INFORMATION LOGISTICS APPROACH FOR CONSTRUCTION INTER-ORGANIZATIONAL INFORMATION SYSTEMS

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ABSTRACT: This paper discusses the importance of the development of an information logistics approach to support collaboration, coordination and information management in internet-based inter-organizational systems for dynamic distributed construction organizations. Information logistics is defined here as the maintenance, tracking, monitor and enactment of information flows within organizational processes. The aim is to optimize information flows in construction inter-organizational information systems.

KEYWORDS: Construction management, information systems, organization theory, simulation models, symbolic modeling.

1. INTRODUCTION

Technological advances in the area of communications, distributed computing, multimedia and information integration triggered new alternatives for construction management. Information technologies, like the Internet, distributed object management and other infrastructure and standards-based technologies, have been utilized to enhance the ability to integrate information from multiple sources. The construction industry is adopting some of these technologies, in order to improve collaboration, coordination, and information exchange among organizations that work in a construction project. The construction community expectation is that, in a near future, every construction partner will be on-line, information will be entered once and accessible to everyone, there will be a full lifecycle support and electronic business will streamline all steps in the construction value system. Business-to-business integration, electronic collaboration and coordination are also desired, as a succeeding step from the existing electronic commerce practice. Much of these expectations are based on the increasingly adoption of internet-based solutions in construction.

In order to meet these expectations and goals many barriers still need to be crossed. The introduction of internet-based technologies by the American construction industry was not a radical technological innovation. Their development, in the adopted configuration, was based on the automation of existing organizational processes and workflow. The fact that it did not introduce significant changes is facilitating its adoption, even by the most traditional project members, in one industry that is considered very conservative. This gradual process has advantages and disadvantages. On the one hand, it helped the acceptance of the internet-based technologies by the construction industry; on the other hand it has presented information-related problems and also limited the potential of this information technology, making it difficult to achieve the industry expectations. Most of these problems and limitations are due to the fact that,

traditionally, information systems were developed inside the scope of individual companies. Now boundaries between construction organizations have weakened. New methodologies and criteria for the design, implementation and utilization of information systems in this new scenario need to be developed. The characteristics of business processes and information flows between organizations need to be taken into account in order to improve the organizational performance.

This paper describes the approach that is being developed at the University of Illinois at Urbana-Champaign, aiming to optimize information flows in dynamic distributed construction organizations. It is based on the analysis of information flows in internet-based project-oriented inter-organizational information systems from previous and current construction projects. The approach involves modeling and mapping information flows in construction processes, identifying and analyzing metadata in construction documents; simulating different configurations of information flows in construction, and the development of an information logistics system.

2. ORGANIZATIONS AS INFORMATION ENVIRONMENTS

The view of the structure and objectives of organizations have been changed with time. According to Mintzberg (1997), the early literature focused on formal structure, which can be defined as the official documentation of relationships among members of an organization. Two schools of thought dominated the literature until the 1950s. The first school of thought, the "principles of management", was led by Henri Fayol and was concerned primarily with direct supervision and formal authority. The second school of thought includes two groups. In the US, Frederick Taylor led the "Scientific Management" movement, whose main worry was the programming of the contents of operating work. In Germany, Max Weber presented the idea of "bureaucratic" structures where activities were formalized by rules, job descriptions and training. The third school of thought was established in the 1950s and 1960s and was originally called "human relations". The proponents of this school sought to demonstrate by empirical research that reliance on mechanisms of direct supervision and standardization was misguided, and could also be dangerous to the psychological health of the worker. More recent research has shifted away from these two extreme positions. Studies have demonstrated that formal and informal structures are interrelated and often indistinguishable. Among these studies, Galbraith (1973) was one of the firsts to explain clearly the role of mutual adjustment devices such as task forces and matrix forms in the formal structures. Another group of contemporary researchers, working under the title "contingency theory", have been investigating the relationships between structure and situation. They do not agree with the notion of the best structural form; instead they sought to identify the particular alternative structural form that is most appropriate under a specific set of conditions.

