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INTELLIGENT VIRTUAL CONSTRUCTION MATERIAL SUPPLY CHAIN ENVIRONMENT

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ABSTRACT

The use of information technology is being encouraged increasingly for exchanging information and coordination activities among participants in a supply chain. This trend can be understood as a consequence of a new strategy of conducting business, which is the concept of virtual enterprise (VE). In the Construction Material procurement, the virtual enterprise is mostly composed of sub-contractors and suppliers having no definite relations, policies and implications. Hence, it is not difficult to perceive the degree of complexity in managing this kind of value-chain as well as coordinating the processes of the material supply chain that is distributed. This paper presents an ongoing research for developing intelligent virtual tools based on Multi-agent systems (MAS), to support the construction material supply chain environment. The MAS views the material supply chain as a virtual environment, that employs concepts from distributed artificial intelligent (DAI) field to organize and coordinate the activities of a material supply chain process. The primary goal is to examine some of the issues associated with the use of MAS within the construction industry. It further describes the potential for the use of agent technology in a collaborative and distributed environment such as the material supply chain environment and then goes on to present conceptual framework for the use of MAS technology in a virtual environment for the automated procurement of construction materials. This is intended to serve as a useful decision support system (DSS) for participants in material supply chain environment, and should allow faster, better, and more economic, collaborative procurement.

KEYWORDS

Supply Chain, Virtual Environment, Construction Material Procurement, Multi-Agent System

1. INTRODUCTION

There is a growing need to improve coordination and integration to enhance the performance of the construction supply chain processes. The importance of developing and maintaining good relations with customers and suppliers in construction is a critical factor affecting project procurement success performance (Love, 2000). The combination of poor relations between customers and suppliers and lack of carefully developed systems for complex and distributed environment, has meant that collaboration and customer's satisfaction is not achieved and this has become endemic features of the construction procurement processes. To overcome these problems industry practitioners and researchers have begun to investigate how virtual enterprise management concepts can be used effectively to improve the performance and productivity of projects. Taking into account: the need for improved relationships between inter and intra–organisational members, complex and dynamic activities (Bresnen, 1996).

The work presented in this paper corresponds to the approach implemented in my research work to support coordination in a construction supply chain management environment. The project aims to model and develop a multi-agent system (MAS) to support the virtual enterprise. The work here focuses on material component supply chain in order to support them with means to interoperate with several value chain networks. The MAS approach provides a useful metaphor for reasoning about collaborative systems. This is evident from the fact that the approach typically involves tasks decomposition, negotiation and delegation of tasks to appropriate agents for execution, whilst proactively coordinating communications and exchanges between individual agents, monitoring their performances, and re-scheduling any malfunctions in service delivery to more capable and willing agents. This is in essence a virtual project management, which can be exploited in material procurement for the simulation of material supply chain management prior to actual start of procurement. This has the potential to significantly improve the quality and decision making output of the entire supply chain and may hold new insights as to how to specify and develop more flexible project systems for the increasingly complex and dynamic material supply chain environment of today and the future.

2. STRUCTURE OF THE CONSTRUCTION SUPPLY CHAIN

The concept of supply chain has evolved enormously in the past few years (Handfield and Nichols, 1999). New (1997) argued that the idea of the supply chain owes much to the emergence from 1950s onwards of system theory, and the associated notion of holism. This may be summarized by the observation that the behaviour of a complex system cannot be understood completely by the segregated analysis of its constituent parts. The use of this idea in regards to supply chains is neither consistent nor straightforward. However, there is a common ground on what qualifies a supply chain. Harland (1996) defined supply chain as:

“A number of entities, interconnected for the primary purpose of supply of goods and services required by end customer.”

In the construction sector, the supply chain can often be extremely complex, particularly on a large project where the number of separate supplying organizations will run into hundreds, if not thousands. Figure 1 displays only the main elements of a typical construction supply network, with the main contractor at the center of the hub. There are links to the client, main supply agencies and to both design and any specialist management services, which are provided externally (Briscoe *et al.*, 2001). The present interest is primarily focused on the supply relationship between main contractor and material component suppliers and the production sub-contractors.

