CONSTRUCTION MATERIAL SUPPLY CHAIN MANAGEMENT: TOWARDS AN AGENT-BASED TECHNOLOGY

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There is a need for managing the material supply chain to enhance performance of the entire project. The material supply chain consists of several participants and activities, but their complex interaction and interfacing need special attention. Conventionally, the interaction of these participants and activities has been carried out independently, and these have hindered performance of the whole project. An approach based on agent system approach is presented to address the problems of a material supply chain domain as part of an on-going research. The system views the material supply chain environment as a collaborative system, where supply chain participants are each represented by autonomous agents that can act on their behalf to carry out specific tasks. This system will employ concepts from distributed artificial intelligence (DAI), such as distributed problem solving to manage and co-ordinate the supply chain participants and activities.

Keywords: agent technology, collaboration, construction material, process, supply chain.

INTRODUCTION

Modern construction project procurement faces ever-increasing problems in managing and dynamically responding to changes in the environment and the needs of their clients, particularly in the Construction material procurement area (Meraghni *et al.,* 1996). This area is given particular attention because of the relatively high percentage of materials costs to total production costs and because collaboration of these participants will permit faster reaction to change in the design or planning. However, the manner in which these participants are coordinated and managed can affect the efficiency and effectiveness of the material supply chain (SC) process. Recent reviews by Latham (1994) and Egan (1998) suggest that the problems could be overcome by using more “collaborative” and “teamwork” approaches, the intention is to add value to the chain. The major issue facing construction industry is knowing what can be done, by whom, to improve the efficiency and effectiveness of the material supply chain process. The growing complexity of the procurement of materials has created the need for more flexible and sophisticated project management tools. These tools must support collaborative geographically dispersed participants in simultaneous planning and scheduling of tasks, and must highlight the critical technical and business risks that challenge successful material procurement.

DEVELOPMENTS IN CONSTRUCTION SC MANAGEMENT

Supply Chain Management (SCM) corresponds to a generic name to represent how supply chain processes are managed. In construction, Supply chain management is a

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way of working in a structured, organized and collaborative manner, shared by all participants in the supply chain. However, before the approach can be understood, it is necessary to have a clear understanding of the supply chain process approach to problem solving. The concept of supply chain provides a useful framework for analysing the construction material procurement process. Christopher (1998) describes the supply chain as the interconnected series of activities concerned with the planning and controlling materials, components and finished product from suppliers to the final consumer. The supply chain process typically comprises sub-processes and tasks. A task is an activity that performs one logical steps in a business process, and could be a manual or automated activity. 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). 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. Thus, the analysis of a number of material business processes from supply chain approach results in several common characteristics being identified (Udeaja and Tah, 2001): multiple organizations are often involved in the supply chain process; organizations are physically distributed, which may be across one site, across a country, or even across continents; inside organizations, there is a decentralized ownership of the tasks, information and resources involved in the supply chain; different groups within the project or inside organizations are relatively autonomous; many inter-related tasks are running at any given point of the supply chain process; and there is a requirement to monitor and manage the overall business process (project).

COMPUTER SUPPORTED SUPPLY CHAIN MANAGEMENT

Computer support is a subject of great importance for the realization of an effective and efficient supply chain management (SCM), and over the past decade there have been several research initiatives around the world aimed at demonstrating the feasibility of computer support in business process (like the SCM) (Roberts and Mackay, 1998). Research in this area has also reached an advanced stage in the simulation of the integrated procurement process of construction materials. In the USA and UK, two simulation exercise by Back and Bell (1994) and Carter *et al.* (1996) respectively estimated that the full exploitation of computer support in the construction materials procurement process could achieve 76-85% reduction in the total cycle time and save labour cost by 50-75%. Clearly, there are two fundamental information technology (IT) applications in business process. The first application is classified under generic information technology (IT) implementation, which covers such areas as; integration, communication, decision support systems (DSS) and visualization and the second deals with IT support specific solutions, such as CAD and planning tools. These IT implementations and support tools are well documented in research works by (Alshawi *et al.,* 1996; Tah *et al.,* 1998 and URL1).

