An Agent-based Cross-enterprise Resource Planning for Small and Medium Enterprises

N. Zhou, K. Xing, and S. Nagalingam

Abstract—**Worldwide cooperation among manufacturing companies is increasingly gaining importance for facing emerging challenges in manufacturing. The traditional Computer Integrated Manufacturing (CIM) systems cannot satisfy the needs of the global market as they are deployed only within an enterprise. A more flexible, comprehensive and integrated methodology is required to overcome distance barriers, facility sharing problems and communication obstacles. These issues have lead to the concept of Virtual CIM (VCIM).**

In this paper, the limitations of the current agent based implementation of the VCIM concept are analyzed. New approaches to addressing these limitations are demonstrated and development of an Agent based Cross-enterprise Resource Planning for Small and Medium Enterprises is proposed.

Index Terms—**Virtual CIM, VCIM, Small and Medium Manufacturing Enterprises, Multi-criteria selection, Agent based systems.**

I. Introduction

Manufacturing enterprises face challenges from worldwide competitors and struggle to extend their business worldwide in today's economic climate. Thus, these enterprises tend to use fully integrated manufacturing systems so that they can have the capabilities to rapidly respond to constantly changing customer requirements and produce high quality products in the shortest possible time at the lowest possible cost. However, Small and Medium manufacturing Enterprises (SMMEs) have difficulties in achieving this flexibility and competing with large companies, since SMMEs often do not have enough resources. By integrating the manufacturing resources of many partner enterprises (which may be located at different regions), smaller enterprises can form a globally integrated SMME network and achieve a competitive edge [1].

Virtual Computer Integrated Manufacturing (VCIM), which is a network of interconnected global Computer Integrated Manufacturing (CIM) systems, extends traditional concept of CIM from a local and centralized system to worldwide co-operation [2]. Today, companies are expanding their business boundaries locally and internationally, merging or co-operating with others across geographical demarcations. VCIM aims to unite and integrate all activities in an enterprise or a network of enterprises to share resources and management objectives through information integration, in a cohesive manner to work as a seamless global CIM system. In a VCIM system, manufacturing resources may belong to different enterprises or be located at different areas, but all have intention of working together in an integrated manner. When receiving a product order, a VCIM system schedules and organizes distributed resources as a temporary production system based on working status information of the resources in real time. As this temporary system disappears when purposes are fulfilled, compared to the tight connection of manufacturing resources in traditional CIM systems, this transient system with VCIM is in a virtual status. To describe this status viewpoint, the word Virtual is used in the concept of VCIM (Virtual CIM).

This article is the revised/extended work based on the paper presented in 2010 IMECS conference [3] and is divided by two parts. The first part reviews the background of VCIM research project. The second part analyzes the current development with Agent-based approaches to build the proposed VCIM system, including the limitations in current system design and potential issues for the system implementation. In the second part, possible solutions to above limitations are discussed. Major changes to current architecture will be demonstrated.

II. The Background of VCIM Research Project

Virtual Computer Integrated Manufacturing (VCIM) is a new concept for Computer Integrated Manufacturing (CIM). In 1997, it was proposed by Lin in his keynote in Singapore. He stated the VCIM concept would be the future evolvement of CIM [1]. The main improvement for the word "Virtual" is to address the limitation by CIM definition. In the traditional concept, CIM is often limited within an enterprise. However due to the global competition and collaboration, a solution was needed to expand CIM to a much wider border. Virtual CIM (VCIM) was defined as a network of interconnected global CIM systems that extends traditional concept of CIM from a local and centralized company to world-wide cooperation [2].

The effort for global collaboration in manufacturing industry never ends. VCIM aims to integrate all manufacturing resources from different entities in different location, and make them work together as a seamless global CIM system [4]. When receiving a customer order, the system searches among available resources and schedules a best path for production schedule. Those resources in the schedule will form a temporary system to fulfill that customer order. The "virtual" came from the concept of Virtual

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Enterprise (VE) studies [5-7]. VE was defined as a collection of companies that are dynamically composed as needed and dissolved after its goal is completed [8]. VE intended to integrate all elements from raw materials in a supply chain as a whole to provide to final customers [9]. However, VCIM has a much wider scope. It has many correlations with other integration concepts such as Intelligent Manufacturing System [10], Holonic Manufacturing System [11]. The aim of the VCIM is to establish cohesive connections among those manufacturing resources. Those resources are often in the form of Small to Medium Manufacturing Enterprises (SMMEs). VCIM is expected to give those SMMEs enhanced competitiveness in Global competition [12].

