Agent-based Electronic Markets for Project Supply Chain Coordination

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Abstract

We propose to develop a framework for agent-based electronic markets (e-markets) for project supply chain coordination, where subcontractors interact and transact with other subcontractors within supply-chain networks with the assistance of software agents. The e-markets for project supply chain coordination complements our agent-based project schedule coordination framework by applying the advanced transaction techniques developed for electronic commerce systems. According to external changes, subcontractors trade not only their timing with other subcontractors through multi-agent negotiation, but also their tasks with the same specialty contractors, which may be in better positions to execute the tasks, through e-markets. The multi-agent decision-support system will help subcontractors explore various new choices and opportunities that the e-markets offer. The business-to-business e-markets support the current project coordination trends in which subcontracting or outsourcing now prevails.

Introduction

Traditionally, construction projects were carried out by general contractors who controlled most of the resources for the projects. Subcontracting, however, became prevalent due to its cost effectiveness and risk distribution. Subcontractors, which are usually specialty contractors, have special technologies and expertise general contractors do not have. Therefore, the role of general contractors has shifted from doing work with their own resources to coordinating subcontractors that actually do the work. Consequently, a project delivery network has been established where subcontractors deliver work to a general contractor which in turn delivers the completed facility to the owner. This description of the project delivery network parallels the definition of the supply chains in the manufacturing industry: "A supply chain is a network of suppliers, factories, warehouses, distribution centers and retailers, through which raw materials are acquired, transformed, produced and delivered to customers" (Chen et al 1999). Therefore, project control can be considered as a special instance of the supply chain coordination. We will refer to it as "project supply chain coordination."

Project supply chain coordination shifts the attention of management. Project supply chain coordination focuses more on utilization of resources which subcontractors have, while project control has focused on early completion of production activities. It is also a subset of construction supply chain management (O'Brien 1998), which takes a general view of the production activities of subcontractors and suppliers in the construction industry.

Project Supply Chain Coordination

Project supply chain coordination seeks resource utilization similar to the goal of the supply chain coordination in the manufacturing industry. However, unlike traditional supply chain coordination, whose nature is a centralized constraint-satisfaction problem, project supply chain coordination employs a distributed approach in which subcontractors play important roles of finding a "good" solution in a distributed manner, based on the "utility transfer scheme" (Kim et al 2000). The utility transfer scheme is developed to compensate subcontractors when disadvantageous agreements are otherwise required. The basic idea of the utility transfer scheme is that one subcontractor proposes to compensate other subcontractors for costs imposed on the latter for the former's replan. In our research, we quantify the utility based on resource utilization. The reasonable assumption about resource utilization is that resource discrepancy between the resource requirements and available resources causes additional costs of either relocating surplus resources or bringing in new resources.

The utility transfer scheme allows subcontractors to trade the timing of their tasks through the "multi-linked negotiation protocol" (Kim et al 2000), where agents need to negotiate with another agent, which in turn needs to negotiate with a third, and so on, until the last agent. This multi-linked negotiation is necessary because subcontractors operating in project supply chains have complex interdependencies and interrelationships. The multi-linked negotiation needs lateral networks which are usually ignored in the traditional supply chains in the manufacturing industry. The utility transfer scheme and multi-linked negotiation protocol are the main findings from our current research about agent-based project schedule coordination.

The ongoing research has shown that having lateral networks provides subcontractors opportunities to explore alternatives to alleviate their losses in cases of external changes, which are ubiquitous in construction. However, the lateral network is confined within the boundary of a particular project. Therefore, you might ask: How can the external lateral networks be established outside of project boundary to connect similar specialty contractors? What opportunities can be explored from interactions through the external lateral networks? What kinds of interaction protocols are needed for interactions among specialty contractors?

Before proceeding further, we would like to define some scope and assumptions we made for the this research: (1) Our research focuses on a particular construction project managed by a general contractor that subcontracts most of work; (2) Our research only considers task re-allocation problems after subcontracts are made by the general contractor. Therefore, our research is different from the subcontractor selection process; (3) There are similar specialty contractors who are willing to bid for any task from subcontractors; (4) The similar specialty contractors are tied with the general contractor. Therefore, they are pre-qualified for the tasks and only price is a factor.

