STANDARD INFORMATION SYSTEM FOR CONSTRUCTION MANAGEMENT

A Thesis

by

KANAT A. SULTANBEKOV

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2000

Major Subject: Civil Engineering

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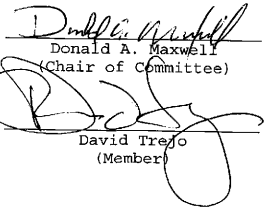
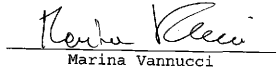
Approved as to style and content by:



Donald A. Maxwell
(Chair of Committee)



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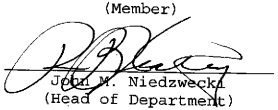

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ABSTRACT

Standard Information System

for Construction Management. (May 2000)

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Construction management, involving numerous decision-making processes, requires constant flow of timely and accurate information. The use of current computer hardware and software makes it possible to receive, store, and process data. However, data communication and integration between different organizations still remains a "gray" area in construction management. There are several means of communication used in the industry: mail, phone, fax and information technology. Yet, only information technology is able to provide full integration of computer systems.

The goal of this research is to develop a standard information system for project management and to compare its performance with a paper-based communication model and paperless non-standard communication models.

Four network configuration models were developed. The performance of these models was compared using Activity-Based Costing Simulation (ABC-SIM).

The concept of the determination of network configuration to enhance the performance of an information system is an abstract idea. This concept could be applied not only to construction project management, but also to other engineering areas and even other industries.

ACKNOWLEDGMENTS

I would like to thank Prof. Donald A. Maxwell, my Committee Chair, for his guidance, patience and help. I would also like to thank Dr. David Trejo, my Committee Member, for his professionalism and valuable comments. I would also like to express thanks to Dr. Marina Vannucci, my another Committee Member, for her understanding and assistance.

I would like to show my appreciation to Dr. James W. Craig, who let me do the survey in his class. I am grateful to Dr. Kenneth C. Williamson III for his useful suggestions and teaching how to build dynamic web sites. I also appreciate Dr. Stuart D. Anderson's constructive comments about my questionnaire and his thoughtful treatment of his classes, where I learned a lot. I am thankful for Dr. Leroy J. Isidore's help and explanation of specific features of the ABC-SIM (simulation software).

I would like to express my gratitude to Dr. Peter B. Keating, who provided me financial support by awarding a Graduate Non-Teaching Assistantship.

Dr. W. Edward Back's lectures inspired me for this research, which was originally intended to be a study on

Electronic Data Interchange. Thank you, Dr. Back for your brilliant teaching.

Special thanks to the students of the Department of Civil Engineering and the Department of Construction Science at Texas A&M University, who kindly participated in my surveys. Gig 'em, Ags!

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CHAPTER I

INTRODUCTION

Background

The competitiveness of today's construction market pushes companies involved in construction processes towards better performance, which is possible only with more efficient management.

Construction management, involving numerous decision-making processes, requires constant flow of timely and accurate information. The use of current computer hardware and software makes it possible to receive, store, and process data. However, data communication and integration between different organizations still remains a "gray" area in construction management. There are several means of communication used in the industry: mail, phone, fax and information technology. Yet, only information technology is able to provide full integration of computer systems

This thesis follows the format of the ASCE Journal of Construction Engineering and Management.

Problem Statement

Most construction companies have developed their own information systems. However, the difference between these systems causes major problems when communicating the data between organizations and projects. The Electronic Data Interchange (EDI) philosophy addresses the information problems to some extent, but the main downside of this approach is the high cost of developing, maintaining, and upgrading of the system.

The rapid growth of the Internet technology triggered the development of web-based communications, which proved to be economical and effective. Constantly increasing amounts of information traffic and the need to use effectively computer networks that serve as information highways bring an issue of network configuration.

The purpose of this research is to determine whether a standard web-based network configuration is beneficial for communication processes between construction projects and organizations, plus how these benefits can be measured. Objectives and hypotheses defined according to the purpose are described in the following sections.

Objectives

The purpose of this research can be reflected in three objectives:

1. To find a common procedure for the development of an information system.
2. To identify a standard information system. This would include computer simulation of the system performance and statistical analysis of the simulation results.
3. To evaluate the performance of the standard information system based on the simulation results.

Hypotheses

The following hypotheses will be tested:

1. Are there good reasons to think that paperless communications are more efficient than paper-based? This hypothesis will be tested based on the comparison of the performance of a paper-based and paperless simulation models.

2. Is it possible to find a common procedure for the development of a standard information system?
3. Are there good reasons to think that a standard information system allows better communications for construction management than a non-standard one? This hypothesis will be tested based on the comparison of the performance of a non-standard and standard simulation models.

Methodology

Research includes the following phases:

1. Analysis of organizational structures of construction projects based on the main categories of contractual arrangements. Organizational structures serve as foundations for the structures of information systems.
2. Development of a network configuration for each category of contractual arrangement. Since different contractual arrangements are the roots for different organizational structures, each of them has to have a distinct network configuration.

3. Analysis of the developed configurations and identification of a common procedure. The procedure will be presented as a list of the major phases.

4. Development of a standard information system's alternatives. This will be done after the paper-based and paperless non-standard options have been considered.

5. Representation of the project delivery process as a logical model. This is needed to prepare ground for the next step.

6. Distinguishing of communication activities among the project delivery activities. This differentiation serves as a bridge between the project delivery and communication activities.

7. Representation of communication processes as a logical model, which will function as a prototype for the paper-based and paperless models.

8. Development of a paper-based communication model that will include the options of sending documents via postal mail, fax, and email.

9. Development of a non-standard paperless communication model. This model will be based on

the network configurations, which are determined for the main types of contractual arrangements.

10. Development of standard paperless communication models based on the standard information system alternatives.

11. Gathering data for the paper-based and paperless simulation models. This will be done with a questionnaire containing questions about paper-based and paperless communications.

12. Computer simulation of the four models. This will be done after the probability distributions and the duration of activities is entered in the models.

13. Statistical analysis of the simulation results. The analysis will allow testing the hypotheses, drawing conclusions, and making recommendations.

14. Recommendation of the most efficient alternative or alternatives.

Evaluation

Three phases of the evaluation can be seen at this stage. The first is the author's evaluation. If the author succeeds in providing the general concept, which could be presented as punch lists for development of standardized information system, then the work can be considered completed. The next phase of the evaluation would be based on the simulation results. Two processes are to be presented as logical models of "modular" and "traditional" information systems. Presumably, the approach, offered in this paper, should be more effective. However, it is still possible that the simulation results would show the opposite. In that case, the concept can be considered mistaken. Finally, the last, and the most important evaluation would be practical implementation of the general concept. This goes beyond the scope of this research, since it would require practical implementation of the concept in at least several construction companies for a considerable amount of time. Although the general concept is being developed for the construction management, it can also be applicable to any other type of engineering activities as well as other industries.

CHAPTER II

LITERATURE REVIEW

Any information system includes three components: technology, people, and organizations (Laudon and Laudon 1998). Technology consists of a storage technology (physical media for storing data) and a communication technology (linking computer systems through networks). People input and manipulate data with the help of technology. Organizations form information systems depending on their organization structures. Each organization is unique and has its own information system that differs from others. The same thing could be said about construction projects. Lack of common structure of information systems causes longer time for information exchange between projects and organizations, higher cost of doing business, and less efficient management.

Literature related to the research topic has been found in four fields of study:

1. Matrix management,
2. Electronic data interchange,
3. Electronic commerce, and

4. Construction practice.

The concept of a project includes identification of needs that will be converted into objectives. These objectives relate to goals, which can be reached with a structured system of activities. This structured system is known as a Work Breakdown Structure and basically shows what needs to be done. Another part of the system is the Organization Breakdown Structure, which shows who is responsible for what task, or in other words, the organizational pyramid. Organizational structure must correspond to the work structure. The matrix management idea is based on the correlation of work and organization structures.

Matrix organization is needed because of the following reasons (Avots 1977):

1. Pressure for a dual focus,

2. Pressure for sharing resources, and

3. Pressure for high information-processing capacity.

Pressure for a dual focus can be described as the necessity to work on multiple projects, with multiple clients and in multiple places at the same time. Most construction companies are doing business this way all around the world. In order to succeed in such an

environment, companies have to use their human and material resources in the most effective manner. This is where the pressure for sharing resources comes into place. This cannot be done without careful analysis of the current situation, which is represented by large amounts of data. Thus, high information-processing capacity and a well-tuned information system can become one of the most important aspects of construction activities nowadays.

There are several issues involved in information processing within a matrix organization (Avots 1977):

1. Development of effective communication channels,
2. Support decision making process by reducing information "bottlenecks",
3. Handling problems of uncertainty, complexity and interdependence of human resources, and
4. Involving more people into management functions.

Electronic Data Interchange (EDI) has been one of the well-known methods of data communication in recent times. "EDI is an information technology where an electronic file or data created by one computer is transmitted to and read by another computer" (Stukhart 1995). Electronic data replaces routine paper documents like invoices, shipping notices, purchase orders, etc. About 70 percent of one's

computer output can become another's computer input. EDI technology eliminates duplicate data entry and provides the following benefits: increased business opportunities, reduced inventory, more accurate decision-making information, lower data entry costs, greater customer satisfaction, reduced order time, and better cash management (Schmied 1999).

However, despite all of the benefits, EDI also has several downsides, for instance: high installation and maintenance costs of value-added networks (VAN), limited number of partners, difficulties with upgrading, and security vulnerability.

Development of the World Wide Web (WWW) has made it possible to communicate and do business via the Internet, which leads to the concept of electronic commerce (e-commerce). This is the use of information technology to automate buying and selling of goods and services (Laudon and Laudon 1998). E-commerce has the following benefits:

1. Paperless transactions provide major savings on mailing, printing, posting, and handling documents;
2. Electronic transactions save time;

3. The Internet can reach new customers and partners, regardless of distance;
4. Reduced staff costs - paper-based business requires large clerical staff;
5. Improved control - online monitoring of an activity's progress.

One of the most important problems of electronic commerce is online security. Public networks are not safe because they are open to anyone. A solution to this problem can be found in separation of the Internet with public domain from the Extranet used by the partners, and from the Intranet, which is available only to a company's permanent employees.

The Construction Industry Institute (CII) at the University of Texas at Austin has done a significant amount of research for construction practice. One of the key research areas is organizational structure of construction companies. This affects how projects are developed and executed. Roles and responsibilities must be clearly identified; otherwise the overall performance would be downscaled by poor scope definition, unclear goals, and lack of communication (Sullivan et al. 1997). Some methods to assist owners and contractors to remove these

uncertainties and possibly prevent problems from occurring have been developed.

The construction industry implements data integration strategies. Some of these strategies are implemented by the integration database concept and data transfer technologies, which help companies to transfer data externally, reduce materials management costs, and enhance the overall flow of project management information (Bell and Gibson 1990).

Project management information is transmitted through computer networks. One of the main objectives for cost-effective computerization will be the achievement of maximum flexibility and compatibility between computer hardware and software (Choi and Ibbs 1989).

There are three major problems that managers have to deal with to achieve inter-company integration:

1. The Industry's fragmentation,
2. The perceived legal and professional risks, and
3. Lack of standards for data representation and communication (Choi and Ibbs 1989).

(This research will provide preliminary framework for standardized data communication)

There are three fields of study related to the research topic: matrix management, computer simulation, and Internet technology. A brief explanation of each field and how it is going to be applied in the research is presented below.

Effective communication channels must provide delivery of the right information to the right people at the right time. Information bottlenecks appear when only top management has the full picture of the process, while middle and lower management gets restricted information (Avots 1977). This does not help employees in understanding how their work influences the overall process. Construction activities involve many uncertainties and complexities, such as human factors, dealings with multiple vendors and subcontractors, environmental, financial, political aspects, weather, etc. Organizational structure should be flexible enough to predict and solve problems in a proactive manner. One of the best instruments for developing efficient organizational and informational structures is computer simulation.

Contractual Arrangements

Contractual arrangements are the basis for the project organizational structure that identifies the relationships between the involved parties. There are four fundamental contractual arrangements:

1. Design/Bid/Build,
2. Design/Build,
3. Construction Management, and
4. Owner/Agent.

Design/Bid/Build is the most commonly used contractual arrangement. It involves three parties: designer, contractor, and the owner. The owner awards a contract to the designer. After design is complete a contractor is chosen based on competitive bids. This type of arrangements requires considerable amount of time, since each step must be completed before proceeding to the next step (Oberlender 1993).

Design/Build approach is usually implemented to shorten the project duration. There are two main players: the owner and the design/build firm. The later is awarded a contract to do all the design and construction work. One

of the key features of this approach is the owner's extensive involvement into the project development.

