E-WORK: THE NEXT ITERATION IN CONSTRUCTION MATERIALS MANAGEMENT SYSTEMS

Daniel Castro-Lacouture[1] and Miroslaw J. Skibniewski[2]

[1] *Ph.D. Candidate, School of Civil Engineering, Purdue University, West Lafayette, Indiana, 47907-1294, USA*
http://bridge.ecn.purdue.edu/~castrola

[2] *Professor of Civil Engineering, Purdue University, West Lafayette, Indiana 47907-1294, USA*
http://bridge.ecn.purdue.edu/~mirek

Abstract: The initiative of implementing Internet-based solutions for the integration of the supply chain of materials will not succeed if there is not assurance of collaboration and communication among the parties in the construction business. Neither EDI nor web-based supply chain applications can facilitate both the process integration and flexibility required by the construction processes practiced today. E-work is a suitable concept for this endeavor because it comprises principles that allow cooperation and collaboration in the organization. The research described in this paper follows upon recent publications on E-work models in order to propose a set of applications in construction materials management systems. Expected benefits are related to conflict resolution and reduction of lead times and subcontractor overhead costs. Implications of this work with respect to the initiatives based on IAI/IFC or STEP models comprise the potential for prediction of materials requirements with the use of task administration protocols and autonomous agents.

Keywords: E-work, materials management, protocols, agents

1. INTRODUCTION

1.1. Supply Chain of Materials in Construction Processes

Construction processes rely in a great extent in the exchange of information and permanent interactions of entities and resources. Even though the configuration and set up of machines is usually different than in the manufacturing industry, the interrelations of relevant participants in a construction process are considerable, and their management will have a direct impact on the success of the project in terms of time, cost, quality and morale.

There are other considerations that need to be addressed when designing a construction materials automation system, such as the effect of design in the construction process, the isolation of materials procurement from design, differences in CAD formats, use of non-integrated databases, brief and usually poorly coordinated contribution of subcontractors in the design and procurement processes, etc [3]. These problems are well documented in the construction literature, and have been in recent years a subject of study of several business organizations such as the Construction Industry Institute in the United States and related bodies worldwide. The initiative of implementing a collaborative e-business solution for the integration of the supply chain of materials, such as steel reinforcement rebars, will not succeed if there is no assurance of collaboration and communication among the players in the construction business [3].

It is possible to deploy an e-commence function with the objective of performing transactions between contractors, suppliers and clients. In fact, that can be done easily and is currently being utilized by construction material suppliers and contractors. Ordering, billing and information-sharing functions are common in the form of Web-based applications [11]. However, by merely setting up a transaction platform framed by e-commerce principles, the success of the integration of critical stages in the construction process is not necessarily guaranteed. Moreover, it is needed to consider a new concept that fosters effectiveness in the overall supply chain system integration, that is, to achieve adaptability of resources throughout the supply chain of materials in the overall construction process, or to rapidly adapt to changes in the required product quantity and design [10]. This concept must integrate the general and specific project design in order to avoid conflicts in the subsequent stages of the project development.

The objectives of the materials supply chain automation consist of minimizing processing costs, enhancing delivery and response times and improving communication in order to expedite conflict resolution. Although the scope of this research is confined to describe the use of E-work models, metrics associated to these model objectives will be originated from time studies, workflow simulation, activity-based costing and frequency of documented delays due to conflicts. The idea of automating the supply chain of materials must consider the multiple sources of disagreement related to negotiation protocols among contractor, subcontractor, material supplier, designer and client, as a consequence of the struggle to obtain better prices and product quality. An electronic market system can reduce customer's cost of obtaining information about prices and product offerings of alternative suppliers, as well as supplier's costs of communicating information and negotiating about the prices and product characteristics [2].

1.2. E-work and Autonomous Systems

E-work is composed of the collaborative, computer-supported activities and communications-supported operations in highly distributed organizations, and also investigates fundamental design principles for their effectiveness [13].