From the literature review, one can conclude that the view of organization is constantly changing and it seems to be affected by changes in culture and technology. These different views made it difficult to reach an agreement about the definition of organizations. Although there is not a unique definition, there are general aspects that are more or less shared. In general organizations are characterized by (Carley & Gasser, 1999):

- *Large-scale problem solving technologies.*

- *Comprised of multiple agents (human, artificial or both).*
- *Engaged in one or more tasks.*
- *Goal driven (however goals can change, may not be articulable, and may not be shared by all organizational members).*
- *Able to affect and be affected by their environment.*
- *Having knowledge, culture, memories, history, and capabilities distinct from any single agent.*
- *Having legal standing distinct from that of individual agents.*

The information logistics approach is based on the theory that organizations are fundamentally information-processing structures. It also adopts the assumption that different organizational structures and different information flows can lead to different organizational performances. These views are grounded on the work developed by Galbraith (1973) and from the contingency theory. In this view, an organization is an information-processing and communication system (Levitt, Jin, Christiansen, Kunz & Cohen, 1998), structured to accomplish a specific set of activities, and composed of limited teams, called agents, that process information. Agents are engaged in an organizational structure. They send and receive messages along specific channels of communications, based on the organizational structure and the processes being conducted. This communication is made through tools of limited capacity, like phones, fax, extranets, e-mails or meetings. The presented approach extends these views to an inter-organizational environment, using construction projects as a framework.

3. ORGANIZATIONAL ENGINEERING

Construction organizations are looking for ways to respond to competitive pressures and increase performance levels by redesigning and continuously improving their production and operational processes. Such efforts must support the integration of these processes with heterogeneous collections of both legacy and emerging information technologies and systems. This is particular important if we consider that the complexity grows significantly in dynamic inter-organizational environments. Hence, researchers are faced with the problem of how to realize these goals in a coherent, scalable, and evolutionary manner.

Organizational Engineering is the process of configuring an organization structure to accomplish a given high-level task while attempting to satisfy stated performance objectives. An organization includes human agents that execute specific tasks, supported by information processing and communication tools. Matrix techniques, workflow modeling and business process modeling are among the techniques that have being used in the organizational engineering process for individual organizations. Some relevant initiatives in these areas are presented.

Eppinger, Whitney, Smith and Gebala (1994) use a design structure matrix to represent the complex inter-relationships among the many design tasks. The models permit us to capture the basic interactive nature of design, whereas traditional project management models utilize simple precedence network models that cannot depict interaction. By explicitly modeling such coupling, they believe that it is possible to reduce the complexity involved in large projects by restructuring entire development procedures. Stephenson and Haeckel (1997) present the concept

of organizational networks. They describe networks as self-organizing organizational structures held in place by relationships of trust. These relationships form reciprocal patterns of communication and exchange achieved largely through face-to-face interaction (e-mail, videoconferencing and letters augment the interpersonal aspect). According to their research, the identification and management of these networks can improve the efficiency and efficacy of an organization. Scacchi and Mi (1997) propose the formulation of an organizational process life cycle founded on the incremental development, iterative refinement, and ongoing evolution of organizational process descriptions. Malone et al. (1998) Process Handbook Project involves collecting examples of how different organizations perform similar processes, and organizing these examples in an on-line process handbook. The handbook is intended to help people redesign existing organizational processes, invent new organizational processes, especially ones that take advantage of information technology, and share ideas about organizational practices. Their representation exploits two sources of intellectual leverage: notions of specialization of processes based on ideas about inheritance from object-oriented programming, and concepts about managing dependencies from coordination theory. The research conducted by Kunz, Christiansen, Cohen, Jin and Levitt (1998) developed a computerized simulation and analysis tool to support the systematic design of organizations. The Virtual Design Team (VDT) incorporates information processing and communication models from computational organization theory that allow qualitative predictions of organizational performance. The input to VDT are the descriptions of design tasks, actors, organization structure and the communication tools available to each actor. The output is a prediction of total processing time required to complete all subtasks, the duration to complete the entire design project and project quality measurements.

3.1 Computational Organization Theory

Computational Organization Theory (COT) uses mathematical and computational methods to study both human and automated organizations as computational entities. COT attempts to understand and model organizations. Researchers use computational analysis to develop a better understanding of the fundamental principles of organizing multiple information processing agents and the nature of organizations as computational entities. According to Carley and Gasser (1999), the main objectives of research in this area are: to develop new concepts, theories, and knowledge about organizing and organization in the abstract, to develop tools and procedures for the validation and analysis of computational organizational models, and to reflect these computational abstractions back to actual organization practice through both tools and knowledge.

Computational organization theories are most often based in existing cognitive, knowledge-based, information-processing theories of individual behavior. However COT extends this to an organizational level and is increasingly adopting a neo-information processing perspective on organizational behavior based on:

- Bounded rationality: Organizational agents are bounded rationally, as there are limits to their capabilities and knowledge.
- Information ubiquity: Large quantities of information in many different forms are widely distributed across multiple agents in organizations, but the fact that the information may not necessarily be correct has to be considered.