Construction Management method is based on agreement between the owner, the contractor, designer, and construction management firm. The construction management firm has to coordinate all the project activities to meet the owner's expectations.

Owner/Agent arrangement sometimes involves the owner's personnel to do a part of design activities. The rest of design can be contracted to an architect/engineering firm. Construction contracts can be awarded to one or several contractors.

Contractual arrangements impact the organizational structure, which serves as a foundation for the informational structure. The main parts of information structures are computer networks.

Networks and Protocols

It is essential to explain the basic terminology that is going to be used in the following chapters in order to ease the understanding of the proposed concept. One of these terms is a node. Node is any device connected to a

network. Nodes can be computers, workstations, shared peripherals, and file servers. Another one is a computer network. Electronic information needs a roadway on which to travel, which is called a network. This is a group of computers that are connected with each other (Doherty 1997). There are three types of networks:

1. Local area network (LAN) is a group of computers in local area connected by less than 1000 feet of cable.
2. Metropolitan area network (MAN) is used for a larger number of computers and larger geographical area, such as a city.
3. Wide-area network (WAN) is used to connect computers across the country or internationally.

Another term is a network topology. This is the physical arrangement of a network (Doherty 1997). There are five main topologies or configurations:

1. Bus,
2. Star,
3. Ring,
4. Peer-to-peer, and
5. Client-server.

Bus topology can be described as a decentralized linear structure consisting of a single connecting line, called the 'bus'. In a bus network a workstation (computer or any other device connected to the network) sends a message to all workstations. Each of these nodes has its own address and its reception circuitry constantly monitors the network in order to determine if any message is being sent to the node (Doherty 1997). The advantage of this configuration is that the failure of a single node does not disrupt the work of the whole network.

Ring topology is a decentralized distribution in which nodes are arranged in a circle. Like in the bus network, workstations in the ring network send data to all other workstations. However, each node has a repeater that amplifies and sends the signal along to the next node. Thus information is passed from node to node. The main disadvantage of this kind of configuration is the network's dependability: when one node stops functioning the entire network is down.

Star network has a centralized topology where a physical layout resembles a star. All the nodes are connected directly to a central network processor. The

processor is the main part of the network. When it is not working the whole network is disrupted.

Peer-to-peer network allows decentralizing information (unlike client-server networks) and getting resources from all nodes. Each computer works as a client and server at the same time communicating directly with each other. Each computer needs to have a peer-to-peer network software installed (Doherty 1997). This type of network has the following advantages:

1. Computers can share drives, so software applications need to be installed only on one computer;
2. There is no need for a network administrator
3. Peer-to-peer network is easy and inexpensive to set up and maintain;
4. For greater security each computer can back up data on other computers' drives.

Client-server networks present a different kind of architecture, where files are sorted on a centralized high-speed computer. This computer is called the server, and other computers using the files are clients (Doherty 1997). Two clients that need to communicate with each other must

go through the server. This configuration has several advantages:

1. It can support a large number of clients;
2. All network services are routed through the server that allows all the tasks to be traced;
3. Inefficient network segments can be reworked;
4. Software upgrades are required only on the server.

There are two popular kinds of network cabling: twisted-pair (also known as 10BaseT) and thin coax (also known as 10Base2). The twisted-pair cable looks like a telephone line consisting of eight wires instead of four. Thin coax looks like the wire used to connect a VCR to a TV set (Doherty 1997).

Information can be delivered in two ways: by 'pushing' and 'pulling'. An example of 'pushing' information is when product manufacturers send technical information to consumers. An example of pulling information is when people connect to a server to get or to 'pull' information. Information Pull decreases the need for manual coordination and reduces a project's time frame (Doherty 1997).

Computer networks consist of cables. The most frequently used cables are copper pair and coaxial, which provide the modem speed of 56 or 64 kbit/s. There is a

constant need of high-speed data traffic in order to communicate larger amounts of information like, for instance, CAD drawings. However, telecommunication networks that are used for the Internet access, are slow and expensive to deploy. Copper pair cables, used for local access, are tremendously costly to replace or upgrade, but were not designed for heavy data traffic. Coaxial cable, used for cable TV networking, deliver large amounts of data more efficiently than copper pair cable, but was developed for one-way information flow. This causes major difficulties in engineering a return path (Ovum 1998).

Wireless Technology

Wireless technology is a good alternative to the wire networks. The advantages offered by the use of wireless method are:

1. Fast delivery of service without the delay of building cable-based solutions
2. Lower cost of wireless service compared to cable solutions

3. No need to rely on the telecommunication infrastructure
4. The ability to serve 'thin' routes cost effectively (Rowe and Agg 1998)

The use of wireless technology brings up an issue of spectrum availability. It is important that all available spectrum parts are utilized with maximum efficiency. Point-to-multipoint radio access systems with intensive frequency re-use and 'cellular type' architecture use spectrum more efficiently than point-to-point applications (Woodfield 1998).

Extensible Markup Language

Extensible Markup Language (XML) is designed for documents containing structured information. This is a mechanism to identify structures in a document. XML specification shows a standard way to add markup to documents. The word 'document' refers to numerous data formats, 'like vector graphics, e-commerce transactions, mathematical equations, and other kinds of structured information.

XML is a meta-language for describing markup languages or in other words, a facility to define structural relationships between the languages. XML was created to help in using richly formatted documents over the WWW. Other alternatives, Hypertext Markup Language (HTML) and Standard Generalized Markup Language (SGML), are not practical for this purpose. SGML has been the standard, vendor-independent approach to deal with structured documentation, but it is not suited for transferring documents over the web. In HTML the tag semantics and the tag set are fixed and do not keep pace with changing technology (Walsh 1998). XML overcomes the problem of database compatibility: regardless of the type and structure of a database XML represents data on the WWW in a standard mode, which (after being translated) is compatible with any database type.

The XML specification identifies the following goals for XML:

1. Straightforward use of XML over the Internet;
2. Support of a wide variety of applications, like authoring, browsing, content analysis, etc.;
3. Easiness of writing programs that process XML documents;

4. Absolute minimum of optional features, since they raise compatibility problems;
5. User-friendliness and clearness of XML documents (Walsh 1998).

Virtual Private Networks

Virtual Private Networks (VPN) use the Internet to securely link two or more private networks (Intranets). VPN consist of 'tunnels' created by encapsulating and encrypting data. The 'tunnel' is secured with a firewall, which is an electronic boundary that limits access to networks that are linked together.

Setting up a proxy server that acts as a bridge between an Intranet and the Internet can create VPN. A proxy can be set up to integrate common security on the VPN. This does not require users to remember different passwords to access VPN. Setting up universal passwords on a per-project basis is the key issue in VPN efficiency (Doherty 1997).

There are three hybrid network alternatives:

1. Private online networks: instead of tunneling through the Internet, the information stays within

an Intranet. This is limited to remote users, since most Intranets have local telephone-line access.

2. Switched virtual circuit (SVC) creates multiple virtual circuits that run several high-speed applications at the same time. SVC service uses frame-relay or asynchronous transfer mode technology that can build a swift and secure pipeline for Intranet traffic.
3. Resource Reservation Protocol (RSVP) enables "bandwidth on demand" by allowing a user to request a specific amount of bandwidth for a data stream and to receive a reply indicating whether the request has been granted (Doherty 1997).

CHAPTER III

SOLUTION ALTERNATIVES

The paradigm of construction is known as "starting each project from scratch". The author believes that predefined network fragments could serve as "modular" information units. Prefabrication, modularization, and standardization in construction can lead to reduced project duration and considerable savings. "Modularization" of information would not only save time and money, but also provide easier control and smoother communications across projects and organizations. In general this could result in a major movement towards reengineering of the whole construction process with wider acceptance of the Total Quality Management (TQM) philosophy, just-in-time (JIT) delivery approach, and more dynamic development of the industry.

Organizational structures of construction projects will be analyzed. Alternatives for the information structure will be developed and simulated based on the organizational structures. The results of the simulations will be analyzed using statistical tools. Statistical

analysis would show the relevance and credibility of the concept proposed in this paper. Simulation program (ABC-SIM) developed at Texas A&M University by Dr. Donald A. Maxwell and Dr. W. Edward Back will be used for the research.

The results of the research will be published on the World Wide Web in order to make them available to the people concerned. If the proposed concept is proved to be valid, a web site will be developed. The site would work as an active on-line expert system that would provide alternative network configurations based on project contractual arrangements.

Access Levels for Contractual Arrangements

There are three main levels of access or levels of security to a web-based information system (IS):

1. Internet;
2. Extranet;
3. Intranet.

The Internet side of a web-based IS provides some general information about the organization or project the system was developed for. Usually this level is built for marketing purposes and has no restrictions for the users.

The Extranet is developed for the organization's clients and partners. This is a secured area for business interaction between partnering firms. The access is restricted for other companies and individuals with passwords and in some cases, firewalls.

The Intranet is an internal network. Only an organization's employees have access to this level. It provides free and secure information exchange between people and departments of one organization.

The primary focus of this research is the extranet, which gathers separate projects and organizations into one information body.

Table 1 shows access/security levels for a Design/Bid/Build project. The levels are given numerical values to allow easier mathematical interpretation. Internet level is given the value of 0. This reflects the idea that users on this level do not have access to any private information. The Intranet is worth 1. This shows that 100% of a company's information is available at this level. The Extranet access is in the middle between the two other levels, therefore is assigned 0.5.

TABLE 1. Access Levels for a Design/Bid/Build Project (General Contractor)

Involved Party	Access*	Notes
Architect/ Engineer	0.5	A/E's job is done before construction begins
Owner	0.5	Awards the contract, yet it is another firm
Consultant	0.5	Another firm
Contractor	1.0	Same firm, full access
Finance	0.5	The owner provides investments
Planning/Cost	0.5	Planning and cost estimation is done by A/E
Procurement	1.0	This is general contractor's (GC) responsibility
Project Mgr.	1.0	GC provides management services
Subs**	0.5	Other firm working under the contract
Other***	0.0	There is no need for continuous and close interaction
Sum	6.0	

* There are three levels of access:

1. Internet - numerical value of 0.0

2. Extranet - value of 0.5

3. Intranet - value of 1.0

** 'Subs' stands for subcontractors

*** Other: governmental and environmental organizations, fire department, etc.

The information shown in Table 1 is built from the general contractor's (GC) perspective because this firm is responsible for all the construction activities. Intranet is shared only with GC employees, which include the procurement people, and the project manager. The GC firm provides the services equivalent to the services of a project manager. Internet side is available to governmental, environmental, and other organizations, since they do not take part in the project delivery. All other involved parties, like the owner, architect/engineer, and subcontractors, have extranet access.

Table 2 shows access levels for Design/Build projects form a Design/Build firm's point of view. Planning, engineering, procurement, construction, and management work is done in-house and is supported with the Intranet access. The governmental, environmental and other agencies are given Internet access. Partnering organizations communicate through the extranet.

TABLE 2. Access Levels for a Design/Build Project (Design/Build Firm)

Involved Party	Access	Notes
Architect/ Engineer	1.0	Design is done by the Design/Build firm
Owner	0.5	Awards the contract, yet it is another firm
Consultant	0.5	Another firm
Contractor	1.0	Construction is done by the same firm, full access
Finance	0.5	The owner provides investments
Planning/Cost	1.0	Same firm
Procurement	1.0	Same firm
Project Mgr.	1.0	Design/Build firm provides management services
Subs	0.5	Other firm working under the contract
Other	0.0	There is no need for continuous and close interaction
Sum	7.0	

Table 3 reflects access levels for Construction Management arrangements. The project manager and procurement specialists work for the same construction management firm and have access to the Intranet. Other organizations, except for the controlling agencies, share the Extranet.

TABLE 3. Access Levels for a Construction Management Project (Construction Management Firm)

Involved Party	Access	Notes
Architect/ Engineer	0.5	Other firms working under the contract
Owner	0.5	Awards the contract, yet it is another firm
Consultant	0.5	Another firm
Contractor	0.5	Other firms working under the contract
Finance	0.5	The owner provides investments
Planning/Cost	0.5	Done by an Architect/Engineer firm
Procurement	1.0	Same firm
Project Mgr.	1.0	Construction Management firm provides management services
Subs	0.5	Other firm working under contract
Other	0.0	There is no need for continuous and close interaction
Sum	7.0	

The information access for Owner/Agent projects is presented in Table 4. Financing, planning, and managing activities are performed by the owner with the Intranet communications. Other firms have the extranet.

