A Multi-Agent System for Supply Chain Management

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Abstract: In today's globalization of manufacturing operations managing the supply chain has become an extremely challenging task as it implies tracking order fulfillment, due dates and billing between partners working at different time-zones, with different currencies, tax systems and way to represent information. To achieve on-line control over the status of an order receipt/delivery in a global manufacturing environment the only possibility is to use latest network technologies for accessing and exchanging electronic information. Latest research in distributed artificial intelligence offers excellent tools for modeling the interactions between different nodes of the supply-chain network. This paper presents a multi-agent system approach to the design of global supply chain management networks. The main advantages of this system in unifying heterogeneous information and offering easy tractability for the manager are illustrated on a particular implementation.

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1 Introduction

The supply chain of a manufacturing enterprise can be regarded as a world-wide network of suppliers, factories, warehouses, distribution centers, and retailers through which raw materials are acquired, transformed and delivered to customers**.** ***Supply chain management*** is the decision-making process that optimizes supply chain performance [1]. In today's competitive business environment industry is recognizing the importance of efficient supply chain management. The major challenge of a supply chain is in coordinating activities across different organizations. The *agility* with which the supply chain is managed at the tactical and operational levels in order to enable timely dissemination of information, accurate coordination of decisions and management of actions among people and systems, is what will ultimately determine the efficient, coordinated achievement of enterprise goals.

While much effort has already been invested in the development of agent technology for manufacturing applications [2], little has been done on the supply chain as a whole. The most extensive research explorations on this topic have been done in Canada at the University of Toronto [3]. They used agents to encapsulate existing software systems in order to integrate manufacturing activities with those of their suppliers, customers and partners.

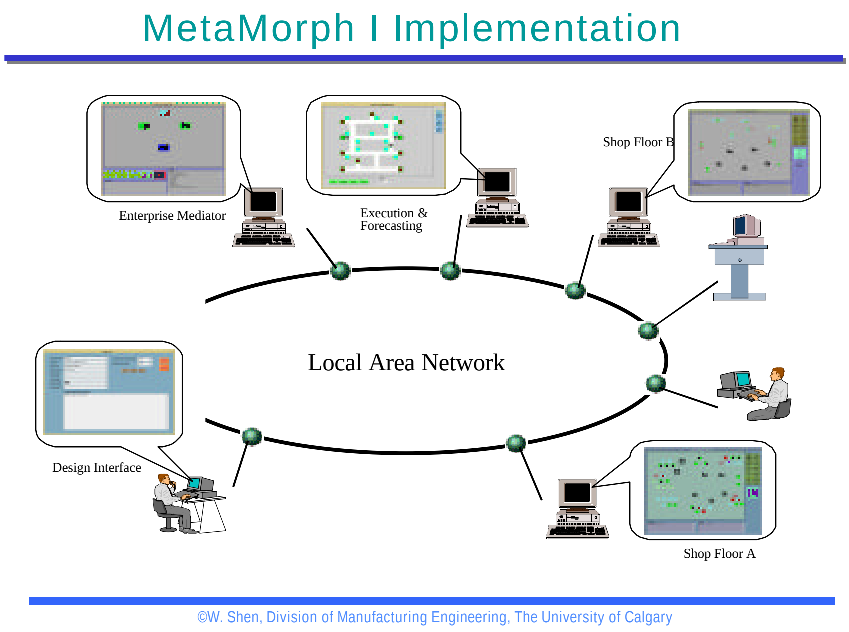
In our approach the supply chain is regarded as a set of entities and processes. Entities may be suppliers, plants, distribution centers, customers, etc. or it may be internal departments such as sales, planning, purchasing, materials, or research and development. A process is simply a series of actions. Entities will be modeled as autonomous agents. This approach leaves a small step between describing a supply chain and designing it as a multi-agent system, reducing the danger of errors in the translation process.

On a ***global level*** system's performance is defined in deadlines which have to be met by delivery of materials and supplies needed for the manufacturing of a product which in turn has to meet the deadline required by a customer. The ***global goal*** can be achieved via several ***local decisions*** taken at the manufacturing site of each part or supply, as well as at the principal manufacturer and at other levels involved (transportation, ordering, etc.) If for example, at one unit in the supply chain a disturbance occurs which affects the production, leading to delay in the delivery of the part manufactured by that unit, decisions have to be made to redirect the respective production towards other units. As another example, if a disturbance in transportation (e.g. airline strike) endangers the delivery of a supply in due time decisions have to be made to redirect the delivery on another route. In general, if a disturbance in functionality has been detected locally, decisions have to be made at the global level to redirect the work towards other available resources. The on-line fault recovery methodology developed by this research is able to reconfigure the structure of the supply chain in minimal time. This paper presents an agent-based control methodology for an architecture enabled with virtual clustering of agents on emerging tasks, able to be responsive on-line to unexpected situations. A proof of concept prototype of such an architecture has been developed for agent systems within the University of Calgary (the MetaMorph system [4]). This architecture is based on partial dynamic hierarchies of virtual clusters (of agents) formed and organized through dynamic task decomposition/ (re)allocation. Agents in the system are dynamically grouped into these virtual clusters that are created and destroyed as needed. To allow agents to participate concurrently in multiple clusters, clones can be created (and destroyed) also as needed. This gives a ***metamorphic behavior*** to the overall system. Coordination within clusters and between clusters is done by mediator agents of several types, Fig. 1 [5].