The goal of E-work for this research is to integrate the components of the construction supply chain of materials, from structural design to procurement and assembly. The utilization of this approach is justified by the assumption that construction processes are composed of highly distributed organizations of autonomous systems. This assumption is based on the unique nature of the construction industry in terms of interactions among business partners, clashing interests, isolated design and procurement, etc. In addition, every construction project is different from another. The materials, procedures, contractors, design firms, or contracts in construction projects may be similar, but the final product is evidently different. It is a customized product that has to evolve from the initial stages of client briefing to the complex states of seismic resistance, fit outs and finishes. That is one strong reason to consider this organization as complex and composed of autonomous systems. These systems are composed of the equipment, hardware or software utilized by various designers, suppliers, subcontractors or contractors in order to achieve the goal of project completion [3].

Figure 1 shows a sample of the numerous interactions among project stakeholders in order to approach the process of design, revision and procurement of materials for the structural reinforcement division of a standard construction project.

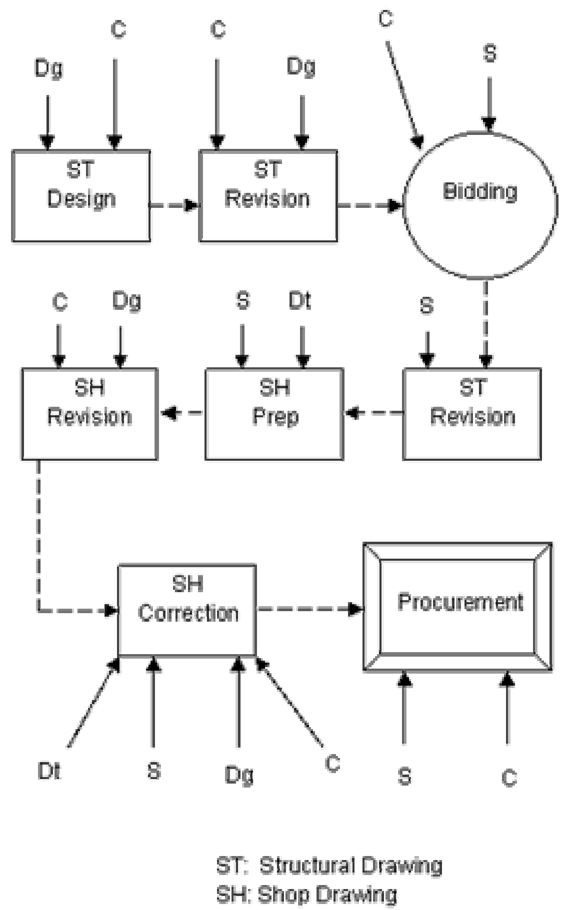

Figure 1. Scheme of interactions during the design, revision and procurement of materials on a standard construction project.

The terms C, S, Dg and Dt stand for Contractor, Rebar Supplier, Designer and Detailer.

2. MODELS OF E-WORK

2.1. Task Administration Protocol (TAP)

Task Administration protocols are defined as the logical rules for the workflow control that enable effective collaboration by communication and resource allocation among production tasks [14]. Effective collaboration, in the context of a supply chain, stands for obtaining real-time information, minimizing cost, increasing levels of service, improving communication and enhancing delivery and response times [8]. Within the context of the construction process and in particular for the case of construction materials management, the following protocols are defined in Table 1.

Table 1. E-work solution algorithm with Task Administration Protocol [6].

Types	Protocols
Inquiry	A ➔ B: request X B ➔ A: answer (X) A,B - agents X – questions
Passing	A ➔ B: tell X A,B - agents X – message
Negotiating	(1) A ➔ B, C: tell X (2) B ➔ A: If ValueB(X) OK, Tell 'acceptB' else Tell X' (3) C ➔ A: If ValueC(X) OK, Tell 'acceptC' else Tell X'' (4) A ➔ B, C: If acceptB and acceptC, end. If acceptB and X'', X=X'', go to (1) If acceptC and X', X=X', go to (1) If X' and X'', X=(X',X''), go to (1) A,B,C – agents X,X', X'' – alternatives
Announcing	A ➔ B,C,D: tell X A,B,C,D - agents X – message
Approving	(1) A ➔ B: request X (2) B ➔ A: If ValueB(X) OK, tell 'approveB' else X' (3) A ➔ B: If approveB, end. If X=X' go to (1) A,B – agents X,X' – alternatives, where X' is lacking approval