III. Current Development and Limitations

SMMEs play a significant role in pioneering new technologies, markets, and creation of knowledge based industries, all of which are important for future growth and jobs of many countries. In addition, they are often characterized by niche specialist markets in which they have expertise. They succeed by providing high levels of responsiveness and personalized service. In many instances, they can offer lower priced products compared to other large enterprise, because SMMEs have less overheads and their labour and management force are the same. However, when SMMEs grow and develop a typical functional structure, they need to develop efficiencies within their total processes to remain competitive. Many growing SMMEs see their profit margin drop as these inefficiencies mount.

Global competition and today's open markets are driving the enterprises to introduce high quality products and services economically and efficiently. A VCIM system is a strategic move that requires manufacturing enterprises to establish close relationships in order to exploit each other's core competencies for the betterment of the SMME network.

Participation in a VCIM is especially challenging for SMMEs. Since, the VCIM activities involve complex operations and these participants of a VCIM system are distributed worldwide, the SMMEs must overcome global boundaries in terms of distances, time, regulatory constrains, as well as cultural and political differences. In addition, some of these partnerships are dynamic and becoming virtual representing the transient status of the collaboration [4].

A. Collaborative Manufacturing

Collaborative Manufacturing (CM) is especially suitable for Small to Medium Manufacturing Enterprises (SMMEs). In CM, all the entities work together for mutual gain. For the nature of limited resource in a SMME, it lacks the ability to delivery total solutions for customers. CM provides such a way that SMMEs can establish close relationship and exploit each other's core competencies to achieve large project. There are a lot of expected benefits from CM, such as Increase global marked share, Improve customer service, Lower production cost, Decrease manufacturing lead-time, and Increase manufacturing throughput [13]. However there are issues prevent implementing CM, like Organizational culture, Data Information Knowledge sharing, and Legacy systems [14].

B. Multi-agent architecture for Manufacturing

Multi-agent systems are developed from distributed artificial intelligence. An agent here is defined as "a computer system situated in some environment and is capable of flexible autonomous action in order to meet its design objectives [14].

Multi-agent system has been widely used in manufacturing industry for many years [14]. In 1999, a survey found out the Multi-agent system had been used in areas like enterprise integration, supply chain management, manufacturing resource planning and scheduling [16].

C. Agent based system architecture for VCIM

To optimize resource sharing and to provide a dynamic integration, an agent-based VCIM architecture has been developed. In the agent based VCIM system, three categories of agents have been identified [5]. These agents include Facilitator Agents, Customer Agents, and Resource Agents. Facilitator Agents are designed to act as coordinators to route the information flow across the VCIM agent community. Customer Agents are designed to provide interfaces for customer to participate in the VCIM system. Finally, Resource Agents are designed as agent interface to encapsulate distributed manufacturing functional entities and connect them with the agent community. The functionalities and responsibilities are described in earlier VCIM research as below [1, 4-6].

In VCIM agent-based architecture, all the agents are connected to the Internet. Facilitator Agents need to register to Customer Agents and Resource Agents need to register to Facilitator Agents. All the communication is delivered via the Internet.

After receiving the customer order, the Customer Agent passes the order to a Facilitator Agent. The Facilitator Agent then works together with those Resource Agents registered to it and make an optimized production schedule.

The optimized production schedule is defined as the cheapest schedule with shortest duration time while it satisfies the customer's required due date/time and delivery destination.

By connecting a Facilitator Agent, a Customer Agent and many Resource Agents through the Internet, these agents can form a basic multi-agent VCIM system. Nevertheless, a real VCIM system includes many Facilitator Agents, Customer Agents and Resource Agent while the functionalities of Resource Agents may include design, manufacture, delivery, material supply and others.