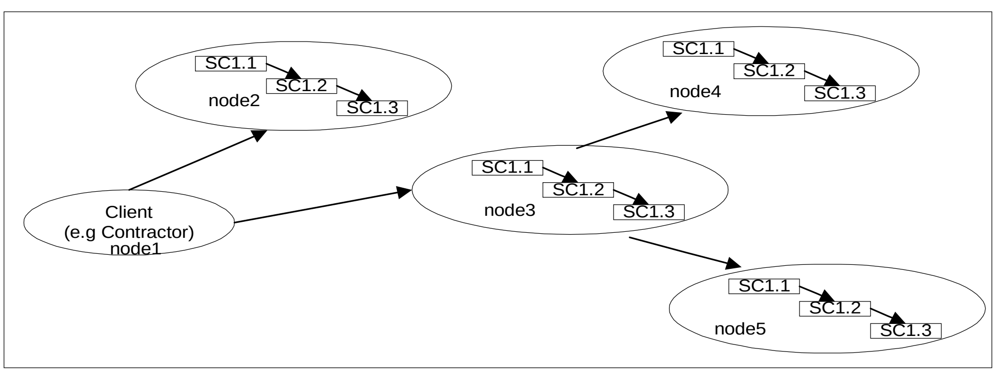

Figure 1: The Supply Chain Process Concept

Figure 1 is a simplification of a real world network. Clearly, the principle material supply organizations will also be dependent on many other organizations that provide raw material and component inputs to their production. Similarly, the main trade contractors will have their own supply chains and many of these will further subcontract out smaller work packages. The specialist construction subcontractors will usually be much smaller firms, small to medium size enterprises, and several of these may be providing labour only services. The composition of the network will tend to be unique to a specific contract, although some favoured suppliers would be used repeatedly by any given main contractor (Briscoe *et al.,* 2001). Figure 1 illustrates a supply chain concept via its production graph. Node 1 is the client enterprise, whereas nodes 2, 3, 4 and 5 are its suppliers. However, The activities of material procurement, involves formal receipt of a tender, running through the award/contract onto delivery and fixing on a construction site, and finally reconciliation and review of achievement (Meraghni *et al.,* 1996).