In order to improve performance, the protocol can trigger and initiate necessary and timely interaction tasks under coordination logic. In order to explain and illustrate an E-work solution with task administration protocol (TAP) it is important to clarify the concept of agent. An agent is a 'program' (autonomous entity) that represents a group of parties [6]. Parties may include 'resources', e.g. humans, machines and computer systems. The role of the agents is to cooperate with each other through protocols to perform specific tasks and to achieve the system's goal. Along the lines of this definition, the active tasks administration protocols (TAP) control rules that tenable effective collaboration among agents and tasks. Protocols provide the rules for agents to procure information [6]. A typical scenario of material procurement, illustrated in Figure 2, may involve a contractor and several steel suppliers. The contractor inquires two rebar supplier agents (a_1 and a_2) about quantity take-off of some rebar material. The two supplier agents respond the request. Based on the responses, a_0 does some checking and sends the decisions and approvals to the three supplier agents.

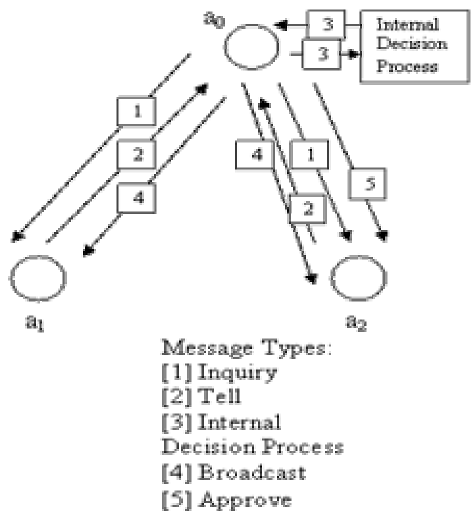

Figure 2. Task administration protocol applied to construction materials management automation.

2.2. Multi-agent Model

Agents are defined as a hardware or software system that can act, interact and respond according to given goals [14]. For the particular case of construction materials management networks, the agents need to feature autonomy and flexibility. Software agents developed specifically for the supply chain may support the ability to closely integrate buyer and seller processes as well as to provide sufficient flexibility to keep up with changes to supply chain operations [12]. As a requirement to be autonomous, the agents need to have [6]: database and protocols, sufficient capability for anticipating their long-term viability domain, measurable output (processing time, waiting time, etc.), ability to learn and a sensorimotor apparatus (protocols, databases and human observation can serve to this purpose). A similar case takes place in construction processes, where the final decision on material quantities is not final until the material suppliers (for the case of steel reinforcement rebars) provide the estimation based on the structural design drawings. Therefore the system of materials procurement has to be initiated without the benefit of planning, which is what happens in most of the cases. An architecture consisting of four agents will be used to illustrate an E-work model for the construction materials management automation on the Internet. Agents to be considered are a forecaster agent, a recorder agent, a planner agent and a reviser agent. The flow diagram for these interactions is shown in Figure 3.

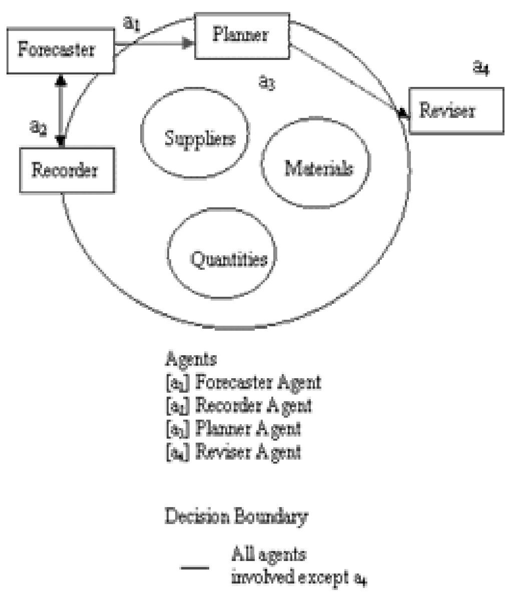

Figure 3. Multi-agent model applied to construction materials management

However, an E-work model of multi-agents can help predict the requirements of materials using knowledge of the supplier past estimations for standard or special cases, in addition to recent observations of other projects in progress or completed. These predicted job requirements can then be used for better planning [14]. In an effort to find the solution to a problem in a flexible manufacturing system, Esfarjani and Nof [4] found out that the challenge consists of managing the distributed material and information flow. The construction process, due to its diverse and almost unlimited source of ideas and methods for materials procurement, handling and procurement, qualifies to be treated as a flexible process.