- Task orientation: Organizations and the agents within and among them are continually engaged in performing tasks.
- Distribution constraints: Organizational performance is a function of the information distribution, use and access.
- Uncertainty: Uncertainty and constraints influences organizational activity.
- Organizational intelligence: Organizational intelligence resides in the distribution of knowledge, processes, procedures across agents and the linkages among agents.
- Irrevocable change: As agents and organizations learn, their intelligence is restructured.
- Necessity of communication: In order to function, agents within and between organizations need to communicate.

In addition to this neo-information-processing view of organizations, researchers in this area share a series of implicit background assumptions. These are (Carley & Gasser, 1999):

- *Modelability: Organizational phenomena are modelable.*
- *Performance differential: It is possible to distinguish differences in organizational performance.*
- *Manipulability: Organizations are entities that can be manipulated and transformed.*
- *Designability: Organizations are entities that can be designed.*
- *Practicality: Organizational transformations can be transferred to and implemented in actual practice.*
- *Pragmatism: The cost of modeling and researching organizations using computational methods are relatively lower than the cost of manipulating or researching similar aspects of actual organizations in vivo, and the benefits gained outweigh the costs.*

The information logistics approach is adopting principles and techniques from COT in order to analyze dynamic distributed inter-organizational environments and the impact of information flows in the construction organizational performance.

4. CONSTRUCTION INTER-ORGANIZATIONAL INFORMATION SYSTEMS

Information technologies, like the Internet, eliminated distance and time as factors for many types of work in many situations. Networked information systems are allowing construction companies to coordinate geographically distributed capabilities and even coordinate with other corporations that work in a common project. Each of these corporations has a specific role in the development of the project. They work together to achieve a common project goal, while keeping their individual objectives, acting as virtual organizations. These networked information systems can create new efficiencies and new relationships between organizations, redefining their organizational boundaries, but there are still some barriers to be crossed. New methodologies and criteria for the design, implementation and utilization of information systems in the inter-organizational scenario need to be developed. The characteristics of business processes and information flows between organizations need to be taken into account in order to improve the organizational performance. Three areas are merit special attention here: information integration, information quality and information logistics.

4.1 Information Integration

As Internet technology for construction projects has evolved, the need for information integration among participants performing different functions and using different software applications has become apparent. Acording to the AEC Working Group (1999), several approaches to information exchange have been attempted, including document file transfer, application programming interfaces, shared databases, paper, phone, e-mail and faxes. All these approaches present limitations. Maher and Simoff (1998) argues that a major hurdle in integrating construction information is related with its variety of data types, including structured data, weakly structured data, raw data and links data.

Let's consider a typical construction information retrieval situation in that a construction manager wants to find all available information about one construction activity, let's say, a building wall. He/she will probably find the drawings in a CAD file, the specifications in a text document, the cost estimates in a spreadsheet, the schedule in a particular application format, the contracts in a text document, and price quotes in different websites. The major task will be how to index, retrieve and integrate information from these different media. Also, these data can be stored in different organizations, with different data formats.

To improve the information integration capability, two approaches have been used. The first is based on the development of a centralized model, based on 4D CAD. The second involves the development of infra-structure to facilitate the integration of distributed information. The adoption of data standards can support this integration in both approaches. Examples of initiatives in this area are presented by Eastman (1999), and include the ISO-STEP, the Industry Foundation Classes created by the International Alliance for Interoperability (AIA), and the aecXML specification that is being developed by the AEC Working Group.

4.2 Information Quality

Information quality is a basic requisite to assure the quality of the final project. By information quality we mean the ability to efficiently and effectively use the information, not only the actual content of the construction documents. The objective here is to make the best use of the information that is being exchanged by the different construction organizations. One way to accomplish this involves the use of metadata.

Some metadata that can be used to improve the quality of construction information include: source, destination, breadth, depth, objectives, rationale, time, accuracy, structure, sufficiency, risk of change, understandability. Metadata can provide additional information that was considered important for construction information management in research developed by Pena-Mora, F., Sriram, D. and Logcher, R. (1995), de la Garza, J.M. and Alcantara, P.T. (1997) and Rezgui, Y., Cooper, G. and Brandon, P. (1998).