2 Brief Description of the Multi-Agent System

The development of the Collaborative Agent System Architecture (CASA) is a joint research project of Intelligent Manufacturing Systems Group (IMSG) in the Department of Mechanical and Manufacturing Engineering and Knowledge Systems Institute (KSI) in the Department of Computer Science at The University of Calgary. The system is detailed presented in [Shen, Ulieru, Norrie, 1999]. The generic Collaborative Agent System Architecture (CASA) is composed of collaborative elements such as agents, local area coordinators (LACs), yellow pages and cooperation domain servers. The objective of the CASA work is to support collaborative software agents by providing easy-to-use domain independent communication and cooperation services over the Internet. These services include conversation messaging services, lookup and search services, and remote call services etc. The provision of these services should significantly reduce the complexity of developing systems of collaborative agents**.** The principal elements of CASA are:

- **Cooperation Domain Server** is the receiver of all messages sent by the agents in the cooperation domain.The cooperation domain server listens to a specified port for new connections. Other agents send requests to this port to create a new cooperation domain, or join an active or inactive cooperation domain. Each agent in a cooperation domain routes all its outgoing messages through the cooperation domain server, which can direct it to a specific agent (imitating point-to-point communication), to several agents (imitating multicast communication), or to all agents in the cooperation domain (imitating broadcast communication).



All incoming messages are received

from the cooperation domain server as well (the original sender's identity is contained in the message header)

- **Yellow Page (YP)** agents are responsible to accept messages for registering services and to record this information in a local database. Other agents may later query the yellow pages to determine what agents offer a specified service and may retrieve descriptions of those agents' locations.
- **Area and Local Area Coordinators (LAC).** An area is a convenient quasi-physical division of the network that can be controlled by a LAC. The area may be a single computer, some arbitrary division of a single computer, or a cluster of computers. A local area coordinator acts both as a representative of the area to the outside world, and a manager for the local agents within the area. Local agents may query the LAC to obtain yellow page services; the LAC may, in turn, pass these requests to one or more known yellow pages and broker the responses. This simplifies network modeling requirements for individual agents.
- **Knowledge Management Agents.** Knowledge management is one of the most important issues in developing multi-agent systems. A knowledge management agent is usually associated with one or more databases and knowledge bases. Some simple knowledge management agents may be implemented by Yellow Page agents in CASA.
- **Ontology Servers.** The ontology server structure and related mechanisms are initially domain independent. It becomes domain specific when filled with domain specific ontologies for a specific application, e.g., supply chain management. Of course, it is not difficult to define the structure and mechanisms for an ontology server, but it is extremely difficult to develop and complete an efficient ontology server for an application domain.

- **High-Level Collaboration Agents.** Although several CASA components such as YPs and LACs also provide basic collaboration (cooperation) services, some complex large collaborative agent systems often need more high-level collaboration services which cannot be covered by YPs and LACs. In order to meet such requirements, the high-level

Suppose a customer from City X, Country A places an order at the City Y, Country B location for certain parts to be delivered/shipped at a due date. The order flows through the particular Cooperation Domain Server of the Corporate CASA dedicated to the particular customer-supplier connection. We will describe now the steps involved in fulfilling the respective order by underlining the agents involved and their roles at each step. Given that each node in

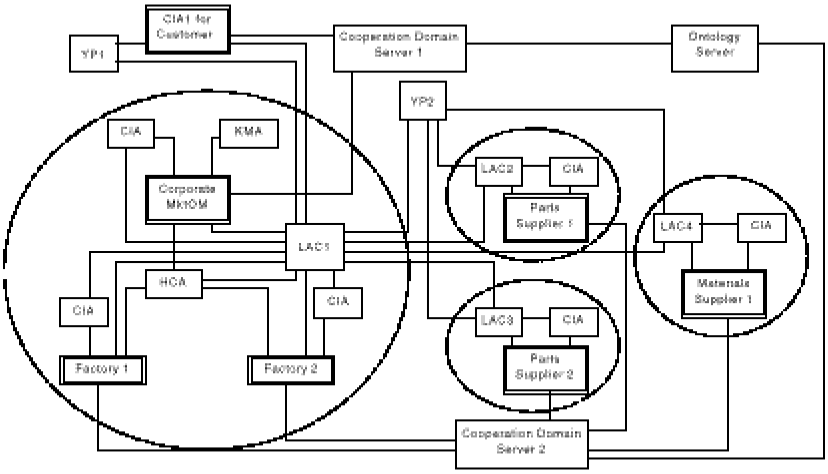


Figure 2. A Scenario for a Simplified Supply Chain

- collaboration agent is proposed as one of important components for ICAS. Such collaboration agents may be implemented by mediators [Ulieru, Norrie, Shen – book chapter]. In most cases, they are static, but they can also be implemented using dynamic mediators.

