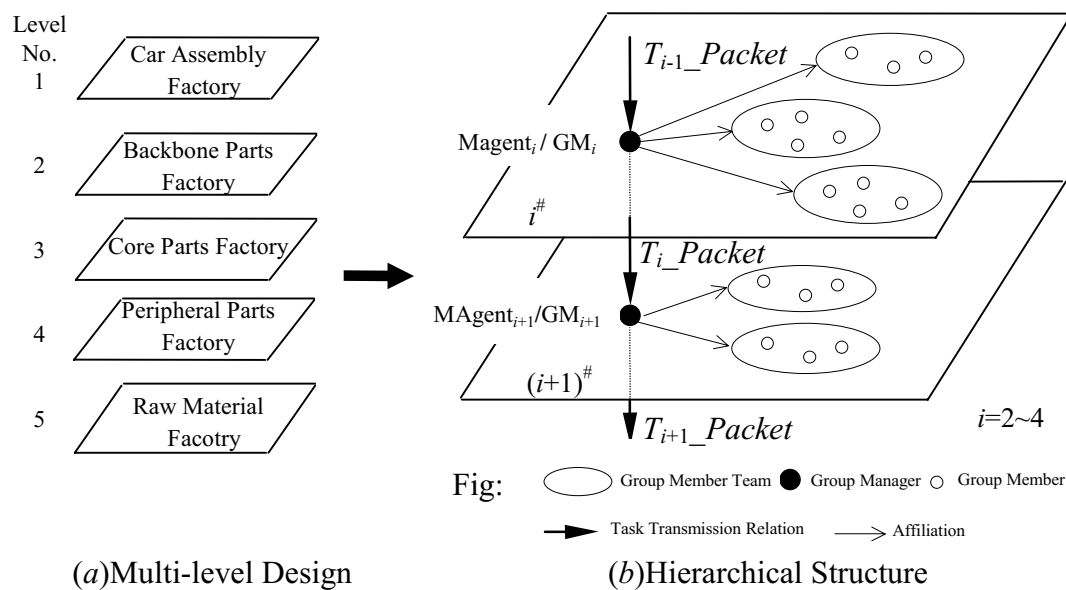(*a*)Multi-level Design   (*b*)Hierarchical Structure

Fig.2   Hierarchical Structure of MASCM

2.2 Description of Hierarchical Organization Structure

MASCM adopts the multi-level plan based on production assembly relationship similar to Bill of Material (BOM) in MRPII system shown in fig. 1. Structure details from the car assembly factory to each part raw material supplier can be divided into five question spaces accordingly, the task plan on level $(i+1)^{\#}$ ($^{\#}$ means a suffix here) is more detailed than that of level $i^{\#}$. This hierarchical structure of the supply chain task is the natural basis for MASCM organization control. In fig. 2(*b*), MAgent$_i$ receives supply task/contract packet T_{i-1}_Packet transmitted from level $(i-1)^{\#}$, and becomes the GM$_i$(Group Manager) to fulfill the task in level $i^{\#}$. GM$_i$ distributes or transfers the supply subtasks in a task packet to several SAgent in the same level, and coordinates the implementation of subtasks and undergoes centralized dispatching and control. All of the SAgent assigned with the subtasks in the same task packet is called Group Member Team. Group Management and Group Member Team jointly form an implementation group aiming at some certain task packet. During the period when the task allocation on this level is being founded, some content which needs resolution/purchase in a lower level is regarded as detail and forms level $(i+1)^{\#}$ task packet T_i_Packet to be passed

downwards. With the recursion and decomposition of the task, these implementation groups come into existence level by level and the Group Managers are linked into hierarchical control.

Following this, all the group managers and members form a hierarchical organization structure of MASCM. At one time, its hierarchical organization structure is described as：

$$\text{Dynamic\_Stru} = （\text{Init\_Stru}，T，\geqslant，F_3）$$

In which：

(1) T is the collection of the task T_Packet transmitted among levels,

$$T = \bigcup_{n=1}^{5} \bigcup_{j}^{n(i)} T_n\_Packet_j$$, function $n(i)$ stands for the number of tasks transmitted between level i

and $i+1$ ；

(2) " $\geqslant$ " represents the leadership or task transmission relationship between group managers, if m_1 , $m_2 \in M$ and $m_1 \geqslant m_2$ ，then m_1 leads m_2 ；

(3) SAgent collection in each level according to map F_2 is SL ，and F_3 is a map，F_3 ： $T \rightarrow 2^{|SL|}$ ，describes the situation that SAgents are organized into an implementation group to carry out tasks.