TABLE 4. Access Levels for an Owner/Agent Project (Owner's Coordinator)

Involved Party	Access	Notes
Architect/ Engineer	0.5	Other firms working under the contract
Owner	1.0	Same firm
Consultant	0.5	Another firm
Contractor	0.5	Other firms working under the contract
Finance	1.0	The owner provides investments
Planning/Cost	1.0	Initial part is done by the Owner
Procurement	0.5	Procurement is done by contractors
Project Mgr.	1.0	Owner's Agent
Subs	0.5	Other firm working under contract
Other	0.0	There is no need for continuous and close interaction
Sum	6.5	

Figures 1 through 4 show the graphical version of access levels.

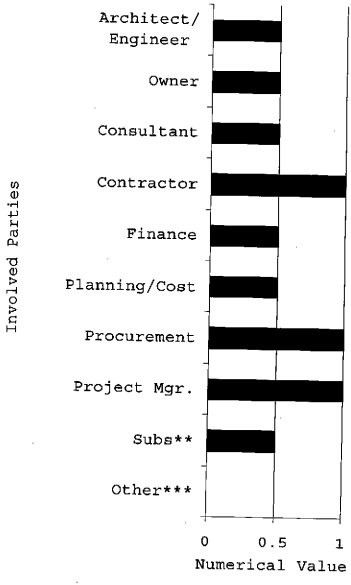


FIG. 1. Access Levels for Design/Bid/Build

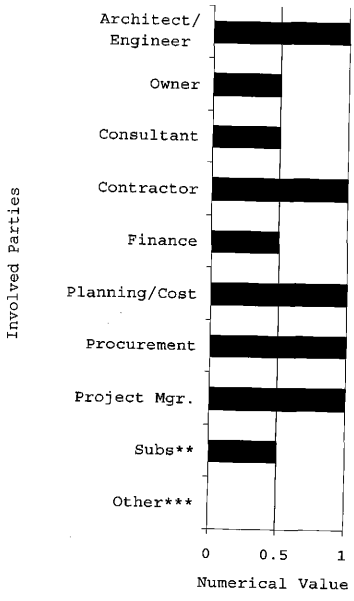


FIG. 2. Access Levels for Design/Build

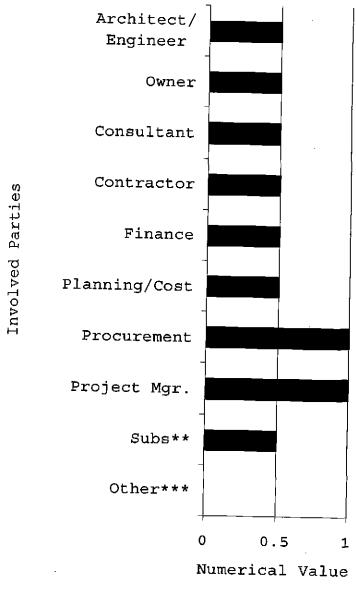


FIG. 3. Access Levels for Construction Management

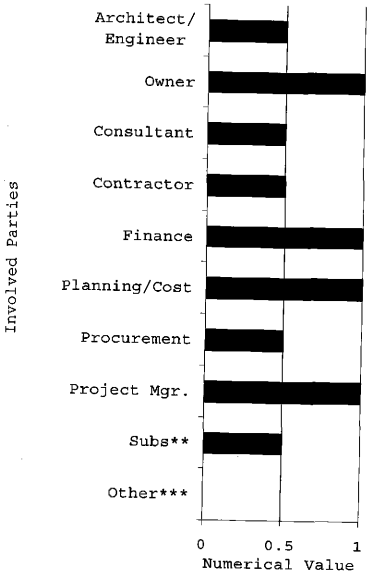


FIG. 4. Access Levels for Owner/Agent

The bars representing involved parties cover the whole extranet area in all the contractual arrangements. The only exception is the "other" category that has access only to the Internet. This figure demonstrates that the extranet is a resource, which is useful to all firms delivering construction projects.

Network Configuration for Contractual Arrangements

Design/Bid/Build arrangement: a schematic draft of the proposed configuration is presented in Fig. 5. The major flow of information can be identified as follows:

1. The owner contracts with an architect/engineer (A/E) firm, which develops the drawings, specifications, etc. This is reflected in the line of communications between the owner and the A/E firm.
2. The owner chooses a contractor based on the competitive bids. There is a communication channel (dotted line) between A/E firm and contractor since they are not bound to each other with a contract.

There is also a permanent communication line between the owner and the contractor.

3. The contractor procures materials and equipment. The line between the contractor and vendors shows the flow of information.
4. The contractor finds subcontractors and works closely with them during the construction phase. The link between the contractor and the subcontractors shows this relationship.

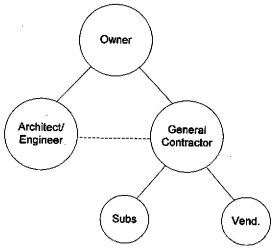


FIG. 5. Ring Topology for Design/Bid/Build Projects

Ring topology seems to best reflect the relationships between the parties involved in the Design/Bid/Build projects. There is a communication ring formed by the three main organizations: the owner, A/E firm, and the general contractor. These organizations operate as separate workstations that send information to each other.

Network configuration for Design/Build relationships is presented in Figure 6. The major information traffic can be distinguished as follows:

1. The owner awards a contract to a design/build firm that is responsible for performing all the project activities. There is a continuous flow of information between the owner and the design/build firm because of the owner's extensive involvement in the project.
2. The design/build firm also interacts with several vendors that supply materials and equipment, and subcontractors that perform all the fieldwork. The vendors and the subcontractors are shown schematically as two nodes, however, in a more detailed diagram the number of nodes can be larger.

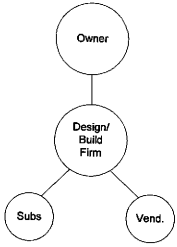


FIG. 6. Star Topology for Design/Build Projects

The star network configuration is proposed for this type of contractual arrangements, since the layout of the relationships resembles a star. The design/build firm plays the role of the central network processor. The similarity with the star configurations can become more visible if each vendor and subcontractor is shown as a separate node.

The scheme of a network structure for a construction management project is presented in Figure 7. Communication links are set up as follows:

1. The owner assigns a contract to a construction management (CM) firm that has to coordinate the project for the owner.

2. The CM firm interacts with other parties involved in the contract: the architect/engineer, contractors, and vendors.

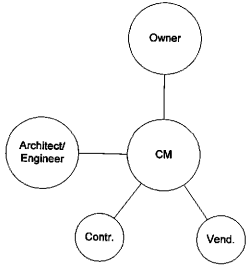


FIG. 7. Star Topology for Construction Management Projects

The star configuration is chosen for construction management arrangements. The construction management firm assumes the role of the central processing unit.

Owner/Agent: the network topology is presented in Figure 8. In this type of projects information is shared as described below:

1. The owner performs part of the design work and contracts the rest of the design to an architect/engineer.
2. The owner assigns contracts to one or more construction firms. However, the owner forces can also do part of the work.
3. Contractor interacts with vendors and subcontractors.

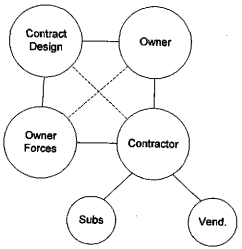


FIG. 8. Ring Topology for Owner/Agent Projects

Ring configuration can be used for this type of projects. There are four main parties: the owner, owner forces, a design firm, and a contractor.

Common Procedure for Network Development

As it was mentioned earlier, the focal point of this research is the extranet. Because the Internet is open to everyone this type of network is not secure enough to send project information. The Intranet is a company's private network, which is designed for each company specifically. Only the Extranet can have a common procedure for development.

Relationships between the sum of the numerical values of access levels in Tables 1 through 4 and the proposed network configurations for different contractual arrangements are presented in Table 5.

TABLE 5. Relationships between access levels and network configurations

Contractual Arrangements	Sum of the numerical values of access levels	Network configurations
Construction Mgmt	5.5	Star
Design/Bid/Build	6	Ring
Owner/Agent	6.5	Ring
Design/Build	7	Star

Figures 1 through 4 show a bar-chart representation of access levels for different contractual arrangements. Bars in the range of 0.5 and 1.0 identify the Intranet access. Bars in the range of 0.0 and 0.5 reflect the extranet access. The number of the Intranet bars, unlike the extranet bars, varies for different contractual arrangements. In fact the number of the Intranet bars changes the sum of the numerical values of access levels. Therefore it is possible to conclude that network configurations depend on the number of the Intranet links.

A common procedure for the development of an information network could be described as follows:

1 Identification of the parties involved in the project delivery: this can be done as a list of companies/organizations working on activities related to the project.

2 Assignment of access levels to each of these parties: this is suggested to be done in a table format with use of numerical values, so that this data can be analyzed statistically.

3 Analysis of the information traffic between the involved organizations is based on the contractual arrangements.

4 Selection of a network topology for the project information system is done after the analysis of the data traffic between organizations.

5 Physical development of the network. This process would include the following:

- Connecting intranets with wires for the local network option;
- Building a virtual private network for the WWW option;
- Developing wireless networks for the wireless option.

Alternative Solutions for the Common Procedure

Figure 9 shows an alternative architecture for the Extranet. The key part of this configuration is the Information Center (IC), which receives, stores, analyses, and sends information to the connected organizations. This is a client/server architecture. The IC plays the role of a server, and the organizations are clients. Clients have to communicate through the server. For more information about client/server architecture see page 20.

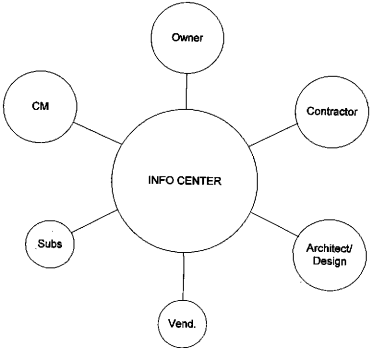
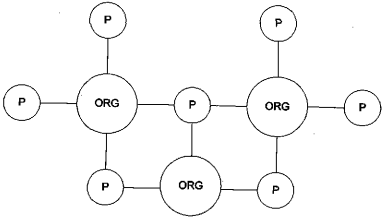


FIG. 9. Client/Server Configuration

The key feature of this configuration is the standardized structure. Regardless of the type of contractual arrangements the network configuration remains the same. Clients are not connected to each other directly, so they do not need to have multiple lines with their partners. Instead, each of them has only one connection to the IC. The IC works as a central processing unit, not only distributing data and switching information traffic, but also organizing and controlling the overall performance. It is suggested that such a center be developed for multiple projects and organizations, so that the data can be exchanged not only between projects, but also between organizations. This would allow usage of a larger amount of information resources. A system with the client/server architecture may or may not convert data into XML format because of the information security concerns.

All the network solutions described so far were designed for a single-project environment where several firms work together on a project under certain contractual arrangements. However, most construction companies have to deal with more than one project at a time. A Molecular model shown in Figure 10 represents a cluster of several projects with basic network topologies. It was called

'molecular' because of the visual resemblance with the molecular structure. As the amount of projects and involved parties increases (Figure 11), the net of the communication links between projects and organizations becomes more and more complicated. This increases the chance of errors in the information exchange.



"P" - Project;

"ORG" - Organization.

FIG. 10. Schematic Molecular Model

The concept of the Information Center for multiple organizations can also be developed for multiple projects. The planet model, presented in Figure 12 is founded on the combination IC for projects and IC for organizations. This

model is termed 'planet' because of the visual similarity with planet structure. The Information Center (the 'planet') has two orbits: one for organizations (satellites) and another one for projects (satellites). This model allows three types of data transactions: organization-organization, project-organization, and project-project.

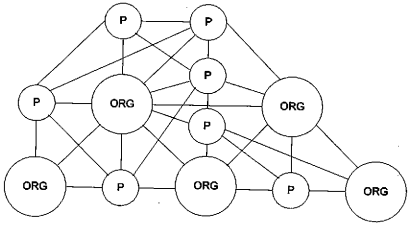


FIG. 11. Schematic Molecular Model with More Nodes

Another alternative is the Orbit model (Figure 13), where there is no Information Center and all the data is transferred being encoded into Extensible Markup Language (XML). Although there is no 'planet', there are still two 'orbits'. This is why this model is called 'Orbit'. One

of the benefits of this alternative is the lack of the need to rely on the IC, which might stop functioning.

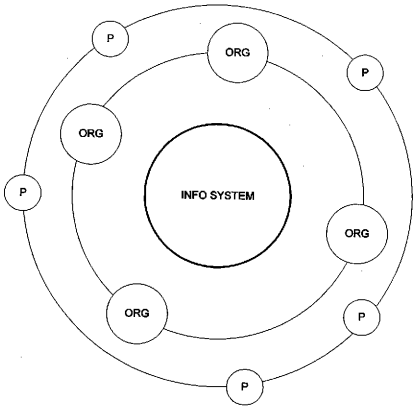


FIG. 12. Schematic Planet Model

Advantages and disadvantages of the three alternative solutions (molecular, planet, and orbit) are listed in Table 6.