2.3. Parallelism Model

An E-work model of parallelism to ensure effectiveness in the Internet deployment of a construction material management automation system must have into account that there are several e-activities present. It is possible to obtain improvements in time and accuracy through the utilization of a client-server model and the assignment of tasks to the available resources, i.e. material suppliers, designers, subcontractors or delivery entities. There will be a coordination agent that allows the parallel execution of tasks, thus having earlier progress or even completion dates. Parallel processing in supply chains has an explicit focus on collaborative problem solving between multiple processors. This problem solving is usually focused more on numerical processing than intelligent reasoning [12]. Figure 4 displays the structure of a parallel tasking, using master-slave architecture.

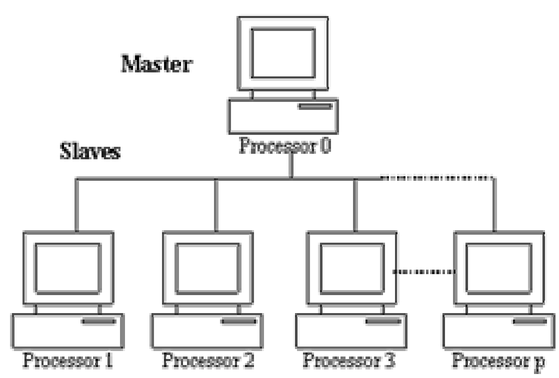

Figure 4. Master-Slave architecture in parallel multitasking.

In order to communicate and cooperate in the Internet, certain procedures must be established to coordinate the interaction of participants in order to effectively accomplish the tasks [16]. In this case there are various types of inquiry, approval or negotiation protocols that are presently used.

There is a need for a coordination protocol that will guide and support the interaction of participants in order to successfully perform the necessary tasks. The ultimate goal of the coordination-related research is to find the most effective coordination scheme that maximizes collaboration effectiveness among participants. The effectiveness in the collaboration among material suppliers, subcontractors, designers and contractors will have a dramatic impact in the overall success of the construction project.

The interaction diagram of a typical workflow for construction materials management shows the different interactions among resources. Figure 5 displays the interaction diagram for a typical supply chain of materials.

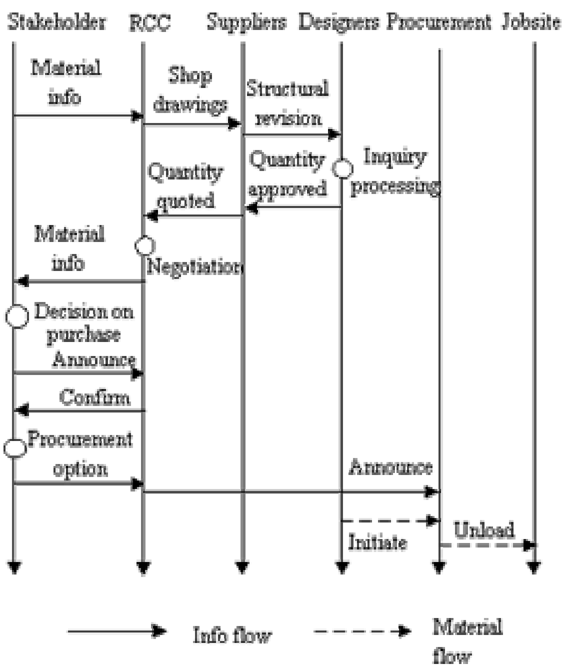

Figure 5. Interaction diagram for a typical supply chain of construction materials.

Interaction diagrams are tools that characterize the elements in the supply chain of information and materials. These tools may be utilized when deploying an e-business solution for the integration of the supply chain. For instance, any request by the contractor of information regarding quantity take-off from shop drawings will flow from the material supplier to the designer for revision and approval. Subsequently, the designer will send the approved drawings back to the supplier for delivery through a web operation center. This e-business approach is aiming to integrate the process of design, estimation, revision and procurement of materials from the early stages of the construction project. The interaction diagram also indicates the decision nodes in the overall process, i.e. inquiry processing, negotiation, decision on purchase and procurement option.