The above description and other research conducted on the use of IT applications in business process indicate that substantial benefits can be realized in the material supply chain management process of the construction industry. However, the construction industry still has a significant gap to bridge to reach best practice in its use of IT to support SCM. Fundamental changes are required in technology, information management, culture and procurement forms to allow an advanced use of IT to support material supply chain process at all levels. The technological infrastructure to manage the transition is readily available and waits to be harnessed.

Deficiencies in supply chain management practice

The modern business process face ever-increasing problems in tracking and monitoring; responding to changes in the environment and the needs of clients. This paper argues that the major reasons for these problems are as follows: the current tools fail to handle the distributed nature of the business process and lack facilities to manage the resources; the existing systems fail to handle process co-ordination, which is characterized by activities such as competitive negotiation; the complex nature of the business process limits the existing tools ability to dynamically predict changes, due to external events, in both the volume and composition of work entering the business process; the integration of existing tools adopts a loose framework as a result of incompatibility in the process and data models of existing systems and existing systems are based on single-user model that views the decentralized business processes as one unit, with a view of one system accomplishing the whole task.

TOWARDS AGENT-BASED MATERIAL SCM

Given the above perspectives of the deficiencies of SCM practices, some distinct requirements of a suitable framework can be identified. The system should involve an inherent distribution of data, problem-solving capabilities, and responsibilities that conforms to the basic model of distributed, encapsulated, problem solving components. The adopted system should maintain the integrity of the existing organizational structure and the autonomy of its sub-parts needs to be maintained. Since business process deals with fairly complex situations, the system should have sophisticated interaction including negotiation, information sharing, and co-ordination, that is, the proposed system, should be endowed with complex social skills that aid collaboration. In a material supply chain, the problem solution cannot be entirely prescribed from start to finish, as such the problem solver need to be responsive to changes in the environment, and to unpredictability in the business process and proactively take opportunities when they arise.

The set of requirements above leaves agent technology (Nwana and Ndumu, 1996) as the strongest solution candidate. These agents are autonomous problem-solving entities, capable of performing services on behalf of their owners (Nwana and Ndumu, 1996). They also emphasize certain attributes such as: sociability, responsiveness, proactiveness and high-level communication (Jennings and Wooldridge, 1996), which are relevant in a collaborative supply chain environment (for example, co-operative and/or competitive negotiation). In this study, a multi-agent system for construction material SCM has been developed to address some of the deficiencies mentioned in the previous section. In the next section, the main focus is on the model for task decomposition, negotiation and execution mechanism, which matches the specific characteristics of material SCM.

AGENT-BASED SUPPLY CHAIN MANAGEMENT MODEL

The work in this research has adopted a decomposable “autonomous agents” approach to specify supply chain model; models are represented as role models (Kendall, 1998), which constitute supply chain participants (e.g. suppliers, buyers and contractors), their structural relationships, interaction protocols and co-ordination policies. The approach thus 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. Hence, it provides a more transparent, unsimplified and essentially indeterminist view of the structure and dynamics of supply chain management relationships. However, in this research the key issues modelled involve task identification and decomposition, selection of suppliers and negotiation, and task execution and delivery.

Task Identification and Decomposition model

The decomposition of supply chain functions and their allocation to agents are amongst the initial tasks in project execution. This stem from the fact that when work is to be done by a collection of participants (organizations) in some co-ordinated fashion, it is important to answer the question of division of labour and organization (which agent does what task, and when). A distribution of task among participants requires that the tasks be formulated and described in ways that account for their distribution or allow them to be distributed. In such a set-up, the activities can be modeled as a transaction between participants that are meant to carry out the tasks. The transaction between these participants can be viewed as predecessor and successor activities. In both form of supply chain activities, three types of supply chain roles exists: the head, the participant, and the tail. In a material supply chain, the supply chain head will be represented by the contractor's organization, whose needs cannot be satisfied locally, they contract a sub-contractor/supplier, who in this case will be represented as the supply chain participant. In most cases, the sub-contractor/supplier will still procure some parts down the chain from other suppliers until the initial request is satisfied. In this chain, the last supplier, who is the final port of call for the resource is represented as the supply chain tail as shown in Figure 1. Furthermore, Figure 1 illustrates how participants within each organization can be decomposed depending on how each organization intends to procure various tasks.