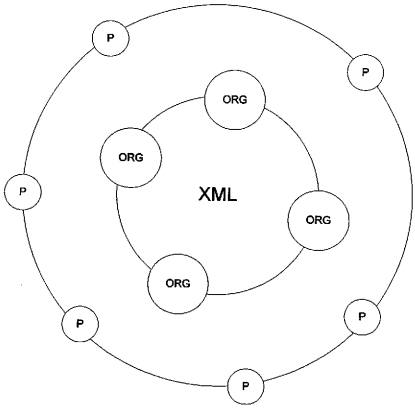


FIG. 13. Schematic Orbit Model

TABLE 6. Pros and cons of alternative solutions

Solution	Advantage	Disadvantage
Molecular	Information security	Complexity
Planet	Standard configuration	Dependence on the IC
Orbit	Independence from the IC	Complexity

Project Phases

The project phases could be represented as follows:

1. After the owner's requests for an engineering study are submitted, conceptual configurations and alternatives for technical feasibility are identified. Costs are estimated and the schedule is developed for each alternative.
2. The Owner reviews the results of the engineering study. The following factors are considered: rate of return, payback period, capital recovery or benefit/cost ratios, etc.
3. If the Owner authorizes the project, detailed drawings, written specifications, final estimations, and contract documents are prepared.
4. Vendors are chosen. Bulk materials procurement is initiated. Engineering equipment is purchased as dictated by schedule.
5. Construction operations are sustained in accordance with project schedules and budgets. Performance of the subcontractors is controlled.

6. Project close out, system testing, disposal of surplus materials, care and custody transfer to the Owner is completed.

Principles of Process Modeling

There are three levels of construction operation models:

1. Descriptive models are used to represent a process as a logical model to simulate the performance;
2. Analysis models require solution alternatives that operate on descriptive data;
3. Decision models concentrate on decision variables (Halpin and Riggs 1992).

The basic elements used for building models include:

1. Normal element, which is a work task without any constraints on its resource entities. Normal elements can have cost and time rates. There also can be 'dummy' activities with zero cost and zero time.
2. Queue indicates the idle state of a resource entity that is waiting to be used;

3. Combi in the ABC-SIM simulation logic is similar to the normal element with the only difference of preceding constrains;
4. Function is a multipurpose node that consolidates entities and counts the number of times an entity passes through a particular point in the model circuit (Halpin and Riggs 1992).

Project Cycle Models

The model of the project development with paper-based communication activities is presented in Figure 14. The model includes the above described project phases, which are preceded and succeeded by information transfers. In reality, information transfers are a part of all project activities, while in the model they are presented as separate units. The purpose of this separation is to be able to concentrate on the communication side of project delivery and to build models of communication activities.

The project cycle model is a general schema that abstractly represents all types of contractual arrangements and does not include the bidding phase.

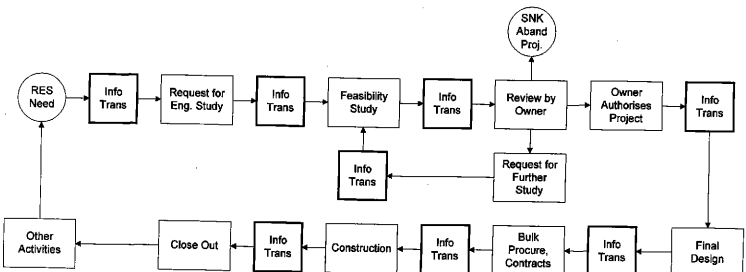


FIG. 14. Project Phases with Paper-Based Communications

The model is called 'Paper' since it represents paper-based communications. The first node in the model is a resource node that initiates the project by sending out a single entity that goes though the first two phases without being diverted. There are three possible outcomes when the owner has reviewed the project:

1. The owner abandons the project. In this case the entity goes to the 'sink' node and the model stops running.
2. The owner requests for more information and more detail, and the entity returns back to the feasibility study phase for further study.
3. The owner authorizes the project and the entity proceeds to the final design stage.

The rest of the project cycle is straightforward. After the project close out the owner may pursue other activities until facing the need for another project. Then the entity returns to its resource and initiates another project.

The Molecular model of the project phases is similar to the paper model (Figure 15). The only difference is the development of an information system, or if it already

exists, upgrade of the IS. This occurs after the owner's authorization of the project.

The distinguishing feature of the Planet model (Figure 16) is the connection to the Information Center (IC), which takes place before the owner sends the request for an engineering study. This would allow transferring the data from the very beginning of the project. There is no need for the parties involved in the project delivery to develop or upgrade the information system.

The Orbit model is analogous to the Paper model (Figure 14) with the only variation of encoding and sending the data through the virtual private networks, instead of sending it by mail. However, this variation is reflected in the information flow models, which will be described below, but not in the project cycle model.

Information Flow Models

All information transfer nodes in the project cycle model have the same structure, which is presented in Figure 17. An information flow process consists of the three main parts:

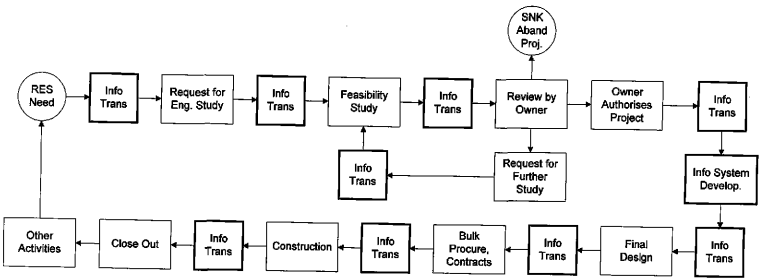


FIG. 15. Project Phases with Molecular Model of Communications

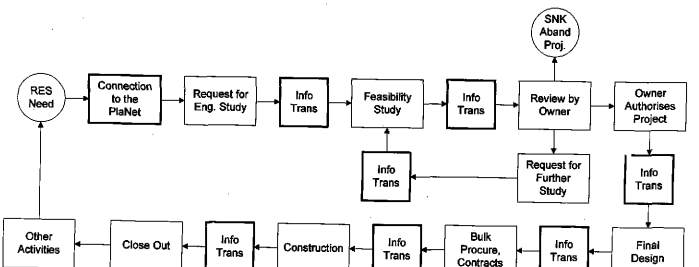


FIG. 16. Project Phases with Planet Model Communications

1. Generation of the data: it includes creating and encoding the data;
2. Data transfer: sending the data through computer networks;
3. Data processing: receiving, decoding, and analyzing the information.

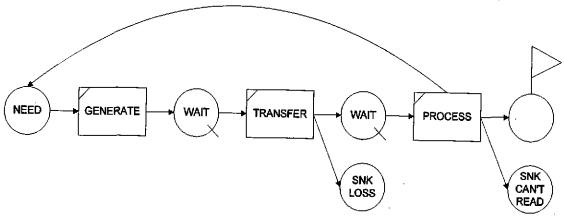


FIG. 17. Information Flow Model

The resource node initiates the model with an entity that goes through the generate and transfer nodes. After that the entity can go either to the process node, or to the sink node. The sink node indicates the loss of the data while being transferred. After going through the process node there are three possible outcomes:

1. If the received data cannot be read, for example because of incompatible format, the entity goes to the sink node;
2. The information flow process starts again and the entity goes back to the 'need' node.
3. When the required number of cycles have been completed, the entity goes to the end node, finishing the process.

Figure 18 shows two general ways of communication in construction management: written and verbal. The verbal way can be split into three categories:

1. Phone conversations with one person
2. Conferences - communication with one or more people at the same time. There can be phone, teleconferences, web conferences, or web-based communication methods known as 'chat' and 'message board'
3. Meetings with one or more people.

The written way can be divided into three groups:

1. Letters - short, not more than five pages documents;
2. Files - documents including more than five pages, for example specifications, reports, etc.;

3. Drawings - engineering drawings.

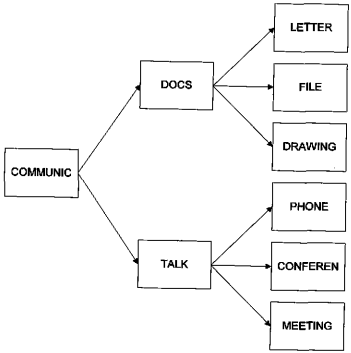


FIG. 18. Communication Options Model

The phone communication model is presented in Figure 19. The first node is a 'dummy' activity representing the selection of phone conversation as a means of communication. After the phone number has been dialed there is a chance that the person on the other end of the line in not available or in other words, s/he is not

reached. When this happens, the caller can either wait to call again later, or not call anymore, then the resource entity goes to the 'sink' node.

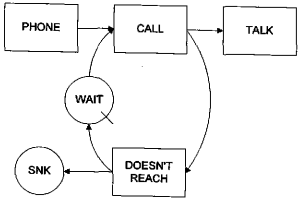


FIG. 19. Telephone Communication Model

There are two possible outcomes in the conference model (Figure 20). One is the rescheduled session that leads to notifying the involved people about the change and waiting for the next session. Another outcome is connecting and communicating during a conference session. The meeting model (Figure 21) is analogous to the conference model with the only exception of arriving instead of connecting.

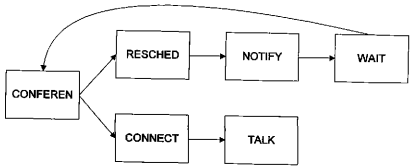


FIG. 20. Conference Communication Model

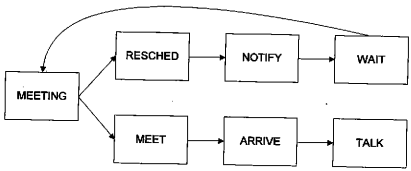


FIG. 21. Meeting Model

The development of the Paper information flow model is done in three parts: generation, transfer, and processing. The Paper model generation phase is presented in Figure 22.

After a document is created it needs to be approved. If the document does not get approved it is edited. The cycle repeats until the document meets the necessary requirements. In the model this cycle is shown as a loop from 'approve' node to 'create doc' node. Before being sent the document can be copied, and the copy filed for the company's records.

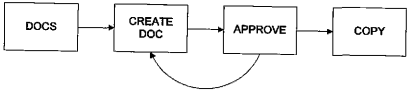


FIG. 22. Information Generation Phase

Figure 23 illustrates the Paper model transfer phase. It starts with a 'send' activity and ends with a 'receive' activity. A document in the model can be sent in three ways: by mail, by email, and by fax. Mail and fax can be domestic or international.

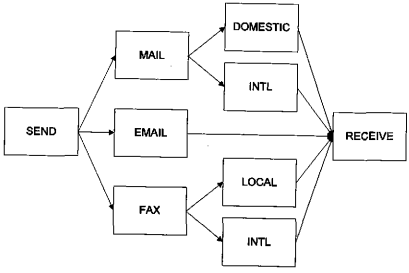


FIG. 23. Information Transfer Phase of the Paper Model

The process phase of the Paper model is presented in Figure 24. After being received, a document can be forwarded if it is addressed for someone else, or read if it came to the right addressee. The receiving person can make the decision based upon the message by him/herself or consult with another person first.

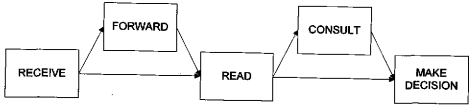


FIG. 24. Information Processing Phase of the Paper Model

The Molecular model is also developed in the three phases. The generation phase of the Molecular model (Figure 25) is similar to the paper model generation phase but is lacking the copy activity since the copying function is performed automatically during electronic transfers.

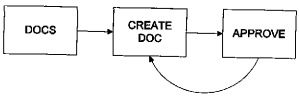


FIG. 25. Information Generation Phase of the Molecular Model

The Molecular model transfer phase is presented in Figure 26. The sent data can be encoded if sent through a Value Added Network (VAN) and a Virtual Private Network (VPN), or it can be sent through a Local Area Network (LAN) without being encoded. The encoding procedure adds the decoding activity when the data is received.

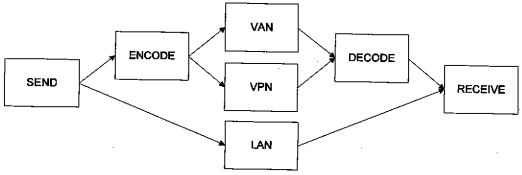


FIG. 26. Information Transfer Phase of the Molecular Model

The processing phase of the Molecular model (Figure 27) can include the options described below. When received, the message can be printed and forwarded in a paper format or forwarded electronically if the message is

meant for another addressee. Similar to the paper model, the decision making process may or may not involve consultation with another person.