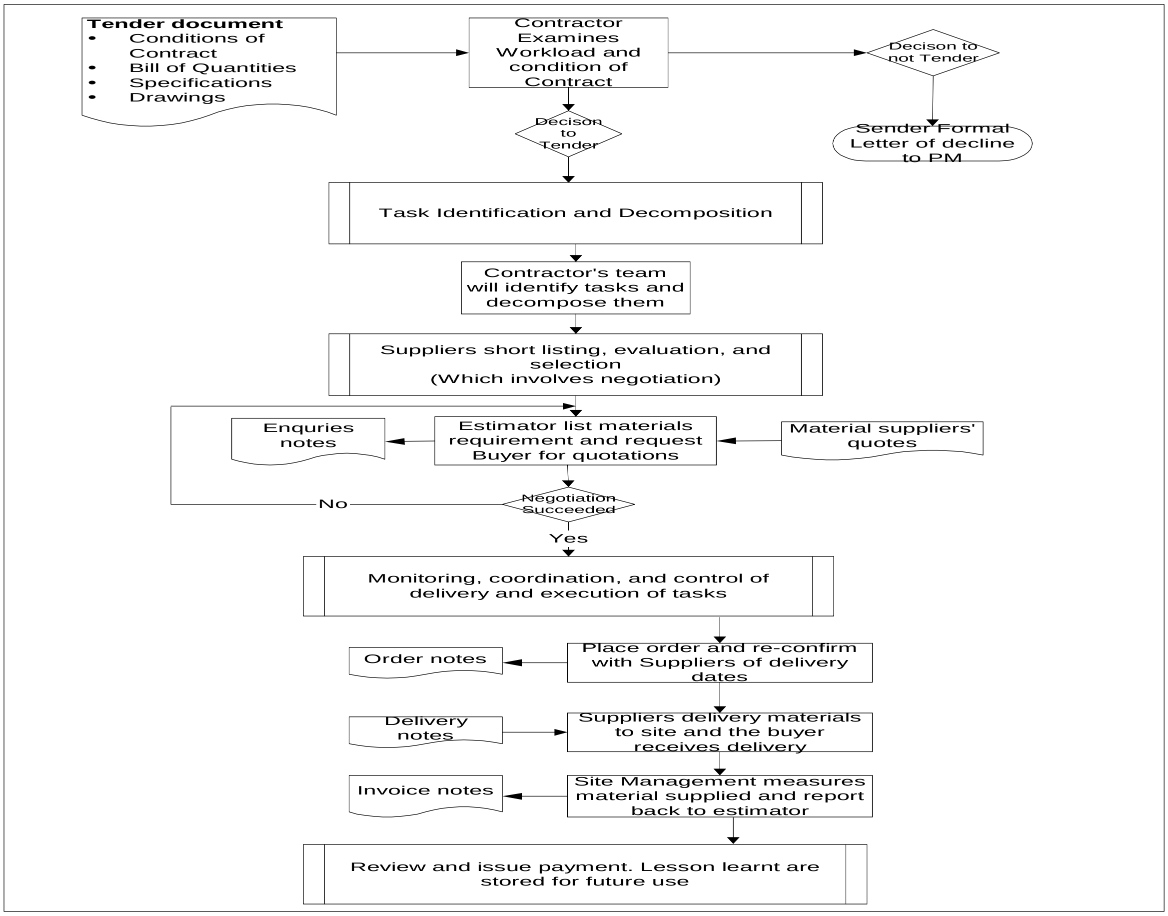

Figure 2: A Typical Material Procurement Process

Figure 2 shows a typical material procurement process lifecycle. The figure clearly shows that the management of material supply chain processes involves a large number of responsibilities. One of which is in itself responsible for determining materials requirements, locating and selecting suppliers, negotiating prices or tasks, expediting to ensure timely delivery, ordering and material payment. Supply chain process is a well-established approach that has proven, to create a proper way of looking at business processes.

3. THE NEED FOR NEW TOOLS

The traditional SC process has shifted, transformed and extended itself into dynamic, complex and ever changing processes (Udeaja *et al.,* 2001). The transformation transcends the physical boundaries of the whole enterprise and reaches into the global and rapidly evolving series of network. Currently, information technology (IT) has been advanced in this area to take on-board these changes. However, these computer applications in this area exist independently of the other applications, and have little or no capabilities for exchanging data. These systems cannot share their knowledge, hence cannot pool their resource or expertise and work together synergistically. Consequently, supply chain team members are frequently unable to consider the implications of their decision until it is too late and uneconomical to change. What seems to be required is a system that supports integration and collaboration of the multi-disciplinary participants that exist in construction material supply chain environment

(Latham, 1994). However, according to Goldmann (1996), previous artificial intelligence (AI) applications have been developed to mirror the fragmentation and diversity without due regards to complex, dynamic and distributed nature of the supply chain environment. Hence, the modern business process face ever-increasing problems in tracking and monitoring; the state of the project, the decentralised nature and dynamically responding to changes in the environment and the needs of the clients. However, some of the major reasons for these problems are listed below:

- Process Collaboration, which is lacking in most computer support approach in business process (such as competitive negotiation).
- Allocation of scarce resources among competing participants, coupled with the distributed nature of modern business processes.
- The modern business process is characterised by dynamic and complex activities, and existing tools fail to incorporate these functions, which may require plans and schedules to be repaired, even when execution is taking place.
- Existing systems are based on single-user model that views the decentralised business processes as one unit, with a view of one system accomplishing the whole task.
- Interoperability of legacy systems that abound the industry. Such tools are generally incompatible with one another, and have failed to address the key need of the industry, - that of support for collaboration.