Since this is a "Virtual" system. It means that the system is an aggregation of many VCIM agents from different SMMEs over the Internet. All kind of manufacturing companies can join the VCIM network as long as they have installed compatible agent software to communicate with Other VCIM agents from other companies. This is very different to the e-Hubs system used by the auto industry. While e-hubs is actually an Internet based B2B market place running third party Web servers. The e-hubs operators charge fees for each transaction over it. In VCIM network, each VCIM agent discovers other VCIM agents and negotiates directly. There is no central controlled operator.

D. Current limitations

Current Agent-based VCIM architecture still need improvement. Wang [1] stated there were three potential issues that affect a VCIM system implementation [1]. These are:

- Development of strategies on information security

(This is related to the potential issues for how VCIM agents can trust each other, how to avoid system abused by false information, how to identify the reliability of each VCIM agents from different domains.)

- Identification of cooperation policy and agreements among partner enterprises

(This is related the potential issues for resource sharing agreement among participating SMMEs. The production resources defined in VCIM have different locations, owners. Some SMMEs may have cooperative agreements, so that they may have price discount or priorities. When choosing Resource Agents for a work schedule. Besides price and time, partnership needs to be included in the consideration.)

- Development of strategies on agent communication

(This is related the potential issues for the large volume of agent communications over the Internet, so that it might lead to high latency and affect the reliability and stability of a VCIM system. An effective communication strategy needs to be developed to minimize the communication data among VCIM agents.)

It is found that the issues listed above were caused by three major limitations for current architecture design that prevent the Agent-based VCIM architecture into real practice. Those are:

1. Network limitation

The VCIM agents reside across the boundaries of many enterprises. According to past research [7], the agent communication between distributed locations is often unreliable. Thus when performing a resource scheduling across the VCIM network, the big number of VCIM agents, extensive volume of exchanging messages, limited bandwidth and unreliable nature of the Internet will slow down the whole process. Unlike a faster and more reliable Intranet inside a single organization, the VCIM system must use the Internet more wisely with less communication volumes and more flexible mechanisms.

2. Agent selection limitation

The VCIM network is designed to be dynamic. This means any time a new VCIM agent may join or quit the network. In earlier architecture, Facilitator Agent deals with the resource scheduling. The Customer Agent just selects an available Facilitator Agent to do the job. It does not address the mechanism how a Customer Agent finds suitable Facilitator Agents and selects the most suitable one among them. Because the architecture define that all Facilitator Agents has the same access to all other Resource Agents. In real world, it is different. A customer usually relies on procurement companies for their product order. Different procurement companies have different expertise, different focuses, different locations or different partnerships. Even for identical production sources, they will have different cost. It is unusual a customer directly dealing with different production resources.

3. Multiple criteria selection limitation

When making selection from proposed work schedule or manufacturing resources, current architecture only uses two factors: cost and time [6]. While in real situation, many other factors need to be considered, such as: quality, friendship, credit, and delivery reliability [8-12]. Lack of a systematical multi-criteria selection method will limits us reaching the optimal result.

E. Research focus

The research focus is to address the above limitations and give possible solutions to enhance the functionality of the Multi-agent based VCIM. Therefore the focus can be divided into three parts.

1. For the network limitation, messages exchange over the network must be minimized. More efficient mechanisms need to be used to optimize message flow and lower network overhead and latency. This part will mainly focus on a redesign of current agent network architecture.

2. For the agent selection limitation, the way for agent communication needs to be improved. This part will focus on changes to agent negotiation and agent communication protocol so that additional agent function can be performed. Detailed steps from customer order to final delivery need to be specified.

3. For the multiple criteria selection limitation, it will focus on two major resource scheduling processes. First process is for a Facilitator Agent to find and select the local resources for a particular order. Second process is when local resource is not enough for that customer order; the Facilitator Agent will find and select external resources. Because in the context of the architecture, all production resources are wrapped into VCIM agents, this part will focus on enabling multi-criteria selection for the VCIM agent selection.