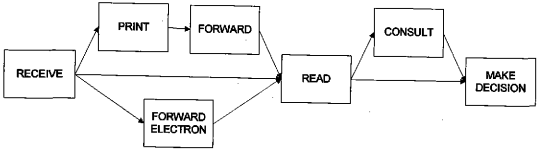


FIG. 27. Information Processing Phase of the Molecular Model

The only phase that differentiates the Planet, Orbit, and Molecular models is the transfer phase. Figure 28 shows the generation phase of the Planet and Orbit models.

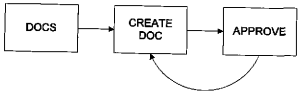


FIG. 28. Information Generation Phase of the Planet and Orbit Models

The Planet model transfer phase is displayed in Figure 29. The information is encoded and sent through a Virtual Private Network (VPN) to the Information Center (IC), where it is redirected to the addressee. If the (IC) stops functioning the sent data might be lost. This would reverse the transfer cycle to its beginning. There is also a possibility that all the data is lost. This would stop the transfer cycle.

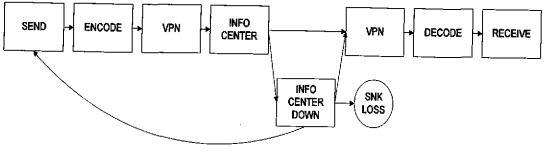


FIG. 29. Information Transfer Phase of the Planet Model

The transfer phase of the Orbit model follows a straightforward pattern (Figure 30). The data is encoded into XML, sent to the VPN (it also can be VAN or WWW), then decoded and received by the user. There still is a chance of losing data while being transferred, but this is encountered in the general information flow model (Figure 17).

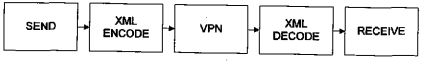


FIG. 30. Information Transfer Phase of the Orbit Model

Figure 31 shows the processing phase of the Planet and Orbit models.

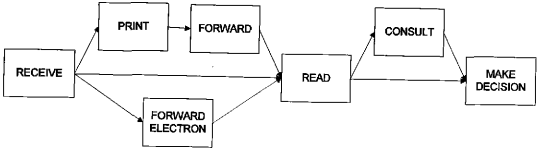


FIG. 31. Information Processing Phase of the Planet and Orbit Models

Simulation Models

Paper model is a combination of generation, transfer, and processing phases, plus verbal ways of communication in Construction Management (Figure 32). When combined the phases cause minor changes in the smaller models.

In the phone communication model if a person on the other end of the line is not reached, the resource entity goes to a sink node, meaning there is no other attempt to connect the person. In the combined paper model the entity goes to the written communications model, that is the activity of preparing a letter, which can be sent via mail, fax, or email.

After the phone conversation is over the entity goes through a 'dummy' node ("question discussed") to the processing part of the model indicating that the required information is received and now is being processed. After a meeting or a conference session is over, the entity is also directed to the processing part.

The written communication model splits into three courses: letter, file, and drawing transactions. The split occurs to allow each option being sent via mail, fax, and email.