2.3 Dynamic Creation of MASCM Control Organization

Dynamic creation of MASCM control organization can be defined as map F_3 to realize the change from parallel structure to hierarchical structure. Map F_3 describes the distribution of subtasks among members in the same level. After the group manager receives task from level $(i\text{-}1)^{\#}$, the cooperative model of relevant task assignment is established according to the tasks list that SAgent can bears in the same level, then select several best ones from those who can bear this task in the list to carry out this subtask (like the selection process of suppliers). This article will focus on maps F_1 , F_2 , F_3 and detailed realization methods of the cooperative model of task assignment.

3. Creation of MASCM Organization Model

3.1 Definition of Organization Model

In order to accurately depict MASCM system organization by an "explicit" language, the organization model is defined as following:

Org-Model = < Org-Struct，Org-Principle>
Org-Struct = < A^* ，Role，Responsibility，Goal，Relation，Ω >
Org-Principle = <Org-Strategy，Org-Law>
In which, Org-Model represents that the definition of organization model is composed of

Org-Struct and Org-Principle. Fundamental organization structure and form is defined by Org-Struct. Org-Principle defines the organization principle for the organization structure of

Org-Struct.

3.2 Organization Structure

The organization structure of MASCM is the distributed model of information, extension and ability to carry out the supply task, etc. between agents. Organization structure defines the inter-relationship, function, responsibility distribution, organization goal between organizational members:

(1) A^* shows the basic members who compose MASCM organization. $A^* = \{A_1,$ $A_2,$ $\cdots,$ $A_n\}$, $A_i (i \leqslant n)$ is the description on agent's sign and calculation resources.

(2) "Role" is the collection of necessary functional components in system organization. Role $= \{r_1,$ $r_2,$ $\cdots,$ $r_m\}$, $r_i (i \leqslant m)$ means the definition of each responsibility.

(3) "Responsibility" is the collection of responsibility assignment, which shows the distribution situation of role in A^*. If $r_i(A_j)$ （$A_j \in A^*$, $j \leqslant n$, $r_i \in$ Role, $i \leqslant m$）means that A_j can complete the responsibility defined by r_i, then the organization responsibility (i.e. the ability in organization structure) can be demonstrated by a collection: Capacity$(A_j) = \{r_{j_1}(A_j),$ r_{j_2} $(A_j),$ $\cdots,$ $r_{j_k}(A_j)\}$, so Responsibility $= \displaystyle\sum_{i=1}^{n}$Capacity$(A_i)$ 。

(4) "Goal" means the collection of organization goal completed by the system. Goal $=$ $\{g_1, g_2, \cdots, g_p\}$. There is a responsibility collection to each organization goal $g_i (i \leqslant p)$ which represents that this goal is fulfilled jointly by agents who bear relevant responsibilities, i.e.: Responsibility$(g_i) = \{r_{x_1}(A_x),$ $r_{x_2}(A_x),$ $\cdots,$ $r_{y_1}(A_y),$ $r_{y_2}(A_y),$ $\cdots\}$ 。Responsibility(g_i), the responsibility collection of g_i, may be statically defined before the implementation of task assignment, i.e. static disassembly of the task. It may also be defined dynamically in implementation process, i.e. dynamic disassembly of the task.

(5) "Relation" refers to the potential inter-relationship between agents who bear some organization responsibilities, including relevant limit, communication, relevant position, etc.

(6) "Ω" refers to the exterior environment exerted by the system.

3.3 Organization Principle

Organization principle is the behavior constraint function based on the organization structure, whose precondition is to satisfy the basic constraint of organization structure definition. Each strategy in the organization principle stands for a formalized system commitment mapped as the law which system members should obey to ensure the implementation of the system commitment.