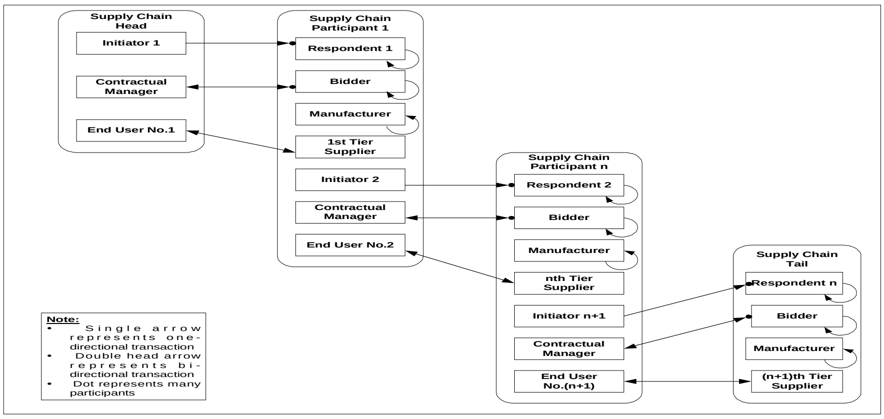

Figure 1: The interaction between Supply Chain participants

Negotiation Model

Negotiation is proposed as a means for agents to communicate and compromise to reach mutually beneficial agreements. The model here examines the problem of resource allocation and task distribution among autonomous agents, which can benefit from sharing a common resource or distributing a set of common tasks. The negotiation strategy adopted in this model is based on the multi-round contract-net (Davis and Smith, 1988), which involves one or more initiators that issue a request for quotation (RFQ), and one or more respondents that reply (see Figure 2). The figure depicts the relationship between protocols and interaction strategies. At each state the agent may need to make decisions about how to behave or respond to its current circumstances, these decisions are made using strategies. To understand the behaviour of this model, this research considers a contractor who needs a material or component, but cannot provide it locally and must therefore contact a sub-contractor/supplier to supply it. Hence, the Initiator illustrated in Figure 2 starts the process by analysing its requirements and determining how much it is willing to pay for the material and how quickly it needs it. Using the expertise encoded into its tendering strategy it formulates a RFQ message containing its requirement, this is then broadcast to all potentially interested parties and the agent moves into the negotiation state to await responses (see Figure 2).

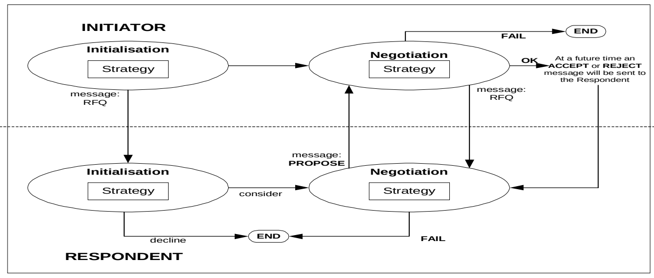

Figure 2: Transition diagram of a typical Negotiation (adapted from URL2)

The arrival of a RFQ message on the Respondent side causes it to move into initialization state. If the Respondent decides to respond, it will move into negotiation state. The negotiation process 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 3). 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. Thus, during negotiation, the Initiator role of the supply chain predecessor negotiates with the respondent in the successor. It involves request message sent out to all potential suppliers, who on their part have to agree to go into negotiation or refuse to negotiate because of other commitments. The final stage of negotiation, will involve the agents applying their negotiation strategies to reach an agreement. This process commences at the supply chain head, and finishes at the supply chain tail.

