Applicability of e-Work models for the automation of construction materials management systems

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Abstract. Manual processes of quantity take-off, bidding and quantity revision of construction materials are the cause of numerous conflicts among construction process stakeholders. This research aims at redesigning these processes in the direction of a collaborative approach using e-Commerce technology. Relevant B2B approaches need to incorporate tools that minimize estimation errors and improve design quality. Recent research on e-Work models allows the proposition of a set of applications in construction materials management systems for the exchange of design and project information among contractors, designers, fabricators and suppliers. Expected benefits include improvements conflict resolution techniques, faster procurement and reduction of lead times. This paper discusses the applicability of e-Work in the automation of construction materials management systems, using knowledge of past estimations in addition to recent observations of other projects in progress or completed.

1. Introduction

The management of the supply chain of construction materials has improved during the past decade, mainly due to research on the use of electronic data management technologies. Benefits to be derived include increased support, staff productivity, reduced procurement lead times, improved data accuracy and enhanced material supplier relationships. The various innovative electronic data management technologies implemented by the construction industry, i.e. bar coding, electronic data interchange, integrated database management systems,
radio frequency identification, aecXML, and e-Commerce have positively influenced the supply chain of construction materials (Castro-Lacouture and Skibniewski 2002). To achieve this effect, the preparation of complex project documents, interactions with the materials supplier and adjustments of slight variations in design can be facilitated through automation. However, the design of a construction materials automation system must address a mechanism for expediting conflict resolution and for preventing the isolation of procurement from design, differences in CAD formats, utilization of nonintegrated databases, brief commitment of subcontractors in the design and procurement processes, etc. 'e-Work' is a suitable concept for this endeavour because it comprises principles that allow cooperation and collaboration in the construction 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.

2. Current practices

The current practices of steel reinforcement estimation, revision and procurement, are expected to find a linear sequence of tasks, processed by resources such as the contractor, designer, rebar supplier and detailer. Under this serial arrangement, communication between participants is fragmented, and depends solely on the presence of the participants of a specific task. Consequently, conflict resolution is not produced in a timely manner since the participants involved in a determined task are not in the position of taking any decisions without going back to a previous task. The fact that different formats are utilized for the presentation of information on reinforcement steel for estimation and procurement makes the situation even more complicated. 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 structural reinforcement in a typical construction project.

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 stakeholders in the construction business. It is possible to deploy an e-Commerce function with the objective of performing transactions between contractors, suppliers and clients. In fact, this can be done without difficulty and is currently being utilized by construction material suppliers and contractors. However, by merely setting up a transaction platform framed by e-Commerce principles, the success of integration of critical stages in the construction process is not necessarily guaranteed. Moreover, it is necessary 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. This concept must integrate the general and specific project design in order to avoid conflicts in the subsequent

Figure 1. Scheme of interactions during the design, revision and procurement of materials on a standard construction project (adapted from Castro-Lacouture and Skibniewski 2002).
3. Previous research

3.1. e-Business solutions for materials management

It is possible to deploy an e-Business solution to achieve a collaborative environment, aimed at facilitating communication and participation of the parties. This collaboration process will ultimately bring benefits to the construction process in terms of cost cutbacks, reduction in delivery times and most essentially, generating a dynamic environment for conflict resolution.

By its nature, e-Business fosters change. The change has been profound and fast as companies adopt the Internet as a primary channel for business interactions. The web was initially used as a one-way channel for communicating text and graphical information to project stakeholders. Then it became a platform for electronically processing orders and displaying catalogues and real-time inventories online. e-Business requires integration of the information and processes needed to conduct business in real time. This requirement may be applied to the design and procurement of reinforcing steel in construction projects, not only because reinforcing steel is a commodity, but because of its inherently conflicting underlying interactive processes. It means that online references and catalogues must connect to the inventory database. Supply chain integration of manufacturers and distributors requires introspection into production scheduling, product configuration and inventory management. Credit authorization, order processing and fulfillment must be integrated to deliver the materials to the project stakeholders.