Under the aforementioned assumptions, we envision that having the external lateral networks will allow subcontractors to use market-based protocols to trade their tasks with similarly specialized contractors, which may be in better positions to execute the tasks. Allowing task re-allocation helps subcontractors to minimize their damage while other specialty contractors have opportunities to utilize their available resources. This will lead to enhancement of global resource utilization in the construction industry.

Such transactions on the external lateral network might violate current binding contracts. The benefits of non-binding contracts were examined through the de-commissioning in the context of multi-agent systems (Sandholm and Lesser 1996). Sandholm and Lesser also claimed that de-commissioning contracts produces better results than the binding contracts by allowing agents to explore and exploit opportunities that do not exist in the binding contracting practices. Therefore, one of our research goals is to examine the benefits of relaxing binding transactions in project supply chain coordination.

Through transactions outside of project supply chains, the outside specialty contractors could be suppliers to subcontractors in project supply chains if the tasks are a part of subcontracts. In this way, these transactions form dynamic supply chains where specialty contractors come in and leave whenever transactions are beneficial for both subcontractors and specialty contractors.

It should be noted that our approach to project supply chain coordination is different from research about modeling and analysis of supply chains. We are proposing a new way of coordinating supply chain partners, rather than studying coordination issues among multiple entities in supply chains.

Agent-supported Project Supply Chain Coordination

The key opportunity for project supply chain coordination is the emergence of the Internet and the World-Wide-Web (WWW). As the WWW evolves and expands to include more business-to-business transactions, information sharing and the level of integration of activities between the supply-chain partners will increase. This new complexity necessitates new approaches to decision-support and information management in order to build highly flexible, fast, secure, and reliable systems that can allow subcontractors to take advantage of the new opportunities.

Software agents are atomic software entities operating on behalf of humans or machines (Moses 1999); software agent technology has been used to automate several of the most time-consuming tasks on many occasions (Maes, Guttman, and Moukas 1999).

We envision that software agents can help subcontractors utilize web-based supply chain coordination. Through our proposed research, the functionality of the project supply chain coordination will be transformed to constructing a virtual supply chain in a multi-agent system through the negotiation process among software agents. The currently developing multi-agent system will allow software assistant agents to evaluate the impact of their changes and advise the human subcontractors. Another functionality resulting from the dynamic nature of project supply chain coordination will be added for the new multi-agent system for project supply chain coordination.

Our agent-supported supply chain coordination approach should be differentiated from modeling supply chain dynamics with a multiagent approach (Swaminathan, Smith, and Sadeh 1998), where software agents model human beings or organizations and are used for simulation. Their use of software agents is perfect for social science, which studies behaviors of human beings and organizations, but agent-supported systems for engineering applications should take advantage of software agents that are capable of handling complex interactions between different entities and the multi-tiered structure of supply chains, which is not realistic in human settings.

Agent-based e-Markets for Project Supply Chain Coordination

Electronic commerce (e-commerce) can reshape the methods of agent-based project supply chain coordination as it has been doing for supply chain coordination in manufacturing (Zeng and Sycara 1999). E-commerce opens up new opportunities for subcontractors by allowing them to more easily trade their tasks in order to make the best use of their available resources. Furthermore, as transaction costs decline, new types of transactions, such as auctions, become feasible for trading tasks between specialty contractors.

Also, the transactions among specialty contractors can be streamlined based on the marginal cost approximation (Sandholm 1993): "the marginal costs of a task to an agent is the cost of the agent's solution with the task minus the cost of the agent's solution without it" (Sandholm 1996, p. 80). Therefore, the marginal cost of a subcontractor will be the highest desired price for the tasks it wants to sell and the marginal cost of a specialty contractor will be its lowest desired price. The specialty contractor will decide its bid price according to an auction type the subcontractor set.