However, research in intelligent systems has opened up new avenues by using software agents for solving collaborative problems. Barbuceanu (1997) identified that heterogeneity in such a system cannot be tackled by a single centralised system. What is required are several agents (Nwana and Ndumu, 1996) coordinating their activities, in order to enable timely dissemination of information, accurate coordination of decisions and management of actions among people and systems. This will ultimately determine the efficiency and the viability of the whole material supply chain.

4. RELATED WORKS

There are several on-going research projects investigating aspects of intelligent work between members of the virtual enterprise. The research projects cut across various disciplines and sectors including construction, manufacturing and other engineering areas and employ variety of strategies and concepts. These recent research includes the following:

- Fox *et al* (1991) integrated the supply chain in a manufacturing enterprise, using building shell to develop a cooperative supply chain environment. Their work identified an appropriate decomposition of supply chain functions and it did provide real-time performance.
- Kunz *et al* (1998) described the vision of the Intelligent Virtual Design Team (VDT) project that extend organizational theory so that it considers individual organizational entities such as actor, activities and both direct and coordination work.
- O'Brien and Wiegand (1998) developed an intelligent workflow management system. Their work adopted service-oriented view to meet the requirements of open distributed enterprise.
- Ugwu *et al* (1999) discussed the potential use of agent-based system for collaborative design in the ADLIB project. Their work is intended to serve as a useful decision support system for designer.
- Petrie *et al* (1999) developed a novel approach for managing complex distributed project using agents and a particular representation based upon a general model of design called REDUX.

The proliferation of research projects demonstrates the increasing interest of researchers in both academia and industry in the problems of distributed decision-making. However, the construction industry still has a significant gap to bridge to reach best practice in its use of intelligent tools. Fundamental changes are required to address the issues of inter and intra – organizational relationship, complex and dynamic activities that exist in a Construction supply chain environment. The research work on intelligent virtual environment addresses how the emerging multi-agent systems paradigm can be deployed to improve collaboration and integration in a construction material supply chain environment.

5. INTELLIGENT VIRTUAL FRAMEWORK

The work presented in this paper emphasizes construction of models that capture the existing structure and the autonomy of its sub-parts, thereby representing the complex and dynamic internal and external processes of organizations involved in the projects. It provides a transparent, unsimplified and essentially indeterminist view of the structure and dynamics of supply chain relationships. However, in this paper the key issues modelled involve task identification and decomposition, selection of suppliers and negotiation, and task execution and delivery. Under the decomposition model, determination of material requirements requires that the materials be identified and described in a way that accounts for their distribution to the various participants or allow them to be distributed. In such decomposition, the activities can then be modeled as a transaction between participants that are meant to procure material requirements. The transaction between these participants can be viewed as a predecessor and successor activities as shown in Figure 3.