Since the supply chain described in this paper displays different scenery in terms of information flow and interaction of participants, it is important to clarify this distinction. The ultimate goal of a reinforcing steel bars estimation and revision process is to produce a reliable source of information for suppliers on which to base their bids. Once the best bid is selected, the contractor and supplier will work together to commence the process of delivery and structural assembly. The most critical nodes of these interactions are not composed of the supply chain of materials itself, but of the supply chain of information that occurs right before the quantity of materials is instantiated for procurement. The objective of supply chain management is to obtain real time information, minimize cost, improve communication among supply chain components and increase flexibility in terms of delivery and response time (Lin and Tserng 2001).

3.2. e-Work and autonomous systems

e-Work is composed of collaborative, computer-supported activities and communications-supported operations in highly distributed organizations. It also investigates fundamental design principles for the effectiveness of these activities (Nof 1999, 2000a, Nof and Anussornmitisarn 2002, Nof and Ceroni 2004). The goal of e-Work in this project 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. This is the reason why this organization is complex and composed of autonomous systems. These systems are composed of equipment, hardware and software utilized by designers, suppliers, subcontractors and contractors toward project completion (Castro-Lacouture and Skibniewski 2002).

4. Models of e-Work in application to construction materials management

4.1. 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 (Nof 2000b). In order to improve performance, this protocol can trigger
and initiate necessary and timely interaction tasks under coordination logic.

In order to explain and illustrate an e-Work solution with a task administration protocol (TAP) it is important to clarify the concept of an agent. An agent is a ‘programme’ (autonomous entity) that represents a group of parties. Parties may include ‘resources’, e.g. humans, machines and computer systems (Huang and Nof 2000). 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.

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 enable effective collaboration among agents and tasks.

Protocols are defined as sequences with precisely defined steps to convey more complex intentions than single communication acts, where the communication act is the basic type of interaction between agents (Wong 1993). Protocols provide the rules for agents to procure information. A typical scenario of material procurement, illustrated in figure 2, may involve a contractor and several steel rebar suppliers. The contractor inquires two rebar supplier agents ($a_1$ and $a_2$) about quantity take-off of a determined rebar material. The two supplier agents respond to the request. Based on the responses, $a_0$ performs an internal decision process and sends back the decisions regarding approvals of the quantity take-off to the supplier agents.

Table 1. e-Work solution algorithm with task administration protocol (Huang and Nof 2000).

<table>
<thead>
<tr>
<th>Types</th>
<th>Protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inquiry</td>
<td>A→B: request X. A,B-agents</td>
</tr>
<tr>
<td></td>
<td>B→A: answer(X) X-questions</td>
</tr>
<tr>
<td>Passing</td>
<td>A→B: tell X X-message</td>
</tr>
<tr>
<td>Negotiating</td>
<td>(1) A→B, C: tell X</td>
</tr>
<tr>
<td></td>
<td>(2) B→A: If ValueB(X) OK, Tell ‘acceptB’ else Tell X’</td>
</tr>
<tr>
<td></td>
<td>(3) C→A: If ValueC(X) OK, Tell ‘acceptC’ else Tell X’’</td>
</tr>
<tr>
<td></td>
<td>(4) A→B, C: If acceptB and acceptC, end</td>
</tr>
<tr>
<td></td>
<td>If acceptB and X’’, X=X’’, go to (1)</td>
</tr>
<tr>
<td></td>
<td>If acceptC and X’,X=X’, go to (1)</td>
</tr>
<tr>
<td></td>
<td>If X’ and X’’, X=(X’,X’’), go to(1)</td>
</tr>
<tr>
<td>Announcing</td>
<td>A,B,C-agents X,X’,X’’-alternatives</td>
</tr>
<tr>
<td></td>
<td>(1) A→B: request X</td>
</tr>
<tr>
<td></td>
<td>(2) B→A: If ValueB(X) OK, tell ‘approveB’ else X’</td>
</tr>
<tr>
<td></td>
<td>(3) A→B: If approveB, end</td>
</tr>
<tr>
<td></td>
<td>If X=X’ go to(1)</td>
</tr>
</tbody>
</table>