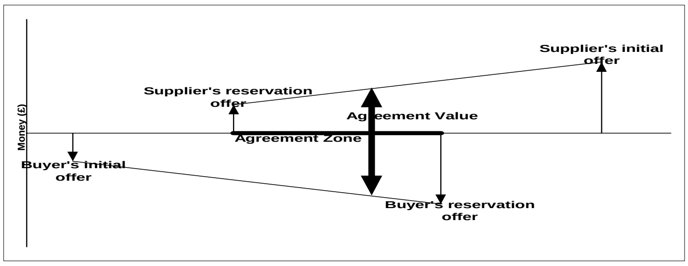

Figure 3: Negotiation growth and decay functions of buyer/supplier

The negotiation model proposed here is a strategic model of negotiation that takes the passage of time during the negotiation process itself into account. The distributed negotiation mechanism that was described is simple, efficient, stable, and flexible in various situations. The model considered situations characterized by complete as well as incomplete information, and ones in which some agents lose overtime while others gain overtime. Using this negotiation mechanism autonomous agents have simple and stable negotiation strategies that result in efficient agreements without delays even when there are dynamic changes in the environment.

Delivery Model

This 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 Producer, and then a Supplier. If supply is agreed upon, the production and delivery of the resource follows immediately. This pattern is repeated for the length of the supply chain, as shown in Figure 1. 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.

AGENT-BASED SCM SYSTEM DESIGN

This section presents the system architecture for the material supply chain that is developed to provide the basic platform for integration of virtual teams and legacy software in a construction material procurement. The system implemented organizes the supply chain participants as a network of co-operating agents (see Figure 4), each performing one or more functions, and co-ordinating their actions with other agents. The focus of this architecture is to support the construction of supply chain multi-agent systems in a manner that guarantees that these agents will engage in an effective and efficient co-ordination, communication and problem solving approach. In doing this, the architecture implemented here revolves around the ZEUS architecture, a proprietary tool developed by BT (URL 2). It utilizes the ZEUS design philosophy, which portrays the agent problem solving ability as made up of the agent-level functionality and domain-level problem solving. The architecture provides the agent-level functionality such as communication, ontology, co-ordination, planning, scheduling, task execution and monitoring, and exception handling using the ZEUS building toolkit and the environment to develop the task agents and information directory (white and yellow pages) using ZEUS problem solving functionalities.

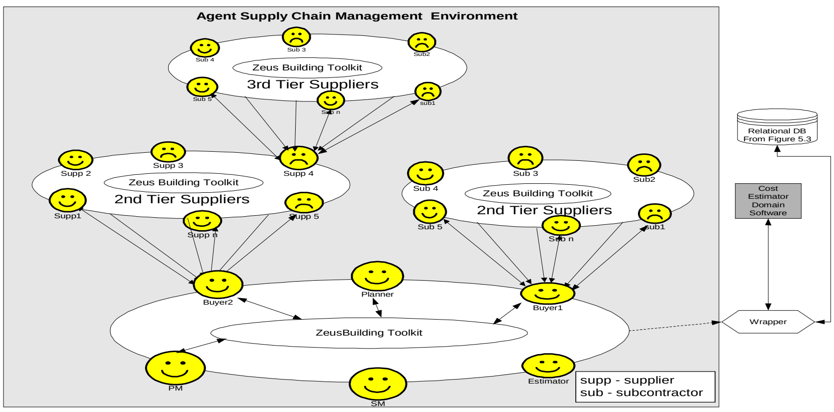

Figure 4: MAS - Supply Chain Management Environment

The task agents can collaborate as co-worker, peer and superior/subordinate agents. The co-worker represents agents of same organizational background and hierarchy, while the peer agents represents agents of same hierarchy, but of different organizations. The superior/subordinate interaction manifest itself in an organizational setting, it allows hierarchical agent system to be constructed in which the superior agent realizes their task through subordinate agents, who in turn may have other subordinates. Figure 4 illustrates these interactions, where the first tier suppliers have a mixture of inter and intra-organizational participants. The agents in this case are implemented as both peer and co-worker agents, where the former represents interaction between contractor’s agents and the PM agent and the interaction within the contractor’s organization (buyer, planner, Estimator etc.) are represented as co-worker. The issue of agent discovery is tackled by configuring the information discovery (white and yellow pages) in ZEUS. The white page also known as Agent Name Server (ANS) is used to keep register of all agents in the environment and the yellow page also known as the facilitator is used as a look-up service for agents’ abilities or expertise.