4.3 Information Logistics

Information logistics is defined as the maintenance, tracking, monitor and enactment of information flows within construction organizational processes. Information is often tightly linked to tasks in a sense that information enhances the ability to act, and tasks create information. According to Galbraith (1973), *"the greater the task uncertainty, the greater the*

amount of information that must be processed among decision-makers during task execution in order to achieve a given level of performance". As business processes are composed of tasks, information is a key element in the improvement of these processes. In conformance to the contingency theory, there is no best way to organize, but any way of organizing is not equally effective. Different networks of information flows and different structure of organizations will lead to different organizational performances. Information logistics aims to optimize this performance by assuring that the accurate and relevant information will be on the right place at the appropriate time and with the required quality.

5. THE INFORMATION LOGISTICS APPROACH

The information logistics approach involves a study of how to optimize information flows in large dynamic distributed virtual organizations. The study is employing data about information flows in internet-based project-oriented inter-organizational information systems in the construction industry. These large virtual organizations arise to manage and coordinate activity and decision making among partners working on large-scale construction projects. Over time, such projects typically comprise up to fifty or more participating individual construction firms. The data available to us ranges into the hundreds of megabytes. It provides a wealth of embedded knowledge about information cost, quality, and timeliness in many contexts, and their relationships to many other factors in the construction environment over time. These data are being extensively analyzed to discover patterns and dependencies in information flows. A selection of performance metrics including availability, timeliness, cost, and quality of information is being used to rank the differential impacts of sets of information flow patterns. Since the datasets have longitudinal data, the evolution of information supply and demand processes, as well as temporal factors impacting performance metrics, are being considered. The aim is to construct a model of information flows that allows us to predict and optimize multidimensional combinations of factors in the information environment of internet-enabled virtual organizations. We envision the possibility of using large-scale simulations to explore and verify predictions derived from analysis of project data, and to extend the analyses and optimization approaches to areas not explicitly covered in the project data from real life.

Data for this research are being provided by Blueline Online Inc, Bricsnet USA (EVOLV) and the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Blueline Online and Bricsnet USA (EVOLV) are two companies that have developed commercial internet-enabled project management and collaboration services developed specifically for construction. They have both agreed to provide access to data from current and past projects that used their "project extranets". Bricsnet USA (EVOLV) has also contacted clients that agreed to provide access from their own databases in support of this research. USA-CERL is providing data obtained from its DrChecks system (Design Review and Checking System). DrChecks is used by USA-CERL to provide a platform for the review and feedback of project-related documents. Data from all of these organizations is being provided on past, completed projects, as well as ongoing and new projects that occur through the course of the research. This allows us to compare predictions we are generating with new data from new projects.

5.1 Implementation Steps

The proposed approach aims to improve construction processes by the optimization of inter-organizational information systems. Four steps are being implemented. The first stage involves the modeling of inter-organizational processes and the associated network of information flows (Figure 1).