（1）Org-Strategy = < Task-Distribute-Strategy，Coordination-Control-Strategy，Communication-Strategy，Conflict-Resolution-Strategy>，in which：

Task-Distribute-Strategy：defines both the representation of the task and the realization method of task disassembly, distribution as well as the result integration and evaluation；

Coordination-Control-Strategy：defines a group of methods or ways for agents to administrate their shared environment. Coordination-Control-Strategy includes the change method, cooperative method of the organization form, balance principle between partial negotiation and cooperative activities, as well as the control strategy to enhance the overall coherence；

Communication-Strategy ：chiefly includes communication protocol and mutual operation protocol, such as TCP/IP based on Internet, CORBA/COM standard and interface protocol of some certain MRPII/ERP softwares.

Conflict-Resolution-Strategy：includes the representation, inspection and resolution of the conflict；

（2）Org-Law：MASCM inspects whether the interaction between organization members corresponds to some principles to maintain the organization model via the law. Law refers to the relevant measures and mechanism which maintain the implementation of the overall commitment, and demonstrates the resolutions while the constraint and regulation is violated. For instance, various communication used in interaction between organization members should be inspected by a special MASCM agency (to be realized by CAgent) to guarantee if this news satisfies with the relevant law. If this news is confirmed effectively by CAgent, then this news will be sent to the receiver as per the address, otherwise it will be returned to the sender.

4. Creation of MASCM Dynamic Hierarchical Control Model

Considering that the supply task is prone to hierarchical disassembly, MASCM organizes the control over the implementation process of the supply chain according to the hierarchical structure of the task. Controlled organization can be defined statically in advance, and it can also be created dynamically during operation. Because in coordination process, the responsibility and inter-relationship of agent may vary according to different tasks of supply and demand and it needs modification in the implementation process, it is more appropriate to dynamically establish the organization controlled by MASCM, whose goal is to organize a group of equal SAgents into a solution group (see fig.3) according to the current task in each MASCM level, and create a hierarchical structure at the control center of the group manager MAgent.
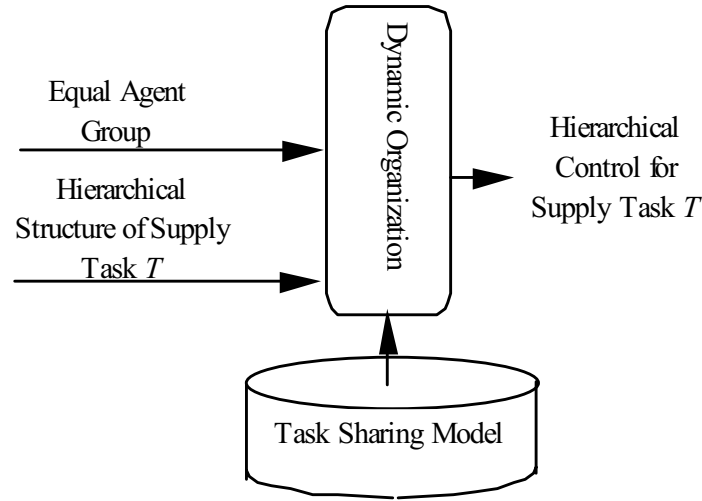
Fig 3 Creation of MASCM Dynamic Hierarchical Control

Currently, there are two relatively mature methods which can be applied in dynamic organization control --- contract network and multi-agent plan both meet some difficulties in application which are the lack of overall viewpoint, pursuit in the coordination of partial cooperative relationship, frequent negotiations (to the method of contract network) or information exchange (to the method of multi-agent plan), etc[6]. By introducing the world model describing multi-agent system --- cooperative model of task sharing, each agent can be provided with certain overall observation ability which is an effective method to overcome those disadvantages above. Based on literature [7], this article puts forward a MASCM dynamic hierarchical organization method based on a cooperative model of task sharing in order to achieve a reasonable organization controlled by MASCM and facilitate the consistence of agent cooperative behaviors.。

4.1 Definition on the Cooperative Model of Supply Chain Task Sharing

[Definition 1] Task T_i is a six-tuple $T_i = (TG_i, PC_i, ST_i, SP_i, CS_i, G_i)$，in which，$TG_i$：Task goal；$PC_i$：Task preliminary condition；ST_i：Collection of subtasks；SP_i：Description on task goal；CS_i：Constraint condition of task implementation；G_i：Requirement of task goal.