IV. Agent-based Architecture and Resource Scheduling Process

This research explores on the revolution of VCIM resource scheduling process and there are three major changes in system architecture, communication protocol and decision making process.

To improve the performance and functionality, an artificial intelligent decision making process needs to be integrated to the Multi-agent framework. A multi-criteria approach is should be integrated into the agent searching and selection process. According to the research focus addressed before, the new improvements over the new VCIM Agent Architecture and Framework based on three parts:

1. Registry Service
2. VCIM Agent Communication Process
3. Multi-criteria selection Integration

The Figure 1 shows the new designed VCIM architecture. All small to medium sized manufacturing enterprises are connected to the Internet, forming a virtual collaboration network. The VCIM Agents reside in each SMME. Customers use their computer to submit orders to the Customer Agent through the Internet. The new Public Directory also connects directly to the Internet. It stands alone, not within any SMME. And it holds all basic information of each VCIM agent and allows queries for agents. The agents inside a SMME will communicate in ACL (Agent Communication Language). The agents in different

SMMEs will communicate in HTTP/SOAP in order to pass enterprise firewalls.

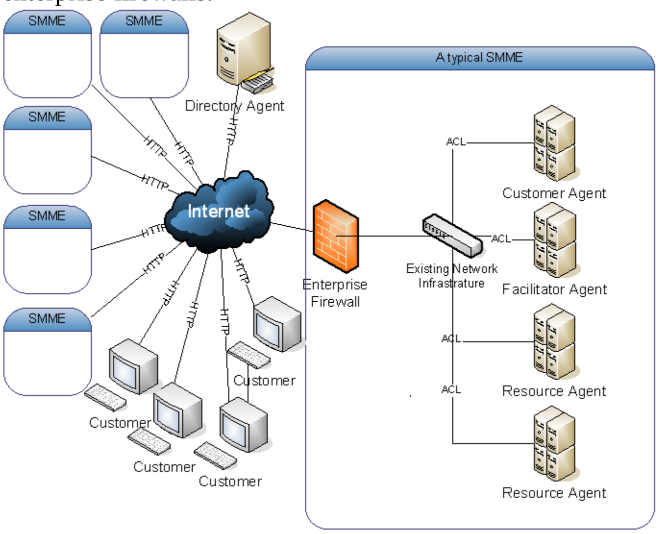

Figure 1. new VCIM Architecture

A. *Registry service*

In order to improve the agent communication over Internet, a central registry like database that holds all the information of each agent across the whole interconnected VCIM network needs to be created to ease the multi-criteria agent searching. Here we define it as a Registry Service. A special agent called Directory Agent is created to provide this service.

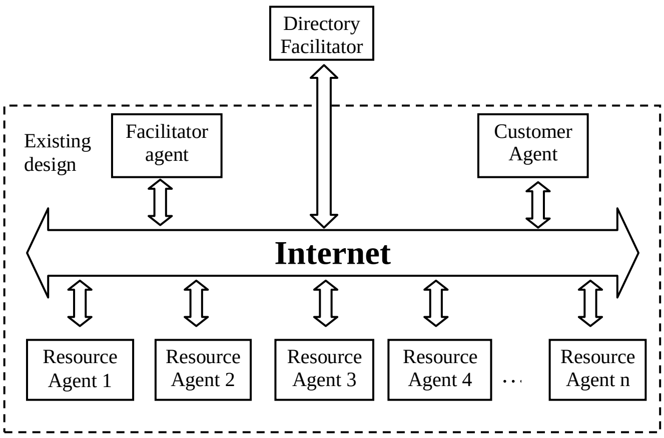

Figure 2. Connection structure of a base VCIM system (Adapted and modified [6])