Agent-based e-markets leverage agent technology to facilitate task reallocation among specialty contractors, resulting in e-markets for agents. Through transactions on the e-markets, agents will form and reform supply chains dynamically such that e-markets will produce a better solution. Through a preliminary survey, we discovered that current internet-based online auctions, such as eBay (www.ebay.com) and Onsale (www.onsale.com), do not support agent-based e-markets. We identified some examples of agent-mediated e-commerce systems which can be used for our e-markets, based on the survey of e-commerce agent technology (Maes, Guttman, and Moukas 1999): AuctionBot (www.auction.eecs.umich.edu), MIT Media Lab's Kasbah (www.kasbah.media.mit.edu), and tête-à-tête (www.ecommerce.media.mit.edu/tete-a-tete/). To the best of our knowledge, AutionBot is the only auction server that allows software agents to bid and create auctions.

For the proposed agent-based e-markets, the research questions are: How can agent-based e-markets help subcontractors trade their tasks with similar specialty contractors outside of the project supply chains? How can agent-based e-markets help subcontractors organize dynamic project supply chains?

Research Objectives

We are proposing to develop agent-based e-markets for dynamic project supply chain coordination. The multi-agent e-markets will be developed to simulate the dynamic situation that a project supply chain coordination system encounters, which requires subcontractors to organize the project supply chain flexibly.

Specifically, the objectives of this research are to define a negotiation protocol for e-markets, to define an e-market ontology, and to develop a prototype for a multi-agent e-market

Research Approach and Plan

The main research focus is how to coordinate subcontractors in supply chains dynamically and flexibly through the agent-based e-markets such that work can be delivered at the right time in a cost-effective manner. This research will be conducted in four phases. The goals of this research will be to design the functionality of agent-based e-markets and to evaluate the results from simulation of case examples on a prototype of e-markets.

Phase 1: Multilateral Negotiation Protocol for e-Markets

The main negotiation technique for e-market will be determined by the characteristics and number of negotiating agents. The specialty contractors outside of the project supply chain do not have interdependencies or interrelationships as much as inside project supply chain partners have. This characteristic makes our multi-linked negotiation protocol less practical. However, the number of specialty contractors is too large to employ practically the simple bilateral negotiation protocol. Therefore, a multi-lateral negotiation protocol, which is also called an auction protocol, is well suited to e-markets for trading tasks. The choice of appropriate auction types, i.e., "English," "Dutch," or "First-price sealed bid," is left to the subcontractors.

For the auction, we will adopt a third-party negotiation protocol (Chen et al 1999). As shown in Figure 1.

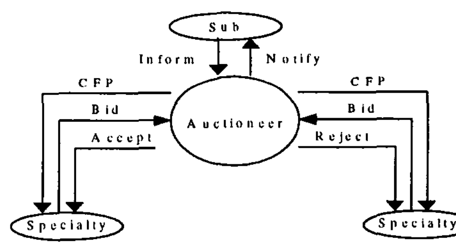

Figure 1. Third-party negotiation (auction) protocol

Therefore, a small set of pre-defined messages between the participating agents will be defined to emulate all the common auction types. According to the third-party negotiation protocol, one subcontractor agent (seller) starts the negotiation by sending a message to the auctioneer. This message includes the tasks that it wants to sell, the highest desired price, and the preferred auction type. After receiving the message, the auctioneer will broadcast it to the specialty contractor agents (bidders) and will organize an auction according to the requirements the seller submits. After several rounds of conversation, the negotiation process will end with a deal that was reached between seller and bidders. It is the auctioneer's responsibility to notify both the seller and bidders of the winner and losers.

As it is assumed that specialty contractors are in the list of authorized specialty contractors maintained by the general contractor, the agents representing specialty contractors are also assumed to be validly authorized for making a deal. However, the deal is just a recommendation. Human contractors always have to approve the deal. Therefore, this is a two-step process, involving contingent commitment in the first stage, and final (human-approved) commitment in the second stage (Nwana et al 1998).

Phase 2: e-Market Ontology

The proposed research focuses on task reallocation among specialty contractors. Task reallocation is different from schedule coordination problems in terms of its need of an ontology. In schedule coordination problems, abstract information, such as earliest start time, is enough for negotiation. In task reallocation, the ontology about tasks to be traded should be defined for transactions among software agents. By this we mean the specification of the knowledge structures used to define tasks and the relationships among these tasks (Albers et al 1999).