[Definition 2] Task Model TM is a two-tuple $TM = (T, R)$，in which $T = \cup T_i$；$R_{ij} = (T_i, T_j, TR_{ij}) \in TR$ represents that there is relationship TR_{ij} between task T_i and T_j.

[Definition 3] Task undertaker TA_i is an agent in MASCM，used to implement some certain task，TA_i is a four-tuple，i.e. $TA_i = (AB_i, C_i, Q_i, M_i)$，in which，$AB_i$：productivity of TA_i；C_i：toggle condition of TA_i；Q_i：realization description of TA_i；M_i：basic information (such as transportation ability, dispatch method, etc.) of TA_i.

[Definition 4] All the task undertakers constitute an agent group TAS，expressed as a two-tuple，$TAS = (TA, TAR)$，in which $TA = \Box TA_i$；$TAR = (TA_i, TA_j, R_{ij})$ means that there is relationship R_{ij} between task undertakers TA_i and TA_j，$R = \{R_{ij}\}$。

According to the above definition, to dynamically establish a MASCM controlled organization is to search a map between TM and TAS，and according to the task goal,

constraint condition, requirement of task goal and system status, etc., select several proper task undertakers to form an implementation group for one task and decide the evaluation method of its work and result integration. Hence, at the beginning, each agent establishes a cooperative model of task sharing at the core of the tasks which agent can bear for the purpose of providing knowledge about overall strategic plan of the controlled organization.

[Definition 5] Cooperative model of task sharing TSM_{Agent_i} is defined as the collection of tasks that agent$_I$ can undertake，i.e.：

$$TSM_{\text{Agent}_i} = \{< \text{tasks that can be undertaken} >^*\}$$

< tasks that can be undertaken >= （T_i，<overall constraint>，<local constraint>，<assigner>，<undertaker>，{<other potential undertakers>}）

In which，"overall constraint" describes the constraints on MASCM system resources relevant to tasks which can be undertaken (including enterprise management policy, market rule, etc.). Breaking the overall constraint will lead to implementation failure；"local constraint" describes partial constraint condition while agent is implementing this task (including logistic, production capability, transportation, storage, etc. inside the enterprise). Only when the constraint condition is satisfied will agent accept this task. The record by task assigner（usually called group manager）and undertaker provides the path of result integration evaluation. Every task has an undertaker expectation list providing the expectation that each agent undertakes this task so as to instruct task assignment.

4.2 Creation of Cooperative Model of Task Sharing

The content of cooperative model of task sharing originates from：①User's description on the new SAgent；②Operation history records of MAgent；③Information obtained from other Sagents through Magent's broadcast. Detailed procedure is shown as below：

（1）According to the requirements, MAgent in level $(i\text{-}1)^{\#}$ creates supply task T_i with a hierarchical structure and then transmit it to Magent in level $i^{\#}$. Task T_i includes several subtasks assigned to each SAgent for fulfillment. Fig 4 (*a*) offers an example of T_i, including subtask description（fig. 4 (*b*)）and subtask dependent relationship（fig. 4 (*c*)）。MAgent in level $i^{\#}$ transmits the received task assignment to the SAgent in the same level.

（2）Each SAgent ensures the task which can be undertaken according to the description of each subtask in task T_i 's hierarchical structure (constraint condition and goal request, etc.) as well as its own situation, thus fill in the blank items such as T_i, <overall constraint>, <local constraint>, etc. in task sharing model and send them back to MAgent.

（3）MAgent collect the relevant information received from SAgent, which constitutes the item <other expected undertaker>, thus a framework of potential control relationship between SAgents is established and becomes a complete cooperative model of task sharing. Shown in fig.5(*a*)，Magent which receives task T_i is easy to obtain the implementation sequence of T_i subtasks according to T_i hierarchical structure. Task assignment model provides a framework