Figure 2 shows the improvement to current connection structure. We can see that along with other agents, the new Directory agent is connected to the Internet. They virtually link together to form a Virtual CIM (VCIM) network. The VCIM network is dynamic because any time a VCIM agent may join or quit. When a new Facilitator Agent joins in the VCIM network, it needs to register itself to the Directory. When a new Facilitator Agent quits in the VCIM network, it needs to de-register itself from the Directory. The Facilitator Agent here represents a SMME. Thus all available production resources within that SMME will be wrapped into Resource Agents and all registered to that Facilitator Agent. When a Facilitator Agent wants to search for internal resources, it just makes queries to all Resource Agents that have registered to him. When a Facilitator Agent wants to search for external resources, it submits queries to the Directory and gets list of available Facilitator Agents from the Directory. Then it makes queries to those Facilitator Agents to find out available production resources. In old implementation, when a new agent joins in the VCIM network, it needs to register itself to a Facilitator Agent. That Facilitator Agent will then pass the register information to other Facilitator Agents. All the Facilitator Agents will synchronize and maintain an identical copy of the registered Resource Agents list. This process takes some time for the information reach all Facilitator Agents. Same problem inside the De-registration process. The delay will affect the really time resource scheduling. The advantage of a directory service is obvious. Not only can the communication volume be minimized, (no more propagation) but also better search response time.

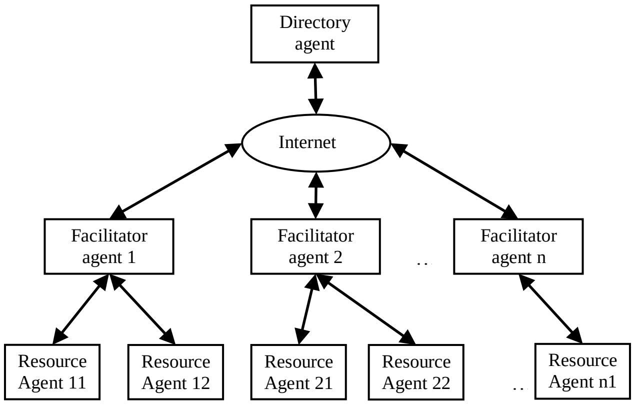

Figure 3. Information flow hierarchy in a for the VCIM system

Figure 3 shows the improvement in current information flow. The messages are transported among different types of agents. The Facilitator Agent needs to register to the new Directory Agent so that the representing SMME can be exposed to the VCIM network. It also uses the Directory Agent for De-registering and Search. The figure also shows that Customer Agent needs talk to Facilitator Agent and Facilitator Agent needs talk to internal Resource Agents. In old architecture, the Facilitator Agent sends requests to all Resource Agents even they are in other companies. In new architecture, the Facilitator Agent only sends requests to internal Resource Agent and external Facilitator Agents. Therefore the information flow across the company boundaries is reduced. This makes the VCIM much easier to implement as in real situation, it is very hard to make direct command to the department in other companies.

B. *Communications and Protocol in Agents based Resource planning*

There two types of production resources in the view of a SMME. One type is internal resources, the other is external resources. Internal resource can be directly accessed by internal IT infrastructure. External resources can be indirectly accessed through communication protocols between two SMMEs. That means a unified IT infrastructure must be setup so that all SMMEs inside the collaborative network are able to communicate.

A full production schedule for a customer order can be three types if focused on utilized production resources:

a. Production schedule with only internal resources

b. Production schedule with combination of internal and external resources

c. Production schedule with only external resources

(Here the external resources may be from more than one SMME)

When processing an order, the SMME will schedule with internal production resources first. If internal resource is insufficient, it will try to search and use external production resources from other SMMEs.

The production schedule involves steps of production and transportation. Each step can be identified as a production sub-task. Each sub-task will be assigned to a production unit. The transportation will be assigned to transportation units if required.

Here is the example how internal and external production resources are utilized. When a Facilitator Agent receives a request from a Customer Agent, it generates all possible production schedules. Then it finds the best suitable production schedule.

Therefore the VCIM resource scheduling is actually a Production Resource Integration. It integrates all production resources from different SMMEs together towards a particular customer order.