EXAMPLE SCENARIO

To further strengthen the argument of this research, the paper will consider a hypothetical example scenario to illustrate the agent application in a material supply chain management using the ZEUS building toolkit. The scenario involves a number of organizations involved in the assembly of alumaco door products. However, in this scenario the research identifies three phases to material supply chain activities: one high level involving task decomposition and two low level activities involving negotiation and delivery.

High Level Activities - Under the high level activities, five principal agents are modelled: Contractor agent, which has two subordinates, DoorsetSupplier and GlassSupplier agents. DoorsetSupplier supplies door handles, and knows Contractor agent as its superior and GlassSupplier as its peer. GlassSupplier supplies glasses, and similarly knows Contractor agent as its superior and DoorsetSupplier as its peer. The Contractor agent also knows another agent FrameSupplier as a peer who produces frames. The FrameSupplier has a subordinate AlumSupplier that manufactures aluminium of different types (see Figure 5). The capabilities of each agent were specified by defining one or more tasks it could perform. The preconditions of each task specified the resources required for the task, and its post-conditions specified the expected effects of performing the task. All tasks had an associated duration and cost, which could be functions of the resources used or produced by the task. The contractor agent, whose responsibility is to oversee the entire procurement could perform many tasks, but chose to decompose it to its subordinates and peer as shown in Figure 1. The links between tasks in the graph specify both the precedence relation between the predecessor and successor tasks, and the resources produced by the predecessor task that are used by the successor task. However, Figure 5 is a screenshot of two ZEUS visualization tools depicting the society and task decomposition when a goal to assemble doors is given to contractor’s agent. From the task decomposition view (bottom), it is seen that the contractor’s agent contracts out the supply of glasses to GlassSuppliers agents, frames to FrameSuppliers and door handles to DoorsetSuppliers.

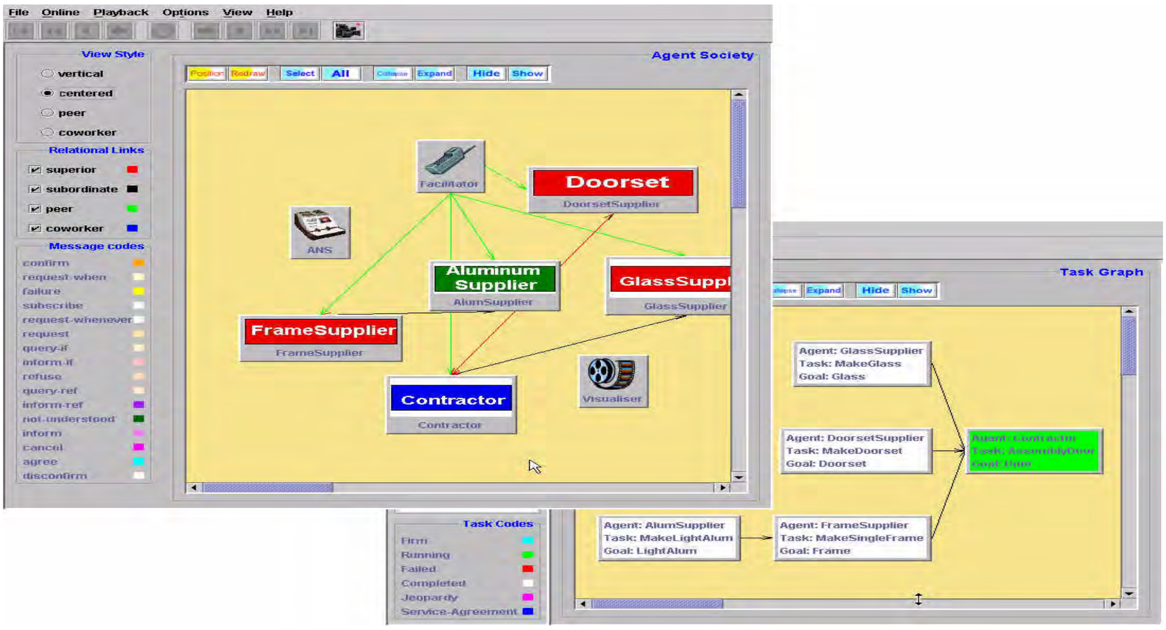

Figure 5: A Screenshot of two ZEUS Visualization tools

Low Level Activities - Under the low level activities, the scenario considers three task agents from the above environment, one representing the contractor's buyer and the others representing two suppliers bidding to provide the contractor with a component that make-up the AlumacoDoor (example frame). Furthermore, the system uses the information discovery method that ZEUS provides, to discover the agents as shown in Figure 6. 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 6 occurring before those further down. The result of the transaction shows that the buyer agent closed the deal with supplier 1 after a series of negotiations as indicated in Figure 7. 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 labelled 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.