of potential control relationship (fig. 5(b)) for T_i subtask to be distributed on the same level, and becomes the basis of dynamic organization control.
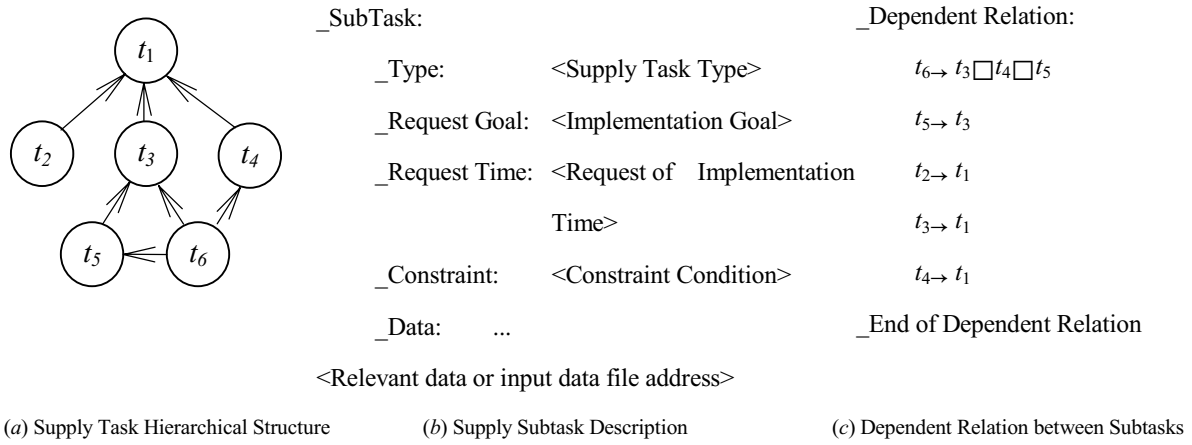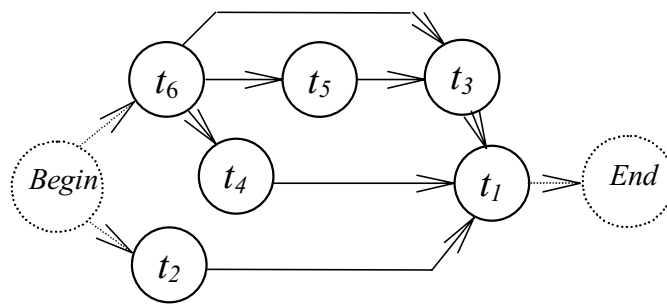

	_SubTask:	_Dependent Relation:
	_Type: <Supply Task Type>	$t_6 \rightarrow t_3 \square t_4 \square t_5$
	_Request Goal: <Implementation Goal>	$t_5 \rightarrow t_3$
	_Request Time: <Request of Implementation	$t_2 \rightarrow t_1$
	Time>	$t_3 \rightarrow t_1$
	_Constraint: <Constraint Condition>	$t_4 \rightarrow t_1$
	_Data: ...	_End of Dependent Relation
	<Relevant data or input data file address>	

(*a*) Supply Task Hierarchical Structure (*b*) Supply Subtask Description (*c*) Dependent Relation between Subtasks