Figure 4 shows the each step when a customer order comes in. The Facilitator Agent in a SMME receives a request from a Customer Agent; it divides the order into subtasks and sends a request to internal Resource Agents to find out whether they can perform the subtasks. The requested internal Resource Agents generate all possible subtask schedules and return the results to the Facilitator Agent. If internal Resource Agents can't handle all subtasks, the Facilitator Agent sends requests to external Facilitator Agents from other SMMEs. The requested external Facilitator Agents generate all possible subtask schedules and return the results to the original Facilitator Agent. If there are multiple responses for a subtask, the Facilitator Agent will compare and select the most suitable external Facilitator Agent for that subtask. The Facilitator Agent then generates all possible production schedules according to received subtask schedules from the internal Resource Agents and external Facilitator Agents. The best suitable production schedule in the VCIM network for that customer order will be identified.

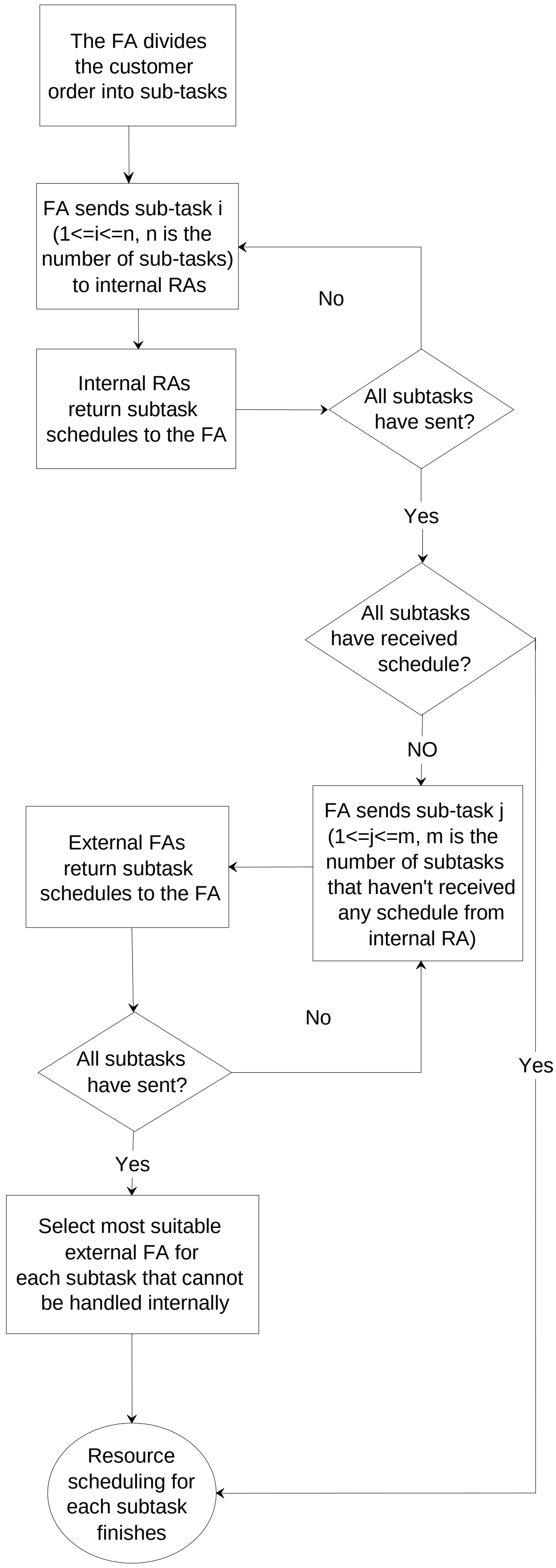

Figure 4. Steps of recourse scheduling for a single order

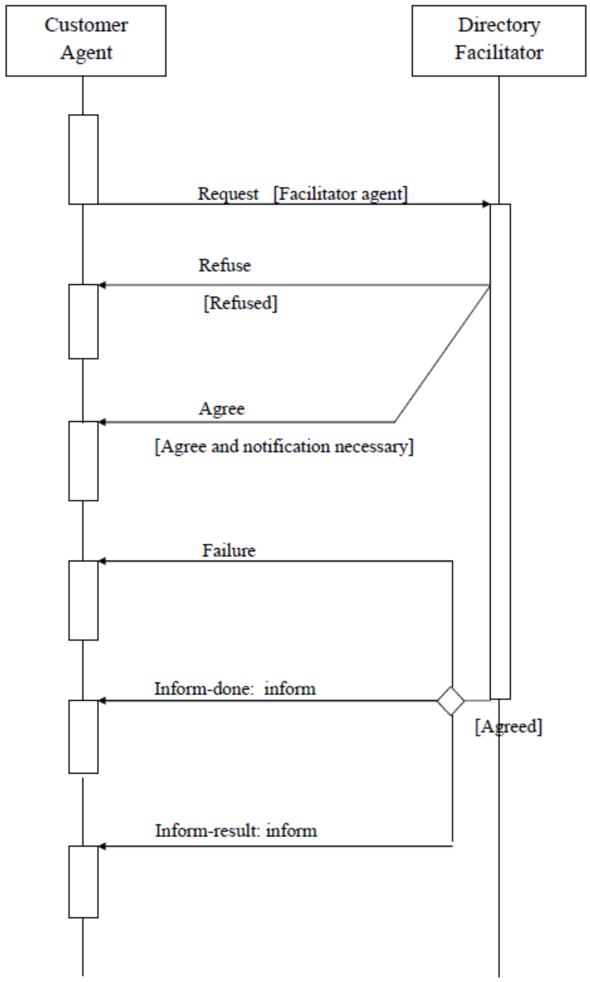

Figure 5. A RIP cycle for Customer Agent searching for Facilitator Agents (Adapted and modified from FIPA spec [8])

Multi-agent communication protocol needs to be defined here to support above agent selection and resource scheduling. In this system, when a customer submits a product order, a VCIM agent search and resource scheduling process is initiated. Protocols to support agent communication linkage and information exchange need to be defined. For example, Figure 5 shows an agent communication protocol used for Customer Agent to search for suitable Facilitator Agents. Here we use Request Interaction Protocol (RIP). The Customer Agent first sends a search request to the Facilitator Agent. The Facilitator Agent replies with either refuse or agree. If agree the Facilitator Agent then process the search based on criteria given by the Customer Agent. If search fails, it returns Failed. Otherwise it returns Inform-done and Inform-result.

There are other scenarios like Resource Agent registering to Directory agent, Facilitator Agent search in the Directory for suitable Resource Agents, order negotiation between Customer Agent and Facilitator Agent, and order negotiation between Facilitator Agent and Resource Agent. For each scenario, an agent interaction protocol is going to be defined.