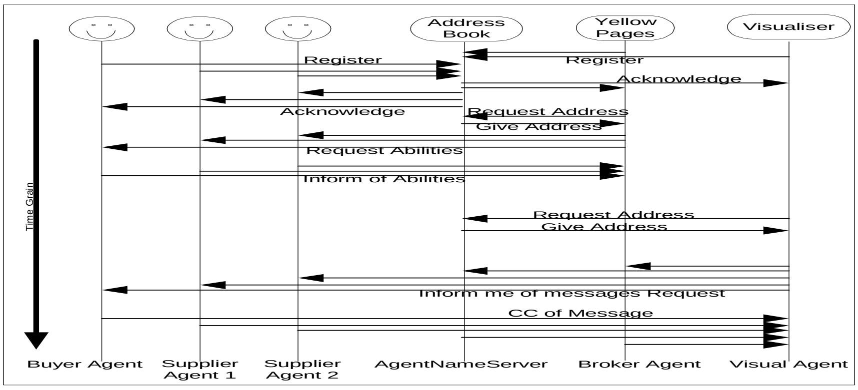

Figure 6: An Interaction Diagram of Buyer/Supplier Agents in Zeus

Figure 7: Trade Transaction between a Buyer and Two Suppliers.

Benefits of the agent-based approach

From the above example, it can be seen that by representing material supply chain participants as autonomous agents, the following benefits are achieved: the model reflects the inherent distribution of responsibility in large organizations, and makes the management of the material procurement transparent to the logical and physical structuring of its components; since negotiation is conducted between autonomous agents through a network, the time and fairness of negotiation is reduced and unwarranted problems are avoided since the agents have to reach a result within a specific time limit; and the model showed that the agents in the supply chain (SC) environment can run simultaneously, and thus it has the potential to improve the efficiency of the SC by allowing the activities of individual sub-tasks to run concurrently. The model and simple scenario presented in this paper has demonstrated the potential for agents in the SC environment. The approach is relatively successful because of the loose coupling between the task activities. Thus, decomposition process and contracting were sufficient to co-ordinate and represent the various agents' activities, to the extent that the entire process was automated.

CONCLUSION

The paper argues that the research evidence to date falls short of capturing the complexity and dynamic nature of the material supply chain. Consequently, the introduction of IT solutions to the problems has managed to some degree, to organize and structure the material supply chain process. These IT solutions are generally incompatible with one another, and to a large extent, have failed to address the key needs of the material supply chain process – that of support for collaboration between its multi-disciplinary participants. This has necessitated the development of agent technology for the material supply chain management. The approach presented, provides solution in improving collaboration amongst construction material supply chain participants using agent technology. The agent-based approach provides a useful metaphor for reasoning about collaborative systems, that emphasize certain attributes such as autonomy, sociability, responsiveness, proactiveness and high-level communication, which are relevant in a material supply chain management. Hence, in a construction material supply chain environment, these agents have the ability to decompose tasks, negotiate and delegate these tasks to appropriate agents for execution, whilst proactively co-ordinating communications and exchanges between individual agents, monitoring their performances, and rescheduling any malfunctions in service delivery to more capable and willing agents. This is in essence a virtual material management, which can be exploited in material procurement process for the simulation of project performance prior to actual start of construction material procurement process. In summary, this paper argues that agent technology can automate the material supply chain management and provide significant added value over and above simple just-in-time techniques and material management.

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URL1: Inter. Alliance for Interoperability http://helios.bre.co.uk/iai/email.htm

URL2: The Zeus Tech.Manual. http://www.labs.bt.com/projects/agents/index.htm