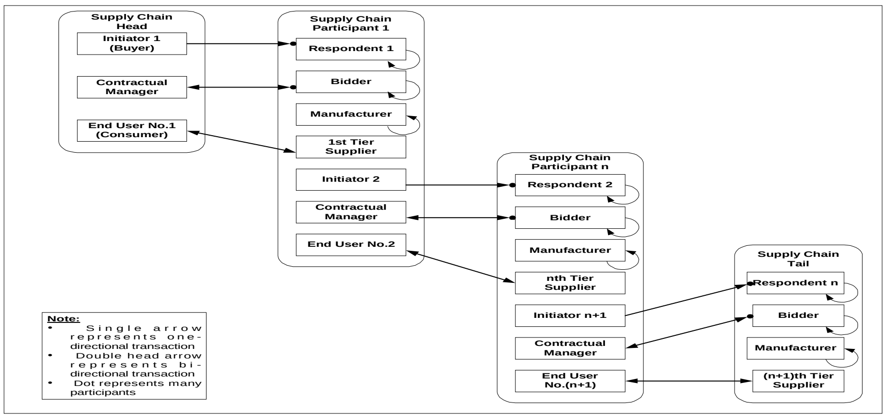

Figure 3: The Interaction Between Supply Chain Participants

The figure shows the decomposition stages within a predecessor inter-organisation and as well as the decomposition within intra-organisations running through to the tail end of the supply chain. The negotiation model build on the decomposition model, the model here examines the problem of material allocation, which involves negotiation between agents. As shown in Figure 3, the buyer initiates the transaction by issuing materials enquiries to the supplier's respondents. The respondents willing to respond will now set-up negotiation with the contractor's team. But before then, the bidder has to contact all other departments in his enclave to make sure that they can provide the resources required by the contractor. In some circumstances, the supplier's organization will need to contract other suppliers before negotiating with the contractor, and in such situation the supplier will take up supply chain head role. The negotiation strategy involves an interactive process of offers and counter-offers in which each agent chooses a deal which maximizes its expected utility value. The scheme for contractor (buyers) and suppliers involves growth-function and decay-function respectively (see Figure 4). The figure depicts that the supplier will offer the material at the highest desired price, and then decreases this price according to the decay function (which is specified as being linear, quadratic or cubic). However, when the desired date to sell the material arrives, the asking price should be about the lowest acceptable price. The converse is true with the buyer and its growth-function as shown in the figure. The delivery model enables the settlement aspect of trading to be separated from the negotiation model. The supply chain predecessor goes from being a Negotiation Initiator to a Consumer, and at the other end a supply chain successor is first a Negotiation Respondent, then a manufacturer, and then a Supplier. If supply is agreed upon, the production and delivery of the resource follows immediately. During delivery, the activities starts at supply chain tail and ends at the supply chain head. Once agreement is reached during negotiation, the delivery phase is entered which also includes production.

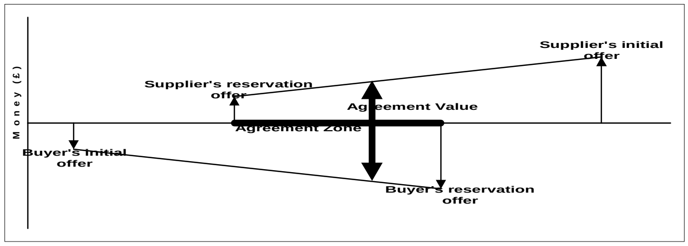

Figure 4: Negotiation Strategy for Growth and Decay Functions

6. INTELLIGENT VIRTUAL ENVIRONMENT

This section describes the intelligent virtual environment at a generic level. The environment is essential for efficient coordination of the interaction and communication between distributed agents. The intelligent virtual environment is broadly based on the ZEUS architecture (Collis *et al.*, 1998), a proprietary tool developed by BT that provides the following services; directory facilitator – yellow and white pages, communication channels, internal platform message transport and a platform for developing domain specific agents and wrapper agents to link to legacy software (see Figure 5).