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

Agents are defined as a hardware or software system that can act, interact and respond according to given goals (Nof 2000). For the particular case of construction materials management networks, the agents need to feature autonomy and flexibility. Nissen (2000) indicated that 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. Owing to a requirement to be autonomous, the agents need to include own database and protocols, sufficient capability for anticipating their long-term viability domain (adjustment to platform or version changes), measurable output (processing time, waiting time, etc.), ability to learn, and a sensorimotor apparatus (protocols, databases and human observation can serve to this purpose) (Huang and Nof 2000). The processing requirements of customer jobs are not known until processing begins. A similar case exists in construction processes, where the final decision on material quantities is not final until the material suppliers (as in the case of steel reinforcement bars) provide the estimation based on the structural design drawings. Therefore, in most cases, materials procurement is initiated without the benefit of planning. However, an e-Work model of multiagents can help predict the material requirement using knowledge of the supplier’s past estimations for standard or special cases, in addition to recent data from other projects in progress or completed. Job requirements determined on such basis can then be used for better planning. In a flexible manufacturing system the challenge consists of managing the distributed material and information flow (Esfarjani and Nof 1998). 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.

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, a recorder, a planner and a reviser. The flow diagram for interactions among these agents is shown in Figure 3.

4.3. 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 an assignment of tasks to the available resources, i.e. material suppliers, designers, subcontractors or delivery entities. There should also be a coordination agent that allows a parallel execution of tasks, thus having earlier progress or even completion dates.

The supply chain of a typical rebar workflow contains tasks that can be performed simultaneously. For instance, the bill of quantities can be revised and the fabrication and assembly tasks can initiate once valid information is available to suppliers. This can be coordinated by a task administration protocol using a parallel e-Work model. Parallel processing in supply chains has an explicit focus on collaborative problem solving between multiple processors. This problem solving, as explained by Nissen (2000), is usually focused more on numerical processing than intelligent reasoning. Figure 4 displays the structure of a parallel tasking, using master-slave architecture.

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. 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 tasks that can be performed simultaneously. The goal of the coordination-related research is to find the most effective coordination scheme that maximizes collaboration effectiveness among participants. With this in mind, it is important to develop an e-Work model deployed on the Internet for the automation of construction materials management systems. 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. 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 for infor-
mation by the contractor 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-based operation
centre. This e-Business approach aims 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 proces-
sing, negotiation, decision on purchase and procurement
option. Figure 5 displays the interaction diagram for a
typical supply chain of materials.

The research developed at the PRISM Laboratory
at Purdue University uses parallel computing to simulate
autonomous agents. This tool, called Teamwork
Integration Evaluation (TIE) focuses on measuring
the coordination performance of all participants
(Anussornitisarn and Nof 2000). Figure 6 shows
an adaptation of the original TIE/Protocol, with out-
puts relevant to the new application in the construction
material automation process.

4.4. Conflict resolution model

The inherent nature of construction processes over-
whelmed with conflicts, creates an opportunity for
improvement through the application of a conflict resolu-
tion model. 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. The process of design, estimation,
revision and procurement of construction materials
displays many conflict-prone situations, which result
from the interaction of cooperating designers, suppliers,
subcontractors or contractors. The new method of
conflict resolution, comprises rational execution of pre-
ordered conflict resolution approaches: direct negotia-
tion, third party mediation, incorporation of additional
parties, persuasion and arbitration or settlement of claims
(Lara et al. 2000).

According to Francalanci and Piuri (1999), the main
cost-differentiating factors influencing choices in conflict
resolution architectures are intensity of processing (mea-
sured 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). This study points out that
previous analyses in the area have failed to consider
management costs, which can be dissimilar across differ-
ent IT architectures. As can be seen in figure 7, the cost of
conflict resolution increases as stages escalate from direct
negotiation to arbitration.

This multiapproach method facilitates computer-
supported conflict resolution. Its performance is
improved through the inclusion of principles for prevent-
tion 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), developed by Nof and his students (Lara et al. 2000) 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 conflict prevention. Therefore the system will be continuously providing feedback to the parties in order to learn from previous experience.
5. Conclusions

The supply chain of materials in construction processes remains a critical competency for the success of the construction business. Even though rapid developments in communication infrastructure abound, the management and control of entities in the supply chain of materials are often not carried out automatically. New approaches for the automation of supply chains of materials have been developed with the emergence of the Internet and its e-Business capabilities. However, the construction industry has yet to utilize in standard professional practice 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 endeavour 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 opportunities for applicability of e-Work models. 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 converse 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. The process of design, estimation, revision and procurement of construction materials displays conflict situations that can be resolved with the implementation of multiapproach methods facilitated by computer-supported conflict resolution.

References


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