Fig. 4

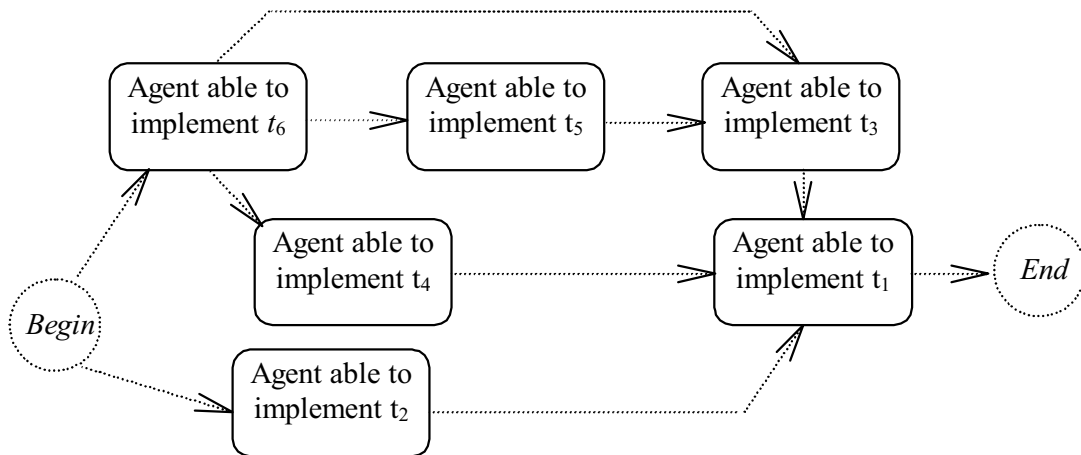Fig.5(*a*) Task Implementation Sequence

Fig. 5(*b*) Framework of Potential Control Relationship

4.3 Dynamic Creation of Control Organization

Once the cooperative model of task assignment is created, the organization of MASCM's distributed cooperative control can unfold level by level from top to bottom according to the task structure under the instruction of control relationship framework between MAgents.

Once every MAgent receives task assignment, it becomes the real partial control center and sends bid to agents in the undertaker list to assign subtasks (i.e. dynamic alliance process of agile supply chain). With the clue of task assigner and undertaker recorded in cooperative model of task sharing, the implementation result of the task in each level will be integrated upwards in a reverse sequence. Finally, a complete implementation process feedback is created.

4.4 Evaluation

The implementation process of MASCM is a typical distributed plan problem. Each agent in the system is distributed in different nodes on the network, each of which is an independent intelligent body seeking the optimized goal for the factory. However, some interests must be deprived for the overall supply chain program in the cooperative process. Because the supplier each agent represents has different production capability and shows some certain complement, the supply task with several subtasks and hierarchical structure must be completed by these agents. In consideration of the hierarchical structure of supply task, the authors use them to realize the dynamic organization hierarchical control.

The cooperative model of task sharing plays an important role in the organization controlled by MASCM. Firstly, as the framework of potential control relationship to assign subtasks, "<other expected undertakers>" lists out the agents which can complete this task in a descending order according to the implementation quality of agent (such as agent's quality coefficient). Therefore when the task is assigned, the task can be assigned to the agent at the top without any negotiation, thus the process of task implementation can be added into the hierarchical structure smoothly.

Secondly, with the unfolding of the implementation process, each agent's situation may change which enables agent not to receive new tasks or not to complete the current task. The creation of cooperative model of task sharing can solve this problem well. Because when this conflict happens, the system can immediately select the less good one from the alternates. Since currently there is no ideal estimation of the cooperative process, the cooperative model of task sharing adopted by MASCM enables each agent to have an overall observation ability to supply the dynamic organization of cooperative solution control.

When agents pursuing different goals encounter conflicts (including order, logistics, resources, transportation, progress and dispatch, etc.), dynamic hierarchical structure instructed by the cooperative model of task sharing renders assistance in resolve conflicts by means of multi-agent negotiation technology. Firstly, "<Assigner>" and "<Undertaker>" in the model provide the agent's name participating in the negotiation; next, if the negotiation fails, "<other expected undertakers>" list of the cooperative model of task assignment is helpful for the system to reconstruct a new implementation organization, that is to assign a new supply to complete the supply task. MASCM imitates the negotiation process between suppliers.

5. End

This article starts from the hierarchical system of the supply chain and the hierarchical structure of the cooperative supply task, with the backgrounds of automobile part supply chain for SVW's Santana, a relevant organization model and dynamic hierarchical control model is designed, which is characterized as:

⑴ Aiming at the design and construction of MASCM system, definite wording is put forward to establish its organization model conception for the purpose of setting human organization rule as the guideline to analyze MASCM system knowledge, behavior's sociality from the point of engineering realization and provide a fundamental framework for each agent's design and integration in MASCM system.

⑵ In consideration of the traits that supply chain task is prone to hierarchical disassembly, the concept of realizing dynamic control as per special tasks and methods of controlling the organization guided by the cooperative model of task sharing.

Because the majority of the enterprise's information systems construction in China is in a preliminary level, research of integrated agile supply chain based on MRPII/ERP similar to MASCM is a long-term arduous job. Presently, relevant research is also in a preliminary stage in the work, therefore, integrating our practical situation, with the experiment of typical automotive parts' supply chain, the research on agile supply chain information system will provide effective information technology resolution program for many enterprises to rapidly establish high-quality and efficient supply chain management information system, which is of realistic significance.

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