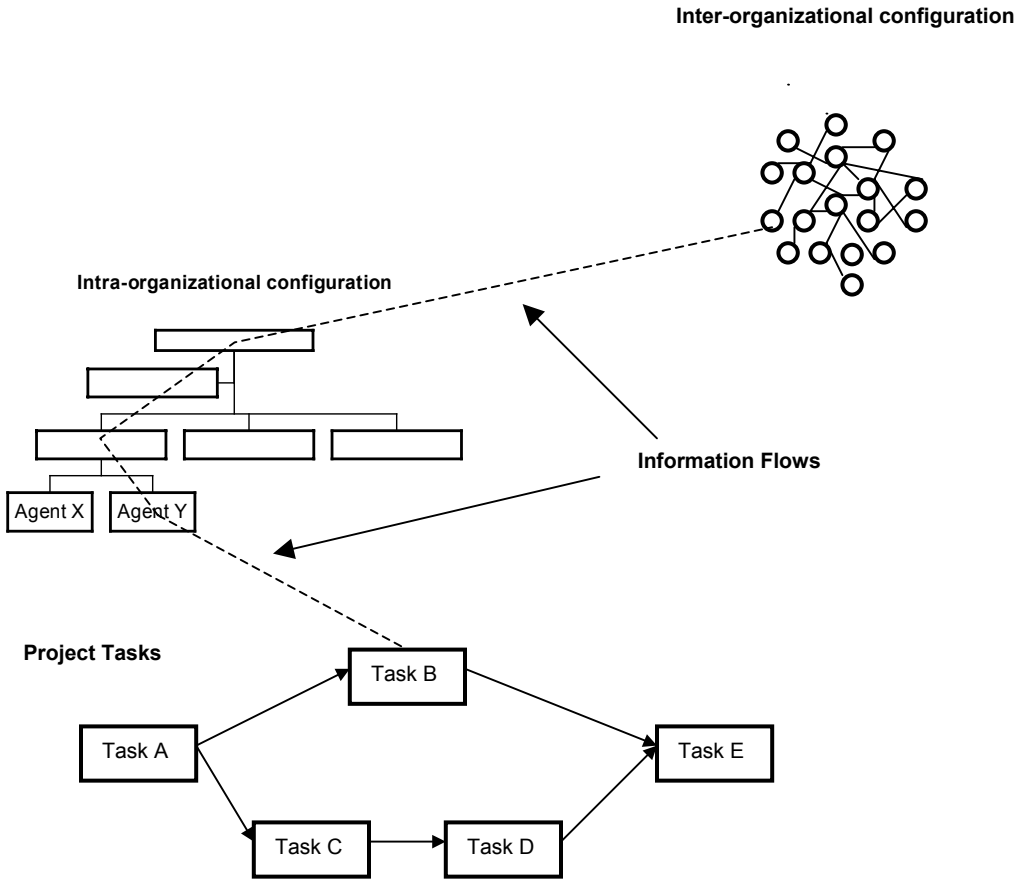

Figure 1. Information flows in construction inter-organizational processes

Concepts from business process modeling and computational organization theory are being used to guide the development of the proposed model for an inter-organizational environment. The elements that are being adopted to build the model include:

- Agents: Agents are members of the construction organizations that perform specific tasks. The tasks that each agent performs are defined in the proposed model. The model also specifies to whom the agent reports, with whom the agent communicates, who reports to the agent, the agent's specific knowledge, skills and capabilities, and so forth.

- Intra and inter-organizational configurations: The intra and inter-organizational configurations include parameters of the organization, like tasks, roles, organizational structure, as well as specific model-dependent parameters that are being defined. Taken together, the parameters with their range of potential values define a parameter space, which in turn defines a space of potential inter-organizational designs.
- Tasks: The construction organizations and their members are engaged in one or more tasks at any point in time. Further, these tasks are linked together in a sequence of related tasks that will be developed along the project life cycle. These tasks may be composed of subtasks, which may themselves be further subdivided. Tasks can be interdependent, independent or dependent, and these dependencies are considered in the development of the model.
- Information Flows: Include the technologies and systems used for processing, storing, retrieving, communicating and integrating information. The approach to modeling technology is to treat it as a communication tool and to differentiate tools in terms of the attributes such as information flows, access times, speed synchronicity and record ability.

The second step comprises the development of an inter-organizational simulation system based on the model previously defined. The development of such system aims to test different configurations of agents, inter-organizational designs, tasks, technologies and information systems. This simulation tool uses the data obtained from past projects to validate its results and refine its performance.

As the focus is on optimization of information flows, simulations are made to analyze the performance of construction design teams under different configurations of information flows and metadata. In this step, factors that can affect the identification, the storage, the flow, the processing, the retrieval and integration of construction information are investigated.

The results of these simulations provide the framework that is necessary to identify the effects of different information flows and different information contents in the performance of the organizations and also identify relevant project information.

The information obtained from the models and simulations are the basis for the implementation of the prototype of, what is defined as an *information logistics system*. This system is intended to be a support tool for collaboration, coordination and information management in construction project team organizations. It aims to maintain, keep track, monitor and enact the flow of information within dynamic distributed organizations. In general, the development of the proposed approach can be used to:

- Adapt information systems in order to maximize their performance in different organizational arrangements.
- Find dependencies, independencies and interdependencies among information and decisions.
- Identify problems related to information transactions between multiple organizations, like bottlenecks or information overflows.
- Establish metrics to evaluate the performance and identify important features in information systems.
- Provide knowledge that can be applied to the development and operation of computer-supported applications or multi-agent systems in dynamic distributed organizations.

6. CONCLUSIONS

Collaboration, coordination and information management are basic requisites for the achievement of a global optimization in construction organizational process. Technological advances in information technology are being used to for this purpose. However, there is still much to improve in order to explore their potentialities and optimize their use in construction management. The information logistics approach aims to optimize information flows in construction, considering the inherent characteristics of the data, information transactions and organizational processes. The steps described leads to the implementation of an information logistics system. This system is presented as an adaptive support tool for collaboration, coordination and information management in construction organizations.

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