C. *Multi-criteria selection Integration*

The VCIM system purpose is to automatically decompose the customer's order into sub-tasks and use computer based resource scheduling to find best production path among available production resources shared by participating SMMEs. This can be discomposed as two major processes as illustrated in Figure 3.

Process 1 is local resource scheduling. In this process, a Facilitator Agent tries to schedule all sub-tasks with local Resource Agents. Due to the nature of limited resources within a typical SMME, some sub-tasks might not be capable of local resources. Thus we need go to process 2.

Process 2 is external resource scheduling. In this process, external production resources outside that SMME can be utilized through negotiation between local Facilitator Agent and external Facilitator Agents.

1) *Factors in VCIM external resource scheduling*

In previous VCIM approach, only delivery time and cost are considered in resource scheduling. While in real world procurement, a lot of other factors affects final decision making. To make VCIM concept more practical, we need think about similar procedures for real person in a company to compare quotation and select outsourcing vendors and factors inside the selection.

According to Kumar [9], there are nine factors to be considered in Vendor Selection. These are price, location, flexible contract terms, cultural match, reputation, existing relationship, commitment to quality, scope of resources, added capability. In order to aim long term supplier relationship, Yao [10] proposed five criteria, cost, quality, project, and certification and delivery performance for the hierarchy. Assessing a group of vendors and selecting one or more of them is a complex task because various criteria must be considered on the decision-making process. Dickson [11] studied the importance of vendor evaluation criteria for industrial purchasing managers and presented 23 vendor attributes that managers consider in such an evaluation, including quality, delivery, price, performance history and others. Weber et al. [12] concluded that quality was the most important factor, followed by delivery performance and price. They found that quality was of 'extreme importance', and delivery was of considerable importance. Hill [13] concluded that quality was an essential factor that qualified a corporation to compete in the marketplace, because vendors with unacceptable quality performance were dropped during the screening phase.