The research developed by the PRISM Lab at Purdue University [14] uses parallel computing to simulate autonomous agents. This tool, called Teamwork Integration Evaluation (TIE), focuses on measuring the coordination performance of all participants [1]. Figure 6 shows an adaptation of the original TIE/Protocol, with outputs relevant to the new application in the construction material automation process.

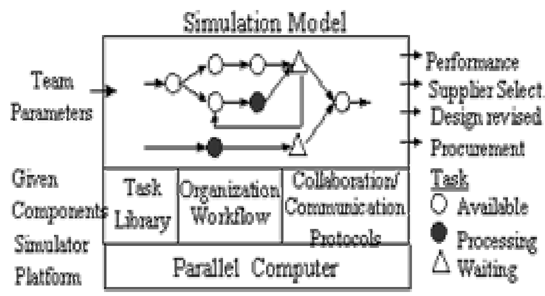

Figure 6. TIE/Protocol for construction material automation (adapted from Anussornnitisarn and Nof [1]).

2.4. Conflict Resolution Model

The inherent nature of construction processes plagued with conflicts, create an area for improvement. An E-work model of conflict resolution will be of great benefit for the automation of construction materials management systems deployed on the Internet.

A collaborative method for facility design is needed in order to increase design quality and shorten the design process development [14]. The process of design, estimation, revision and procurement of construction materials displays lots of conflict situations, which result from the interaction of cooperating designers, suppliers, subcontractors or contractors. The new method of conflict resolution, MCR, developed by Lara [9] and Lara et al. [10] comprises rational execution of pre-ordered conflict resolution approaches: direct negotiation, third party mediation, incorporation of additional parties, persuasion and arbitration or settlement of claims.

The main cost-differentiating factors influencing choices in conflict resolution architectures are: intensity of processing (measured by task complexity), intensity of communication (measured by quantity of exchanged communication) and extent of communication (measured by the level of networking in the process) [5]. This study points out that previous analyses in the area have failed to consider management costs, which can be dissimilar across different IT architectures. As it can be seen in Figure 7, the costs for conflict resolution increase as stages escalate from a direct negotiation to arbitration.

Cost Progression

Stage 1: Direct negotiation

Stage 2: Third party mediation

Stage 3: Incorporation of additional parties

Stage 4: Persuasion

Stage 5: Arbitration

Figure 7. Cost of conflict resolution stipulated in MCR [9].

This multi-approach method facilitates computer-supported conflict resolution. Its performance is improved through the inclusion of principles for prevention of conflict perpetuation. Along the same line of logic, the implementation of computer-based learning increases the usefulness of the method. As expected, the integration of conflict detection and resolution results in an increased effectiveness of the facility design process. The facility design language (FDL) provides a uniform support framework for communication among facility designers in a distributed environment, thus allowing distributed users to develop, evaluate, reconcile and modify CAD system models of the facility. This language fits the needs of the construction process due to its strong dependency on CAD drawings for information exchange and quantity take-off revision.

Figure 8 shows the arbitration steps to be included in the construction material process in order to incorporate prevention, therefore the system will be continuously providing feedback to the parties in order to learn from previous experiences.

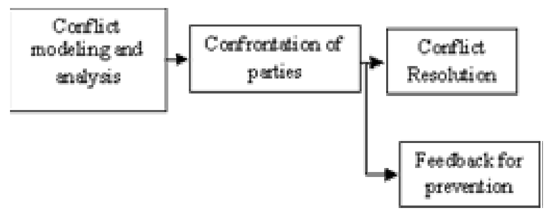

Figure 8. Sequence of steps in the prevention stage.

2.5. Model of Next Generation of ERP Systems

An E-work model that incorporates design considerations is desirable for the successful practice of construction materials management automation. As indicated by Nof and Anussornnitisarn [15], the key for the successful implementation of ERP systems is to be able to anticipate the problems.