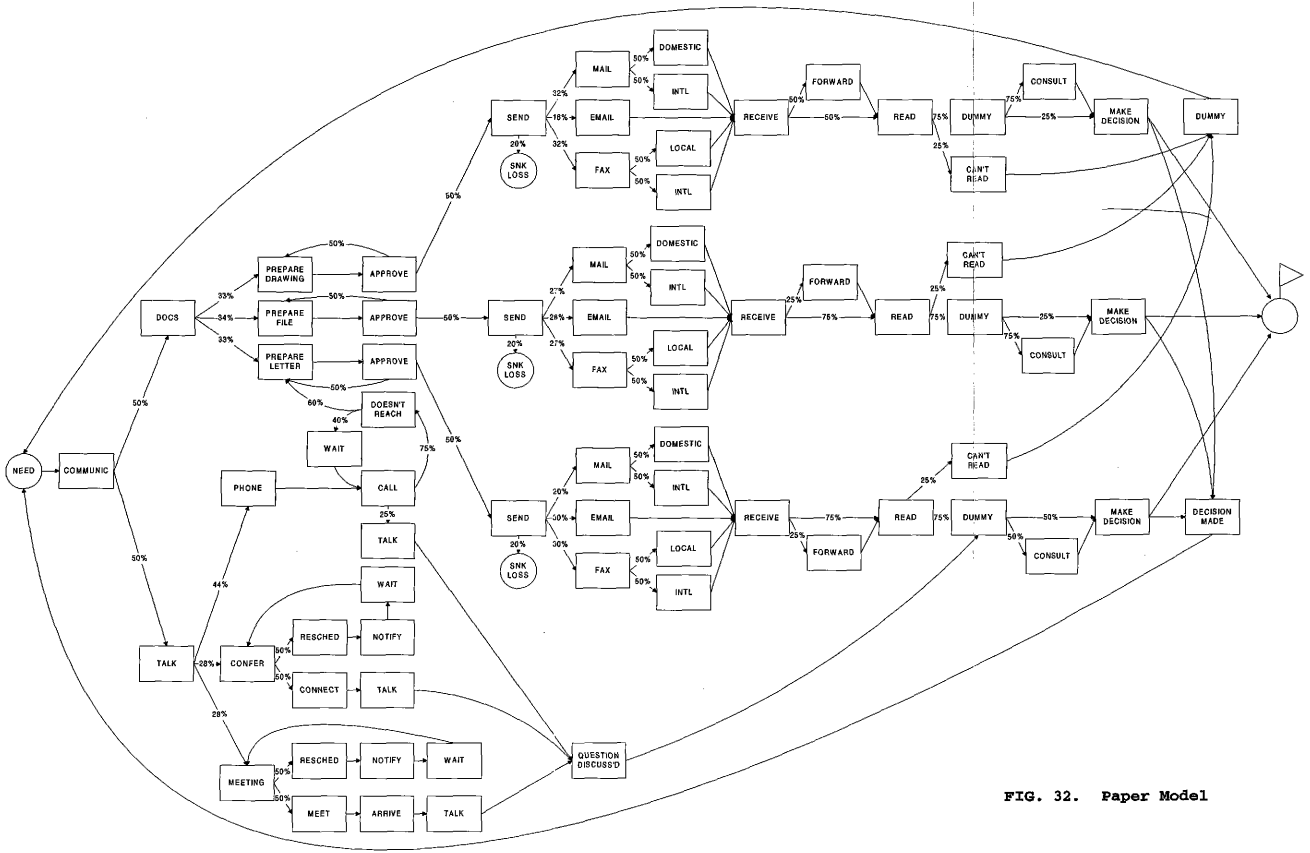


FIG. 32. Paper Model

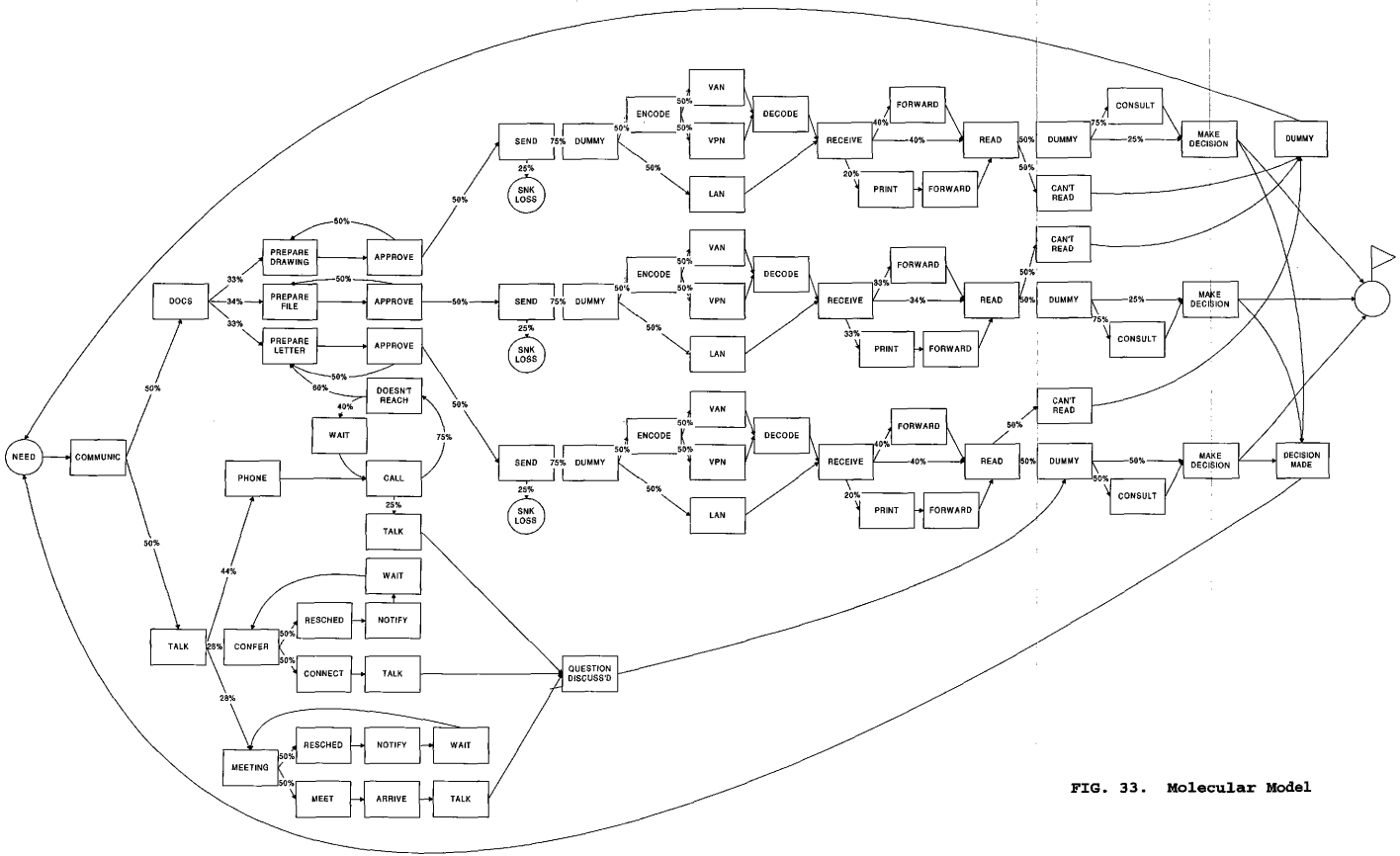


FIG. 33. Molecular Model

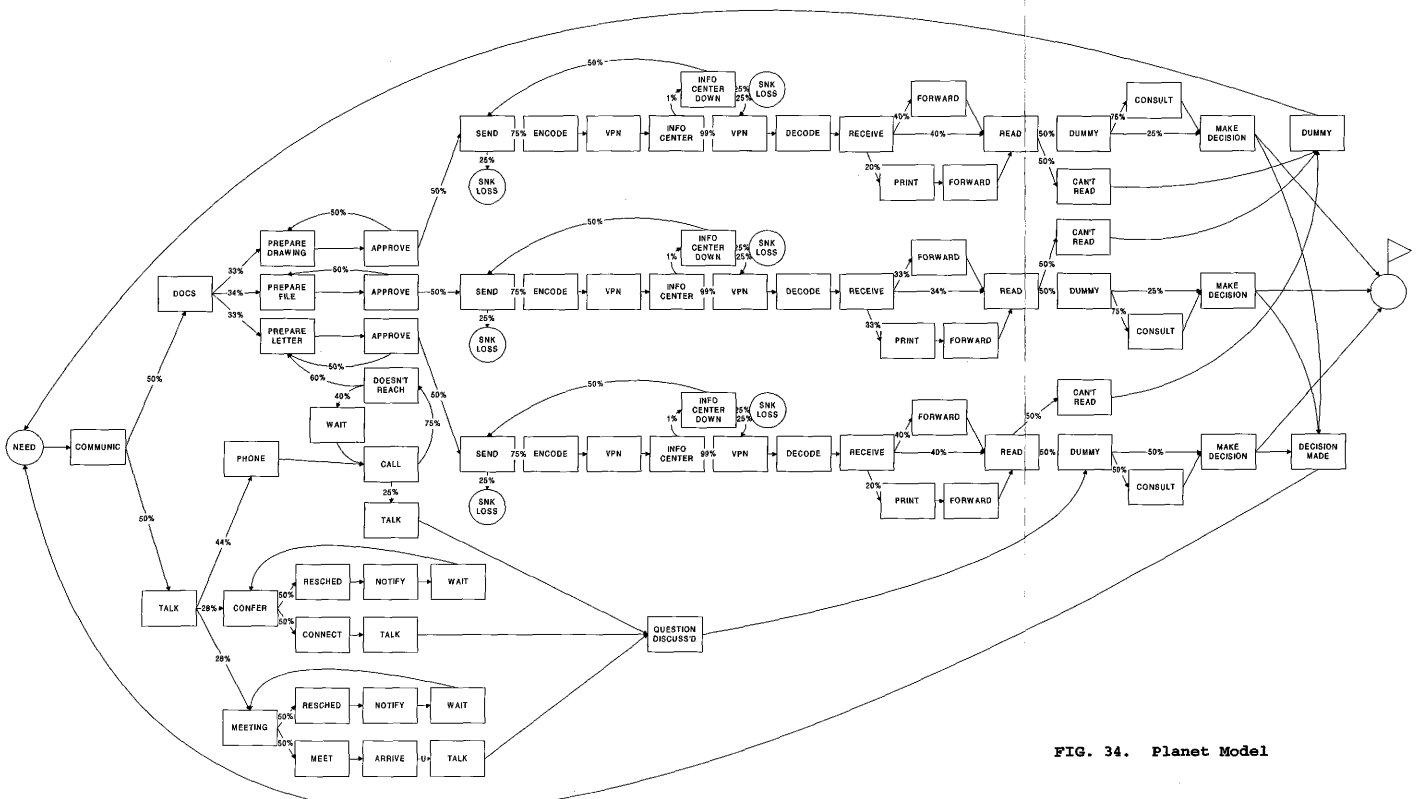


FIG. 34. Planet Model

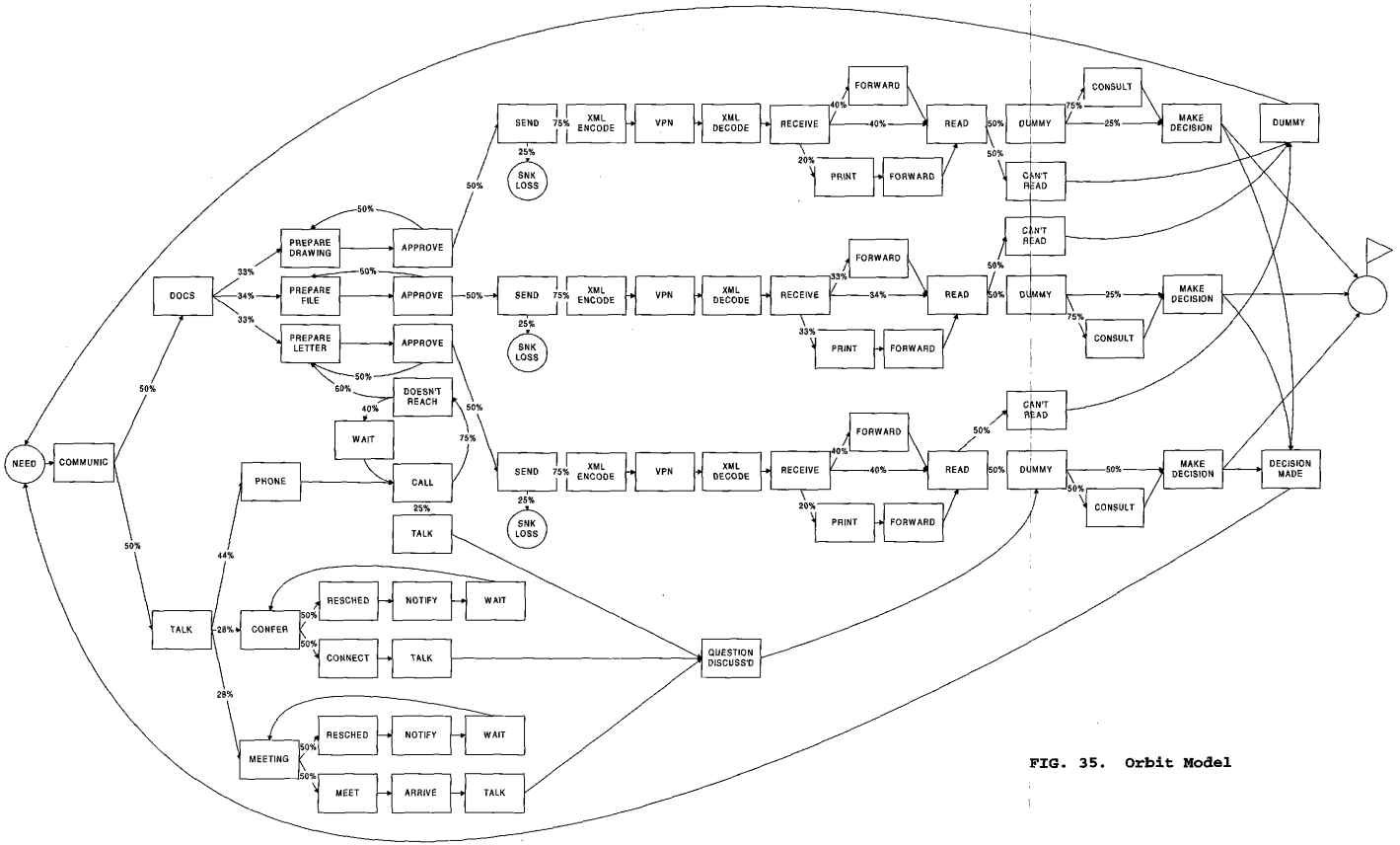


FIG. 35. Orbit Model

In the processing part after the decision has been made the entity goes to the very beginning of the model starting a new cycle.

The Molecular (Figure 33), Planet (Figure 34), and Orbit (Figure 35) models are combined in the same fashion as the Paper model, including the same modifications to the models' components.

After reaching the 'Docs' node in the Paper model the entity has three options: to go to the 'prepare drawing' node, to reach the 'prepare file' node, or to move to the 'prepare letter' node. Each of these branches has a probability assigned to it, which provides only one way at a time for the entity to go. Probabilities are assigned to all the branches in the four developed models.

Pilot Survey

The next step after developing simulation models is gathering data to input in the models. The data were gathered by means of a questionnaire. Students at Texas A&M University were chosen as the survey participants.

The pilot survey (Appendix A) was conducted in order to determine approximate ranges of communication

activities' duration as well as probabilities of different outcomes (or branches) included in the simulation models. The participants were asked to provide minimum, maximum, and most likely numbers for the activities' duration. The probability questions had five possible answers:

1. No (representing 10%);
2. Not likely (30%);
3. Maybe (50%);
4. Most likely (70%);
5. Yes (90%).

Seven students participated in the pilot survey. Based on their answers featuring minimum, maximum, and most likely values, the next questionnaire (Appendix B) was modified to provide an user-friendlier interface and arrange data into clusters. The results of the pilot survey are presented in Tables 7 through 14.

TABLE 7. Results of the Pilot Survey (TABLE A1)

#*	Question	Participant Numbers**							AVE ***	SD* ***
		1	2	3	4	5	6	7		
1	If you need to communicate with another organization, would contact them by phone (vs. send a letter, fax, or email)?	30	90	90	70	50	50	70	64	22
2	When you call another organization, do you usually reach the person you need to talk to at the first time?	30	50	70	30	50	70	10	44	22
3	When you do not reach the person you need to talk to, would you wait and call him/her again (vs. send a letter, fax, or email)?	30	70	90	70	70	50	90	67	21
4 a	When you need to send a document to another organization, would it be • A letter?	90	70	90	70	70	70	90	79	11
4 b	• Specifications, reports, etc.?	90	70	90	-	-	50	30	66	26
4 c	• An engineering drawing?	90	50	30	-	-	10	10	38	33
5 a	Does a document get approved at the first time, if it is • A letter?	30	50	50	70	70	30	70	53	18
5 b	• Specifications, reports, etc.?	30	30	70	50	-	70	30	47	20
5 c	• An engineering drawing?	30	30	30	30	-	50	10	30	13
6 a	If you need to send a document, would you send a document by • Mail?	50	50	70	-	70	70	90	67	15

TABLE 7. Continued

#*	Question	Participant Numbers**							AVE ***	SD* ***
		1	2	3	4	5	6	7		
6 b	• Fax?	90	70	70	-	-	30	30	58	27
6 c	• Email?	90	70	90	70	-	50	90	77	16
7	Do you often send documents to other countries?	90	70	50	30	10	90	90	61	32
8	After you received information from another organization, would you need to consult with somebody else before you make a decision?	90	70	90	70	70	90	70	79	11
9	When you send a document, does it get lost or sent to the wrong address?	70	50	30	30	30	30	30	39	16
10	When you receive a document, does it need to be forwarded to another person or department?	50	50	50	70	50	30	50	50	12
11	Is it likely that you cannot read the document (for example, foreign language, or unknown format)?	50	50	50	30	30	50	30	41	11
12	If you cannot read a document, would you ask the sender to send another one (vs. throw it in the trash)?	90	90	90	90	70	30	70	76	22

* "#" means question number,

** "-" means Not Answered.

*** AVE stands for Average,

**** SD stands for Standard Deviation,

TABLE 8. Results of the Pilot Survey (TABLE A2 - Minimum Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1	How many times do you usually contact other organizations (the owner, designer, etc.) a day?	-	1	0	0	1	0	-	0	1
2	How long would you talk on the phone with someone from another organization?	-	1	3	0	1	2	-	1	1
3	If you did not reach someone by phone at the first time, how long would you wait before you call again?	10	30	60	60	1	30	-	32	25
4 a	When you need to send a document, how long does it take to prepare the document (for example, to find and print out), if it is • A letter?	60	60	30	10	30	30	-	37	20
4 b	• Specifications, reports, etc.?	240	480	60	240	-	50	-	214	175
4 c	• An engineering drawing?	240	480	120	-	-	10	-	213	202

TABLE 8. Continued

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
5 a	When you need to send a document, how long does it take to approve, if it is • A letter?	0	1	5	0	0	0	-	1	2
5 b	• Specifications, reports, etc.?	0	480	120	0	-	0	-	120	208
5 c	• An engineering drawing?	240	480	120	-	-	0	-	210	205
6	How long do you have to wait until a document is actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)?	120	60	60	0	720	5	-	161	277
7	How long does it take to forward a document (for example, through the internal mail system)?	120	120	240	0	5	10	-	83	96
8	How long does it take to read a document (which might be a letter, a report, or an engineering drawing)?	10	60	30	5	2	30	-	23	22
9	If you decide to consult first, how long does it take?	60	60	30	0	5	50	-	34	27
10	How long does it take you to make a decision?	0.5	60	60	0	5	30	-	26	29

TABLE 9. Results of the Pilot Survey (TABLE A2 - Most Likely Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1	How many times do you usually contact other organizations (the owner, designer, etc.) a day?	-	6	0.2	4	3	0	70	14	28
2	How long would you talk on the phone with someone from another organization?	-	5	5	15	1	7	70	17	26
3	If you did not reach someone by phone at the first time, how long would you wait before you call again?	50	60	60	4	5	120	90	56	42
4 a	When you need to send a document, how long does it take to prepare the document (for example, to find and print out), if it is	240	60	45	20	45	120	50	83	76
	• A letter?									
4 b	• Specifications, reports, etc.?	480	2400	120	480	-	180	70	622	889
4 c	• An engineering drawing?	480	2400	180	-	-	60	-	780	1094

TABLE 9. Continued

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
5 a	When you need to send a document, how long does it take to approve, if it is • A letter?	60	240	60	480	0	0	-	140	188
5 b	• Specifications, reports, etc.?	480	1440	240	480	-	0	-	528	547
5 c	• An engineering drawing?	480	1440	480	-	-	0	-	600	604
6	How long do you have to wait until a document is actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)?	240	240	240	120	720	20	-	263	241
7	How long does it take to forward a document (for example, through the internal mail system)?	240	240	480	10	5	20	-	166	190
8	How long does it take to read a document (which might be a letter, a report, or an engineering drawing)?	60	120	45	10	5	50	-	48	42
9	If you decide to consult first, how long does it take?	240	240	60	60	10	60	-	112	101
10	How long does it take you to make a decision?	1	480	120	60	15	60	-	123	180

TABLE 10. Results of the Pilot Survey (TABLE A2 - Maximum Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1	How many times do you usually contact other organizations (the owner, designer, etc.) a day?	-	10	5	8	5	0	-	6	4
2	How long would you talk on the phone with someone from another organization?	-	15	10	90	3	12	-	26	36
3	If you did not reach someone by phone at the first time, how long would you wait before you call again?	100	480	180	960	60	480	-	377	340
4 a	When you need to send a document, how long does it take to prepare the document (for example, to find and print out), if it is • A letter?	480	480	100	480	60	240	-	307	199
4 b	• Specifications, reports, etc.?	960	4800	240	1920	-	180	-	1620	1912
4 c	• An engineering drawing?	960	4800	240	-	-	120	-	1530	2211