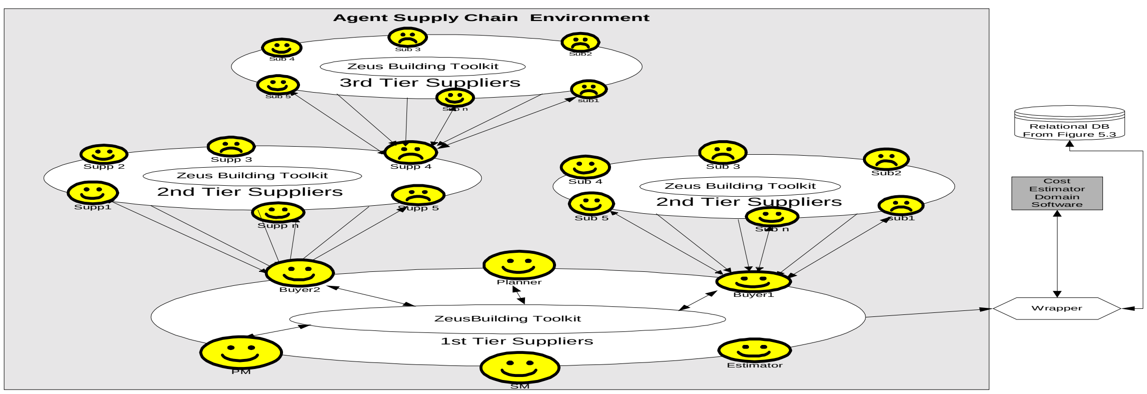

Figure 5: Intelligent Virtual Supply Chain Environment

ZEUS uses TCP/IP messaging built on Java to achieve interoperability (Nwana *et al.*, 1999) and other message transport protocols such as FIPA (Dicksinson, 1998), KQML and KIF (Finn and Labrou, 1997). On the other hand, the domain specific and wrapper agents can collaborate as co-worker, peer and superior/subordinate agents. The co-worker represent agents of same organizational background and hierarchy, while peer agents represents agents of same hierarchy, but of different organizations. The superior/subordinate agents support a nested (hierarchical) agent system in which higher-level agents (superior) realize their functionality through lower level agents (subordinates). The lower level agents have the same structure as the higher level ones and can, therefore, have sub-agents as well as tasks in the environment (see Figure 5).

7. CASE STUDY EXAMPLE

The example looks at a Door_Assembly process, its process involves a task hierarchy and task delegation as shown in figure 6. The example here, automates only the negotiation and delivery phases with three task agents, one representing the contractor's buyer and the others representing two suppliers bidding to provide the contractor with a component that make-up the Alumaco_Door (example Door_Handle). Furthermore, the system will use the information discovery method that ZEUS provides, to discover the agents as shown in Figure 7.