With consideration of previous research on Vendor Selection and VCIM, the comparable factors for VCIM resource scheduling are identified as following:

The Facilitator Agent finds available internal Resource Agents or external Facilitator Agents for a particular sub-task. Because it can only choose one VCIM agent to do the task, it needs to find out the best suitable VCIM agent through a multi-criteria method. The comparable factors for this problem are: Credibility, Friendship, Price, and Lead-time.

Credibility: A property that indicates the quality and reliability of an external production resource based on its past production history. Higher credibility means higher potential to achieve tasks within contracted time and quality.

Friendship: A property that shows the relationship between two enterprises. Higher friendship means closer relationship. It will affect the preference in resource selection.

Price: A property that shows the offered price by external resource provider for a sub-task. It is the direct cost to the sub-task.

Lead-time: A property shows the length between start and stop time for a external resource to finish the sub-task

2) Multi-criteria Selection Process

As multiple factors that have been identified in VCIM resource scheduling, a multi-criteria selection approach is to be integrated. In the recent years, AHP method has been widely adapted as a decision making tool for outsourcing vendor selection problems. Many researches showed that the AHP is very effective solution to different kinds of Multi-criteria vendor selection, such as Manufacturing outsourcing vendor selection [15], Information system outsourcing vendor selection [16], E-business outsourcing vendor selection [17], and 3PL (third-party logistics provider) vendor selection of a 4PL (fourth-party logistics providers) system [18].

As shown in Figure 6, the hierarchy construction has three layers for VCIM agent selection in Resource Scheduling Process. Suitable VCIM Agents are compared by five factors: Credit, Friendship, Quality, Price and Time to find out the most suitable VCIM agent for this process.

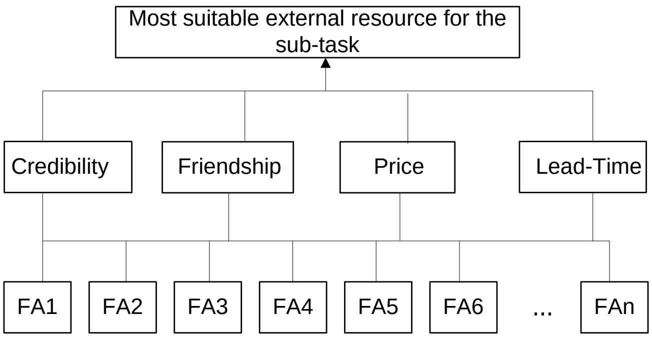

Figure 6. Hierarchy construction model for VCIM External Resource Selection.

The comparable factors in VCIM are quite similar to those factors in Vendor selection. As shown in previous Vendor Selection research, the AHP is suitable to solve the Resource Selection here. However, in AHP the comparison is done by human determination. As we use software agent to determine the weights of comparison, a Fuzzy Logic system will be integrated to migrate human reasoning into computer language. When weighting the importance, the Fuzzy operation will be used to output a linear value of 0-9. This will provide more accurate comparison than discrete value used in importance weighting of normal AHP. Based on the result from the above Fuzzy AHP process, the Facilitator Agent will find the most suitable external Facilitator Agent for that particular subtask.

V. Conclusion

VCIM is a way forward to the SMMEs in many countries, where the globalization has impacted dramatically on manufacturing industry. VCIM provides a facility to share resources of partner enterprises that are geographically distributed and provides a competitive edge for SMMEs to be in equal footing with large organizations that have abundance resources to meet the challenges imposed by the globalization. This article discusses an advanced Agent-based Cross-enterprise Resource Scheduling Process that will help the SMMEs in global competition. As can be seen, future work to do is on optimizing Agent based resource scheduling. This will involve designing new agent behavior, communication protocols, and an effective multi-criteria selection method Model.

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