TABLE 10. Continued

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
5 a	When you need to send a document, how long does it take to approve, if it is • A letter?	240	480	480	2400	0	0	-	600	908
5 b	• Specifications, reports, etc.?	960	2400	960	2400	-	0	-	1344	1041
5 c	• An engineering drawing?	960	2400	1440	-	-	0	-	1200	999
6	How long do you have to wait until a document is actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)?	480	480	480	480	720	30	-	445	225
7	How long does it take to forward a document (for example, through the internal mail system)?	480	480	1440	60	-	30	-	498	570
8	How long does it take to read a document (which might be a letter, a report, or an engineering drawing)?	120	240	60	30	15	60	-	88	83
9	If you decide to consult first, how long does it take?	480	480	120	480	30	120	-	285	216
10	How long does it take you to make a decision?	300	960	120	960	30	120	-	415	431

TABLE 11. Results of the Pilot Survey (TABLE A3)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1	If you need to communicate with another organization, would you contact them by phone (vs. contact them electronically)?	30	50	90	30	50	50	-	50	22
2 a	If you need to send a document electronically, would you send it through	-	70	90	70	50	30	-	62	23
2 b	• Local network (LAN)?	-	30	90	50	50	50	-	54	22
2 c	• Secure Internet networks (VPN)?	-	30	90	70	50	50	-	58	23
3	• Network between partners (VAN)?	30	30	30	10	50	50	-	33	15
4 a	If you have an Information Center that stores and processes all the data, would it go down every time you send information?	70	70	50	90	50	70	-	67	15
4 b	If the Information Center is down will the following events happen? • Data is recovered/saved	30	50	30	10	30	30	-	30	13
4 c	• Data is not saved and you need to send your document again	30	30	30	10	30	10	-	23	10
	• All the data is lost									

TABLE 11. Continued

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
5 a	When you receive a document electronically, do you • Forward it electronically?	90	90	90	90	50	70	-	80	17
5 b	• Read and do not forward it?	30	90	30	30	70	50	-	50	25
5 c	• First print it out, then forward it (because the person it is addressed to does not have a computer)?	70	30	50	30	50	70	-	50	18
6	When you send a document electronically, does it get lost or sent to the wrong address?	30	30	30	30	30	50	-	33	8
7	When you receive a document electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	30	30	50	50	30	50	-	40	11
8	If you cannot read a document, what is the probability that you ask the sender to send another one (vs. delete it)?	50	90	70	70	70	50	-	67	15

TABLE 12. Results of the Pilot Survey (TABLE A4 - Minimum Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1 a	When you need to send a document electronically, how long does it take to prepare one (for example, scan it or copy the file), if it is	1	60	10	1	5	30	-	18	23
	• A letter?									
1 b	• Specifications, reports, etc?	1	60	30	1	60	50	-	34	28
1 c	• An engineering drawing?	1	60	60	-	120	10	-	50	48
2 a	When you need to send a document electronically, how long does it take to approve it , if it is	0	60	10	0	0	0	-	12	24
	• A letter									
2 b	• Specifications, reports, etc?	0	60	60	0	120	0	-	40	49
2 c	• An engineering drawing?	0	60	180	-	120	0	-	72	78
3	If you send a document electronically, how long would it take to encode the data?	1	30	1	-	30	10	-	14	15
4	If you decide to consult with somebody else after you receive information electronically from another organization, how long would it take?	1	60	10	0	30	60	-	27	28

TABLE 13. Results of the Pilot Survey (TABLE A4 - Most Likely Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1 a	When you need to send a document electronically, how long does it take to prepare one (for example, scan it or copy the file), if it is • A letter?	2	120	45	5	10	60	-	40	46
1 b	• Specifications, reports, etc?	2	120	90	15	90	120	-	73	52
1 c	• An engineering drawing?	2	120	90	-	240	60	-	102	88
2 a	When you need to send a document electronically, how long does it take to approve it , if it is • A letter	0	240	20	120	0	0	-	63	98
2 b	• Specifications, reports, etc?	0	240	120	120	240	0	-	120	107
2 c	• An engineering drawing?	0	240	300	-	240	0	-	156	144
3	If you send a document electronically, how long would it take to encode the data?	10	60	5	-	80	20	-	35	33
4	If you decide to consult with somebody else after you receive information electronically from another organization, how long would it take?	4	240	30	4	60	120	-	76	91

TABLE 14. Results of the Pilot Survey (TABLE A4 - Maximum Values)

#	Question	Participant Numbers							AVE	SD
		1	2	3	4	5	6	7		
1 a	When you need to send a document electronically, how long does it take to prepare one (for example, scan it or copy the file), if it is • A letter?	5	480	60	30	15	120	-	118	182
1 b	• Specifications, reports, etc?	5	480	120	180	240	180	-	201	158
1 c	• An engineering drawing?	5	480	240	-	360	60	-	229	199
2 a	When you need to send a document electronically, how long does it take to approve it , if it is • A letter	0	480	60	24	0	0	-	94	191
2 b	• Specifications, reports, etc?	0	480	480	24	360	0	-	224	241
2 c	• An engineering drawing?	0	480	1920	-	360	0	-	552	794
3	If you send a document electronically, how long would it take to encode the data?	60	180	30	-	120	30	-	84	65
4	If you decide to consult with somebody else after you receive information electronically from another organization, how long would it take?	8	480	60	24	120	180	-	145	176

The idea of the pilot survey is to find the extreme (minimum and maximum) values and to determine the shape of the distribution. The sample mean can be estimated as follows:

$$\bar{x} = \frac{Min + ML + Max}{6},$$

Where ML - Most Likely value.

The sample standard deviation can be calculated using the following formula:

$$s = \frac{Max - Min}{6}$$

A triangular distribution is assumed to describe the data. The minimum and maximum values discovered using the pilot survey could be close to the real numbers. However, there is a chance that the most likely values are skewed because of the little experience that the students have.

Although each separate activity in the simulation model might have a significant error or deviation, the overall simulation outcome will presumably have a much lower error. This is because when added together activities will balance each other out.

Survey

A copy of the survey is presented in Appendix B. There are two criteria for the selection of the participants: first is knowledge of construction processes and second is the acquaintance with information technologies. Both of these criteria are met by the selection of students taking classes related to information communications in the Departments of Civil Engineering (Constructed Facilities Division) and Construction Science. The first course is CVEN 638 "Computer Integrated Construction Systems" taught by Professor Donald A. Maxwell. The second course is COSC 641 "Construction Management Communications" taught by Dr. James W. Craig.

The questionnaire is divided into three parts:

1. Paper-based communications - this part contains probability and time questions for the Paper model.
2. Paperless communications - probability and time questions for the Molecular, Planet, and Orbit models.
3. Experience information has two questions: (1) number of years of experience and (2) specialization of the participants.

All questions have multiple choice answers (five answers for each question). Probability questions have the following answers:

1. Never (representing 0%);
2. Rarely (25%);
3. Sometimes (50%);
4. Often (75%);
5. Always (100%).

"Thirty students were asked to fill out the survey. Twenty-four of them returned the survey." The results are presented in Tables 15 through 20 as well as in Appendix C.

TABLE 15. Survey Results (TABLE B1)

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
1	Do you have partnering organizations (for example, the owner, designers, vendors, etc.) outside the US?	1	3	5	0	50	100
2	Do you have partnering organizations outside your state?	1	3	5	0	50	100
3	When you contact a partnering organization, do you use verbal communications (for, example, phone calls or meetings)?	1	4	5	25	75	100

TABLE 15. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
4	When you contact a partnering organization, do you use written communications (for, example, emails, letters, drawings, etc.)?	1	4	5	25	75	100
5	When you need to communicate with someone from a partnering organization, do you contact him/her by phone (vs. send a letter, fax, or email)?	1	4	5	25	75	100
6	When you need to communicate with someone from a partnering organization, do you meet with him/her?	1	3	5	25	50	75
7	When you need to communicate with someone from a partnering organization, do you participate in a conference session (for, example, phone, video, or web conferences) with him/her?	1	3	5	0	50	100
8	When you call another organization, do you reach the person you need to talk to at the first time?	1	2	5	25	25	100
9	When you do not reach the person you need to talk to, do you usually wait and call him/her again?	2	3	5	25	50	100
10	When you do not reach the person you need to talk to do you usually try to reach him/her by mail, fax, or email?	2	4	5	50	75	100
11	Do meetings with people from partnering organizations get rescheduled?	1	4	5	25	50	100
12	Do conference sessions with people from partnering organizations get rescheduled?	1	3	5	0	50	100

TABLE 15. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
13	Do you send letters to partnering organizations?	1	3	5	25	50	100
14	Do you send sets of documents like reports and specifications to partnering organizations?	1	3	5	50	50	100
15	Do you send engineering drawings to partnering organizations?	1	3	5	25	50	100
16	Do you send letters to your partners via postal mail?	1	3	5	0	50	100
17	Do you send letters via fax?	3	4	5	50	75	100
18	Do you send letters via email?	2	4	5	25	75	75
19	Do you send sets of documents like reports and specifications via postal mail?	1	3	5	0	50	100
20	Do you send sets of documents via fax?	1	3	5	0	50	75
21	Do you send sets of documents via email?	1	4	4	0	50	75
22	Do you send engineering drawings via postal mail?	1	3	5	0	50	100
23	Do you send engineering drawings via fax?	1	2	4	0	25	75
24	Do you send engineering drawings via email?	1	3	4	0	50	75
25	When you send a letter, does it get lost?	1	2	4	0	25	75
26	When you send a set of documents, does it get lost?	1	2	3	0	25	50
27	When you send an engineering drawing, does it get lost?	1	2	4	0	25	75
28	When you receive a letter, does it need to be forwarded to another person or department?	2	3	5	25	25	75

TABLE 15. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
29	When you receive a set of documents, does it need to be forwarded to another person or department?	1	3	5	25	25	75
30	When you receive an engineering drawing, does it need to be forwarded to another person or department?	1	3	4	0	50	75
31	After you received a letter from another organization, do you need to consult with someone else before you make a decision?	2	3	4	25	50	75
32	After you received a set of documents from another organization, do you need to consult with someone else before you make a decision?	1	3	5	25	75	100
33	After you received an engineering drawing from another organization, do you need to consult with someone else before you make a decision?	1	4	5	25	75	75
34	After you received a letter, does it happen to be unreadable (for example, foreign language, or unknown format)?	1	2	4	0	75	75
35	After you received a set of documents, does it happen to be unreadable?	1	2	4	0	25	75
36	After you received an engineering drawing, does it happen to be unreadable?	1	3	4	0	25	75

* MD stands for "Mode"

The minimum, maximum, and the most likely values featuring triangular distributions were entered into the simulation models. In the places of probability branching relative probabilities were entered. The determination of a relative probability is shown by the following example. If the probability of one outcome according to the survey results is 75%, and the probability of another outcome of the same activity is 50%, the relative probabilities are calculated as follows:

1. Total probability = 75 + 50 = 125%
2. Relative probability 1 = 75 / 125 = 0.6 = 60%
3. Relative probability 2 = 50 / 125 = 0.4 = 40%

The survey options distinguish the numerical data ranges (time ranges), out of which one number is picked. This number is defined in the following manner:

1. If the chosen range is the lowest of the provided options (for example, "<10 minutes"), half of the value is entered in the model (5 minutes).
2. If the chosen range is neither the lowest nor the highest (10-20 minutes), the mean value of the range is entered in the model (15 minutes).

3. If the range is the highest of the options (>60 minutes), the lowest value of the range is multiplied by 1.5 (60*1.5=90 minutes).

The values for all models were calculated this way.