3 Application: Managing the Supply Chain

In the context of this application Supply Chain Management (SCM), is a corporate-wide initiative that includes teams from Corporate, Business Units, and Marketing Regions.

To describe the agents and their roles in the context of the SCM application lets consider the "order-management" scenario in Fig. 2.

the supply chain has its own way of processing information (bills/orders), there is crucial need for a highly developed ontology server that could wrap-up each individual application into a buffer translator and bring it into the overall system via conversion of its output representation in the language understood by all agents in the chain.

1 - The Market Operations Management Region (MktOM) receives customer requirement/order and responds with a receipt acknowledgement. MktOM is a LAC agent which decomposes the customer requirement into its particular orders and directs each individual order to a CIA. The CIA validates the order making sure that it is processible and that if Market Project Mgmt. is required, the order manager must ensure that a Project manager & project #

have been assigned

2 - The Regional MktOM CIA agent creates a sales order(s) as a "direct delivery" order, based on the order which it has been assigned by the LAC. It assigns a sales order number to the entry.

3 - The Regional MktOM LAC assigns items from the Corporate sales order to it's supplier(s).

4 - Supplier MktOM LAC creates a sales order(s) in their system. Since the order originated from a different MktOM LAC (either the Market Region LAC or other supplier MktOM LAC) the LACs are linked via an ontology server.

5 - The Supplier Supply & Demand process sources the order. The CIA agent assigns sequential processing order numbers, and carries customer lines forward.

6 Purchase order information, including account distribution, is sent to the supplier's LAC agent as PO. For catalog orders commitment is from the supplier to the originating MktOM LAC, and must match the original order number.

If more than 1 External Supplier is involved, repeat steps 4-7 per External Supplier, otherwise go to Step 8!

If Corporate External External suppliers are involved continue with Step 8, otherwise go to Step 12.

7 External Supplier LAC creates a sales order(s) in their system. CIA receives the processing order (PO) from MktOM LAC (no receipt acknowledgment is provided).

8 The MktOM LAC reviews the responses from the suppliers, and completes any required negotiations.

9 Sales incentive value of the supplier sales order is sent to the Sales Incentive Mgmt system by the Logistics LAC.

10 Price/Cost will be sent to the Finance LAC. If the Item category is Customized, the CIA will use this cost.

11 - When ready, the External Supplier packs and ships material via their own system under coordination of the Logistics LAC.

12 - The Supplier Delivery CIA picks the order. A transaction is sent to the Common Database for the quantity issued.The stock person picks the material. At the advice of the CIA.

13 - If more than 1 supplier is involved, Repeat step 13&14 per supplier, otherwise go to 16!

14 - The Originating MktOM LAC receives the shipment information. Upon receipt, a financial transaction is generated to record this information. in the supplier's Contract Ledger inventory and Inbound Intransit. The receipt is sent to the region's High Level collaboration agent. Upon receipt, a financial transaction is generated to record inventory and unaudited payables

15 The Logistics LAC receives the materials from each supplier into the Marshaling Location and records that receipt in the Database.

16 - The Logistics LAC "rolls-up" the order status (receipts and shipments) updating across the whole multi-tiered orders hierarchy. (all the CIAs involved in the transaction.)

17 - When the complete order has been received, and it is time to ship the Corporate Logistics LAC will pack/ship per the original sales order (unless told otherwise) to the customer, via the MktOM LAC.

18 - Referencing the original MktOM sales order, the Logistics LAC generates a top level ship advise to the original MktOM LAC and, if required, to the end customer including all freight and insurance, if applicable.

19 - Upon delivery to the designated ship address, the Logistics LAC receives & stores Proof of Delivery for "corporate carriers." It is available for external reference - if MktOM LAC requires it.

20 - As required, the originating MktOM LAC invoices the customer in the currency of the sales order

21 - The financial transaction is created y the Finance CIA for Receivable, CIP, and Tax Updates to Global Database

after post integration transactions are generated by Database Agents.

5 Conclusions

The main objectives of the SCM system are: cut costs, shorten development time, speed up product delivery, consistency across divisions, create a collaborative culture to fully leverage Corporate's global resources, declare the global processes as corporate assets, provide common processes and supporting tools, guarantee common performance measurements across the Corporation, enable the Corporate organizations to quickly adapt to global market dynamics, provide a single source for customer order information.

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