For the particular case of construction materials management, some considerations need to be addressed in order to fit the purposes of the new generations of ERP systems. Firstly, when material suppliers are required to provide a take-off of a structural drawing, the design process should be able to detect, synthesize and prioritize the problems that might occur with the interacting participants. Secondly, the design should be able to provide the grounds for the protocols to be used and what and when to communicate. Priority schedules for the different participants of the construction process (contractor, subcontractor, supplier and designer) must be kept active. Third, the independent entities should be able to participate in the design process. This is an ambitious goal, but this way coordination with other agents will be possible, therefore problems can be anticipated and dealt with in a timely manner. Finally, the new ERP system will recognize conflicting intentions among distributed entities. If there is a pattern of miscalculations by a designer that is being rejected by the materials supplier, the ERP system should be able to trigger an action (agent) on the contractor, allowing the system to foresee an upcoming conflict therefore evaluate the design. A similar case may be encountered the other way around. If the material supplier is not providing an accurate take-off of materials, the ERP system triggers an action framed by an active protocol, anticipating the conflict and informing the supplier about the possible solution to the inconvenience. Figure 9 shows the concept of the next generation of ERP systems.

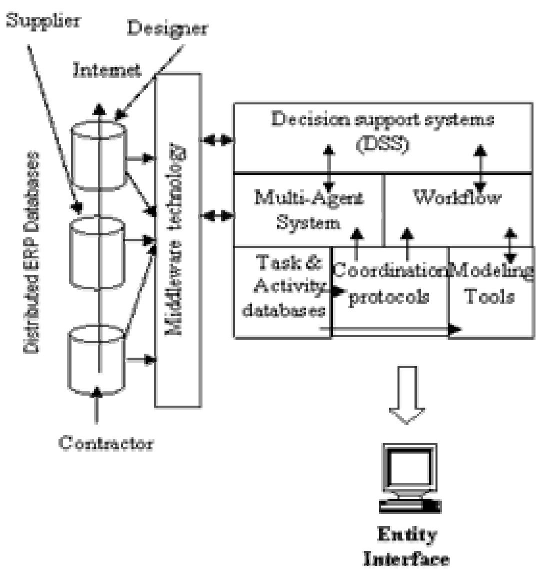

Figure 9. Next generation of ERP systems [15].

The communication infrastructure of parties involved in an integrated ERP system for the construction industry will depend on models such as the STEP, EDI or IAI/IFC. A subset of these models, SUMMIT, can be used to support the integration of supply chain management applications [7]. This approach developed a framework to automate the tendering, ordering, delivery, invoicing and payment processes of house systems, equipment and services in their supply chain, and where members have different backgrounds regarding information and communication technologies.

3. CONCLUSIONS

The supply chain of materials in construction processes remains a critical competency for the success of the construction business. Even though fast developments in communication infrastructure through models of EDI, STEP or IAI/IFC, the management and control of entities in the supply chain of materials are very often not carried out automatically. With the incursion of the Internet and its e-business capabilities, new approaches for the automation of supply chains of materials have been developed. However, the construction industry has yet to utilize intelligent tools for the resolution of common conflicts in the planning, design, procurement and delivery of materials.

E-work is a suitable concept for this endeavor because it comprises principles that allow cooperation and collaboration in the organization. E-work has provided benefits to the exchange of information and collaboration among autonomous systems in manufacturing organizations. The nature of construction processes in terms of occurrence of conflicts, autonomy of interacting systems, distributed organization and sequencing of tasks in the supply chain provides areas for applicability of E-work models. The research described in this paper builds upon recent work and publications on E-work models applied to systems of manufacturing organizations.

Autonomous agents can help predict the requirements of materials using knowledge of the supplier past estimations for standard or special cases, in addition to recent observations of other projects in progress or completed.

The sequencing of tasks for the exchange of information prior the procurement and delivery stages can be achieved via task administration protocols, whose defined steps convene more complex intentions than single communication acts.

Interaction diagrams provide information on different interactions among resources, allowing stakeholders to consider parallel processing for an effective automation of supply chain processes focusing on characterization of entities and decision nodes.

Finally, the process of design, estimation, revision and procurement of construction materials displays conflict situations that can be resolved with the implementation of multi-approach methods facilitated by computer-supported conflict resolution.

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