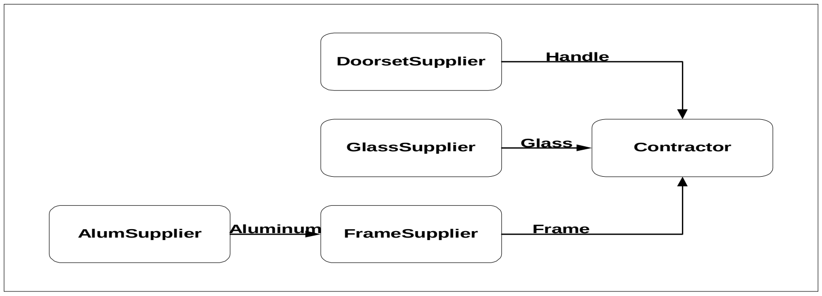

Figure 6: Supply Chain Participants of Door Assembly Process

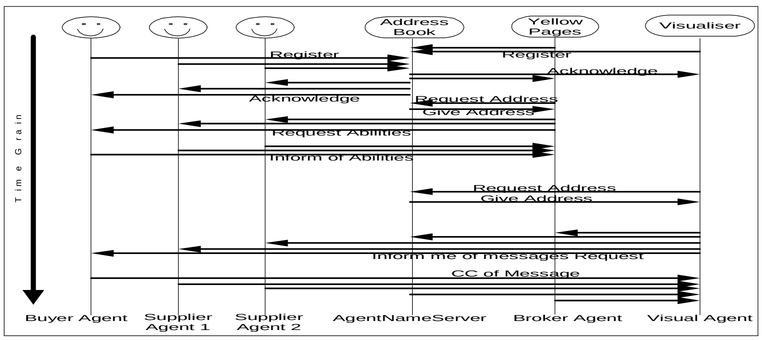

Figure 7: Interaction Graph of Buyer & Suppliers Agents

The interaction that occurs between them at start-up shows that all agents register with the nameserver, who in return acknowledges their existence. The activity in the environment is triggered off if a Buyer agent needs a material. It will then query the facilitator to determine the agents in the society that have the capabilities to provide the resources. The facilitator will then respond back, by providing the agent with the address of potential agents, who can provide the resources. It is important to note that the interactions shown are time ordered with those at top of Figure 7 occurring before those further down. The result of the transaction shows that the buyer closed the deal with suppler 1 after series of negotiations as shown in Figure 8. In the Figure, three trade windows represent the interface for the various agents involved in the scenario. Each has an interface area showing what the negotiation position is and three buttons below labeled inventory that opens up a list of materials available and the amount available for transaction. The other buttons are the selling and buying buttons depending on who is the buyer and who is the seller. The interface that the buttons open has two buttons, one for choosing the material from the ontology database and the other the trade button that initiates the transaction.

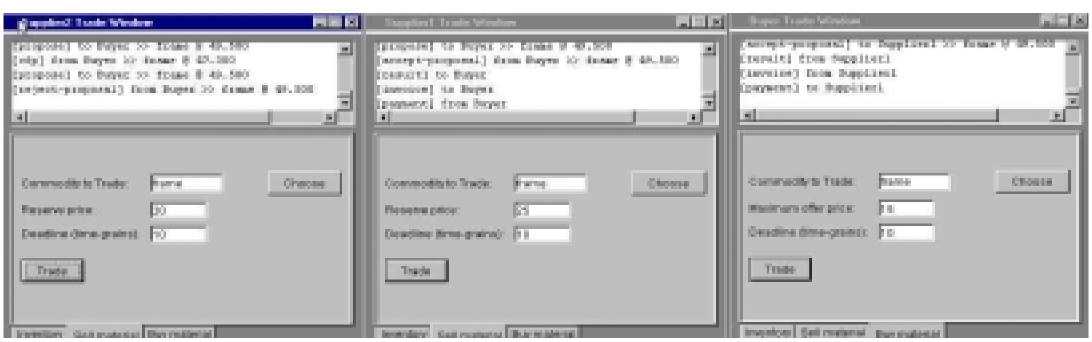

Figure 8: Trade Transaction between a Buyer and Two Suppliers

8. CONCLUSION

This paper presented an approach to coordinate and integrate the construction material supply chain in a virtual environment. It corresponds to the development of high and low – level functionalities – that help an enterprise to deal with many activities within the project. In the early part of the paper, the general concept of supply chain was described and the rationale for its adoption in the construction industry. A comparative review of existing tools in the supply chain environment was presented and the limitations in their use were also highlighted. This chartered a course for development of a new system adopting virtual principles. An example scenario of the use of the system developed was also presented to illustrate how the system works. The following conclusions can be drawn from the work presented in this paper:

- There is a need for improvements to the way the construction industry procure projects, so as to achieve client satisfaction and overall improvements in efficiency, effectiveness and profitability.
- There is a need to develop an appropriate framework or system for the construction supply chain, as existing systems are not appropriate in their present form.
- The argument that has been developed in this research is that existing research tend to conceive narrowly the complexity and dynamics of the supply chain processes and compound the error by focusing upon somewhat distinctive empirical setting. However, the system developed here, reflects and maintains the integrity of the existing structure and the autonomy of its sub-parts, thereby representing the complex internal processes of organisations involved in the project. Hence it provide a more transparent, unsimplified and essentially indeterminist view of the structure and dynamics of the supply chain relationships.
- Furthermore, it improves the negotiation process, by automating the process and also removing unwarranted human and obscure factors, which will reduce the timing for negotiation between participants.

Many construction participants are responding to this increasing importance of project development by incorporating aspects of virtual enterprise practices to improve their project development capability. Simultaneously, construction participants are also trying to make their supply chain more effective, and more efficient. Intelligent virtual environment application has the potential to make construction projects less fragmented, improve project quality, reduce project duration, and hence reduce total project cost, while creating more satisfied customers.

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