While defining our e-market ontology for tasks according to criteria such as clarity, coherence, extendibility, minimal encoding bias, and minimal ontological commitment (Gruber 1995), we take significant advantages of reducing the scope of the ontology because our agents are grouped based on their specialties, which need to be defined as ontologies.

Phase 3: Prototype for Multi-Agent e-Market

The multi-agent decision-support framework will consist of agents which implement functionality of project supply chain coordination, and an auctioneer which specializes in auctions, as shown in Figure 2.

All agents understand the e-market ontology, bid according to the auction's multi-lateral distributive negotiation protocol, and use the Knowledge Query and Manipulation Language (KQML) to converse. A

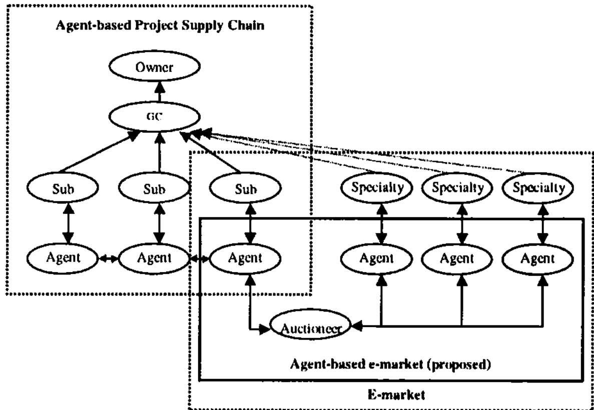

Figure 2. Agent-based e-Market Framework

simple multi-agent prototype will be built to test viability of this framework.

This new multi-agent system will be implemented through the incorporation of the AuctionBot, an agent-mediate e-commerce server, which was developed at the Artificial Intelligence Laboratory (AIL) of the University of Michigan, into our currently developing multi-agent system built on top of the ProcessLink (www.cdr.stanford.edu/ProcessLink/), which was developed at the Center for Design Research (CDR) of Stanford University, as shown in Figure 3.

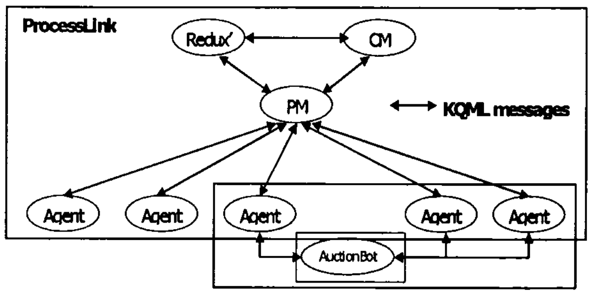

Figure 3. Agent-based e-Market architecture

Since the AuctionBot provides TCP/IP interface for software agents (Wurman, Wellman, and Walsh 1998), our agents on ProcessLink can access to include AuctionBot into our multi-agent e-market system for project supply chain coordination.

Phase 4: Verification and Evaluation

The multi-agent prototype system will be used to perform the Charrette test (Clayton, Kunz, and Fischer 1998), which is used by the Center for Integrated Facility Engineering (CIFE) at Stanford University to test the effectiveness of software systems. The subjects of the preliminary test will be graduate students of CEE department at Stanford University.

After the analysis of the preliminary test, the main test will be conducted with the involvement of an industry group. The Charrette Test will be conducted to compare two processes: one is a conventional "manual" process and the other is an innovative computer-aided process. The variables to be tested will be the usability, speed, and accuracy of the prototype system.

Expected Contributions

The proposed research will add a distributed coordination model for construction supply chain management. We believe that it is the first effort to model an e-market for specialty contractors in the construction industry with a multi-agent systems framework.

It is expected that our framework will create a new business model for trading tasks among specialty contractors, which we will refer as "lateral markets" compared to the traditional "vertical markets" between general contractors and specialty contractors as well as between specialty contractors and suppliers. Therefore, this lateral market framework can be extended to respective e-markets for general contractors and for suppliers. While we use the term "task," the items to be allocated can be resources as well if the ontology for the resource model is defined.

It is expected that our research will provide a foundation to develop a project supply chain coordination system that allows subcontractors to identify and analyze their resource constraints in a given schedule, and helps them explore and exploit many alternatives for a better solution.

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