TABLE 16. Survey Results (TABLE B2)

#	Questions	ANSWERS			VALUES (min)		
		MIN	MD*	MAX	MIN	MD	MAX
1	How many times do you usually contact partnering organizations (for example, the owner, designers, vendors etc.) a day?	1	2	4	3	8	18
2	When you do not reach someone by phone at the first time, on average how long do you wait before you call again?	1	3	5	3	150	720
3	What is the average length of your phone conversations with someone from a partnering organization?	1	2	5	3	8	30
4	What is the average length of your conference sessions (for, example, phone, video, or web conferences)?	1	5	5	3	30	30
5	When a conference session has to be rescheduled, on average how long does it take to agree with the involved people about the time of the next session?	1	2	5	8	23	180
6	When the conference session is rescheduled, on average how long do you wait for the next session?	1	4	5	30	720	1440

TABLE 16. Continued

#	Questions	ANSWERS			VALUES (min)		
		MIN	MD*	MAX	MIN	MD	MAX
7	On average how long does it take you to arrive to a meeting place if it is in the same city?	1	3	4	8	45	90
8	What is the average length of meetings with people form a partnering organization?	1	2	5	15	45	360
9	When the meeting has to be rescheduled, on average how long does it take to agree with the involved people about the time of the next meeting?	1	1	5	30	30	1440
10	When the meeting is rescheduled, on average how long do you wait for the next meeting?	1	3	5	120	720	2880
11	On average how long does it take to write a letter to a partnering organization?	1	3	4	15	90	180
12	How long does it take to create a document like a specification, a report, etc. to send to a partnering organization?	1	3	5	120	720	2880
13	How long does it take to create an engineering drawing?	1	5	5	120	2880	2880
14	How long does it take to approve a letter that is going to be sent to a partnering organization?	1	4	4	15	720	720
15	How long does it take to approve a document like a specification, a report, etc. to send to a partnering organization?	1	4	5	60	1440	3600

TABLE 16. Continued

#	Questions	ANSWERS			VALUES (min)		
		MIN	MD*	MAX	MIN	MD	MAX
16	How long does it take to approve an engineering drawing?	1	4	5	60	1440	3600
17	How long do you have to wait until a letter gets actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)?	1	3	4	30	360	720
18	How long do you have to wait until a set of documents gets actually sent?	2	3	4	150	360	720
19	How long do you have to wait until engineering drawings get actually sent?	2	3	4	150	360	720
20	How long does it usually take to forward a letter (for example, through the internal mail system)?	1	2	5	5	35	720
21	How long does it usually take to forward a set of documents like specifications, reports, etc.?	1	3	5	5	150	720
22	How long does it usually take to forward an engineering drawing?	1	2	5	5	35	720
23	On average how long does it take to read a letter?	1	1	4	5	5	90
24	On average how long does it take to read a set of documents like specifications, reports, etc.?	1	3	5	30	180	720
25	On average how long does it take to read an engineering drawing?	1	3	5	30	180	720

TABLE 16. Continued

#	Questions	ANSWERS			VALUES (min)		
		MIN	MD*	MAX	MIN	MD	MAX
26	How long does it usually take to consult about a letter?	1	1	5	15	15	360
27	How long does it usually take to consult about a set of documents?	1	2	5	30	120	720
28	How long does it usually take to consult about an engineering drawing?	1	3	5	30	270	720
29	How long does it take you to make a decision about a letter?	1	2	5	5	35	720
30	How long does it take you to make a decision about a set of documents?	1	2	5	5	35	720
31	How long does it take you to make a decision about an engineering drawing?	1	2	5	5	35	720

TABLE 17. Survey Results (TABLE B3)

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
1	If you need to send a letter electronically, do you send it through a Local network (LAN)?	1	3	5	0	50	100
2	If you need to send a set of documents electronically, do you send it through a Local network (LAN)?	1	2	5	0	25	100
3	If you need to send engineering drawings electronically, do you send them through a Local network (LAN)?	1	3	5	0	50	100

TABLE 17. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
4	If you need to send a letter electronically, do you send it through a secure Internet network (VPN)?	1	3	4	0	50	75
5	If you need to send a set of documents electronically, do you send it through a secure Internet network (VPN)?	1	3	4	0	50	75
6	If you need to send engineering drawings electronically, do you send them through a secure Internet network (VPN)?	1	3	4	0	50	75
7	If you need to send a letter electronically, do you send it through a network between partners (VAN)?	1	3	4	0	50	75
8	If you need to send a set of documents electronically, do you send it through a network between partners (VAN)?	1	3	4	0	50	75
9	If you need to send engineering drawings electronically, do you send them through a network between partners (VAN)?	1	3	4	0	50	75
10	If you have an Information Center that stores, sends, and processes all the data, does it stop functioning when you send information?	1	1	4	0	0	75
11	If the Information Center stops functioning, do your data get lost?	1	2	3	0	25	50
12	If the Information Center stops functioning does it save/recover your data automatically?	1	2	5	0	25	100

TABLE 17. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
13	If the data is not saved in the Information Center when it stops functioning, do you need to send the data again?	1	3	5	0	50	100
14	When you send a letter electronically, does it get lost?	1	2	4	0	25	75
15	When you send a set of documents electronically, does it get lost?	1	2	3	0	25	50
16	When you send an engineering drawing electronically, does it get lost or sent to the wrong address?	1	2	4	0	25	75
17	When you receive a letter electronically, are you the final addressee?	1	3	5	0	50	100
18	When you receive a set of documents electronically, are you the final addressee?	1	3	5	0	50	100
19	When you receive an engineering drawing electronically, are you the final addressee?	1	3	5	0	50	100
20	When you receive a letter electronically, do you need to forward it electronically to another person or department?	1	3	4	0	50	75
21	When you receive a set of documents electronically, do you need to forward it electronically to another person or department?	1	3	4	0	50	75
22	When you receive an engineering drawing electronically, do you need to forward it electronically to another person or department?	1	3	4	0	50	75

TABLE 17. Continued

#	Questions	ANSWERS			VALUES (%)		
		MIN	MD*	MAX	MIN	MD	MAX
23	When you receive a letter electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	1	2	4	0	25	75
24	When you receive a set of documents electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	1	3	4	0	50	75
25	When you receive an engineering drawing electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	1	2	5	0	25	100
26	When you receive a letter electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	1	3	3	0	50	50
27	When you receive a set of documents electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	1	3	4	0	50	75
28	When you receive an engineering drawing electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	1	3	4	0	50	75

TABLE 18. Survey Results (TABLE B4)

#	Questions	ANSWERS			VALUES (min)		
		MIN	MD*	MAX	MIN	MD	MAX
1	When you need to send a letter electronically, how long does it take to approve it?	1	1	5	8	8	720
2	When you need to send a set of documents electronically, how long does it take to approve it?	1	2	5	30	150	1440
3	When you need to send an engineering drawing electronically, how long does it take to approve it?	1	2	5	30	150	1440
4	When you send a letter electronically, how long does it take to encode the data?	1	1	4	3	3	120
5	When you send a set of documents electronically, how long does it take to encode the data?	1	1	4	3	3	120
6	When you send an engineering drawing electronically, how long does it take to encode the data?	1	2	5	3	18	2160
7	How long does it take to consult electronically about a letter?	1	2	5	5	35	720
8	How long does it take to consult electronically about a set of documents?	1	2	5	5	35	720
9	How long does it take to consult electronically about an engineering drawing?	1	2	5	5	35	720

Twelve (out of 24) survey participants have one to five years of experience (Table 20 and Figure 36) in construction and project management (Table 21 and Figure 37). Some of them worked in more than one area, for example construction and design. Figure 36 and 37 graphically represent students' experience and specialization data.

TABLE 19. Experience Data (TABLE B5)

Number of years of experience	<0.5	0.5-1.0	1.0-5.0	5.0-10.0	>5.0
Number of students	3	2	12	3	3

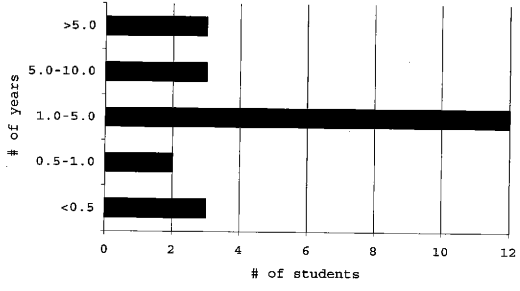


FIG. 36. Experience Data

TABLE 20. Specialization Data (TABLE B5)

AREA	# OF STUDENTS	AREA DESCRIPTION
1	11	Planning/Cost Estimation
2	9	Design
3	5	Procure
4	12	Construction
5	12	Project Management
-	2	N/A

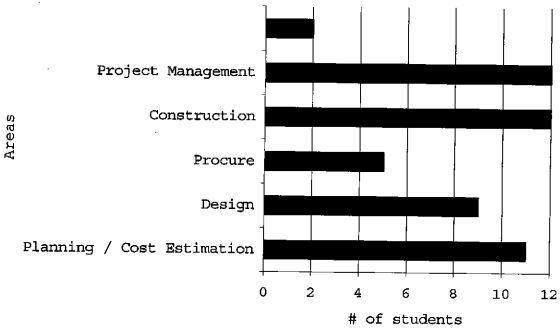


FIG. 37. Specialization Data

Simulation

Activity Based Costing Process Simulation (ABC-SIM) developed by Donald A. Maxwell[1] and W. Edward Back[2] was used to simulate the four communication models.

The input parameters were probability branches and duration of activities. The output parameters were duration of the full simulation runs and number of 'flags' or completed communication cycles per simulation run. Six hundred runs of each model were completed.

Simulation Results

Graphical interpretation of the simulation output is illustrated in Figures 38 through 41. The statistical analysis of the simulation results is presented in Tables 22 through 25. The analysis included the following steps:

1. All the data was organized in the ascending order;
2. The data was separated into several ranges or clusters;

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[1] Prof., Dept. of Civ. Engrg., Texas A&M Univ., College Station, TX 77843-3136.
[2] Asst. Prof. 1995-1999, Dept. of Civ. Engrg., Texas A&M Univ., College Station, TX.

3. The number of values falling into each cluster was counted;
4. Corresponding to the values cumulative probabilities were calculated;
5. Cumulative probabilities of all the models were plotted and compared.

The left side of Tables 22-25 shows cumulative distribution of the communication cycles' duration, which in other words describes how much time is needed to complete communication processes.

The right side of the same tables reflects cumulative probability of the number of flags, or how many documents/messages have been generated, transferred, and received during one simulation run.

Figures 42 and 43 provide the graphical summary of the results calculated in the right and left sides of Tables 21-24. The interpretation of the results is given in the next chapter.

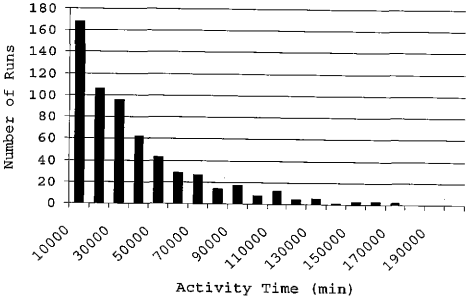

FIG. 38. Activity Time for the Paper Model Runs

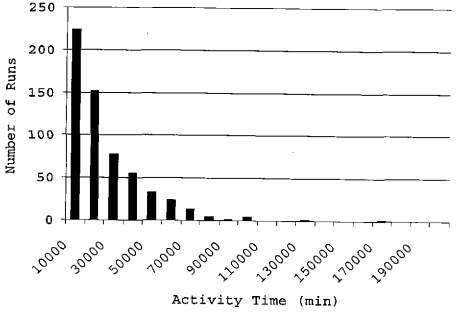

FIG. 39. Activity Time for the Molecular Model Runs

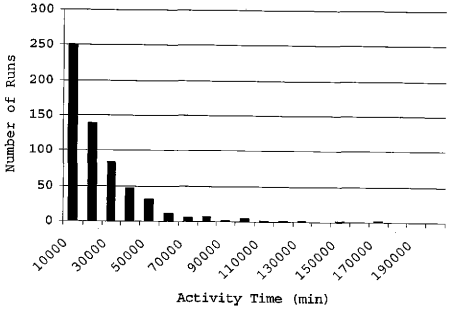

FIG. 40. Activity Time for the Planet Model Runs

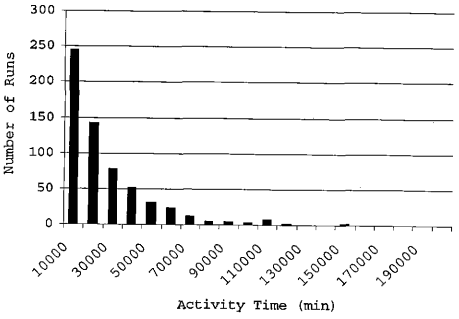

FIG. 41. Activity Time for the Orbit Model Runs

TABLE 21. Cumulative Probability for the Activity Time and Number of Flags (Paper Model)

Activity Time			Number of Items Processed		
CLUSTER	*NV	**CP	CLUSTER	NV	CP
10000	168	28%	2	183	31%
20000	106	46%	4	104	48%
30000	96	62%	6	78	61%
40000	62	72%	8	69	72%
50000	43	79%	10	41	79%
60000	28	84%	12	33	85%
70000	27	88%	14	29	90%
80000	14	91%	16	15	92%
90000	17	94%	18	15	95%
100000	8	95%	20	8	96%
110000	12	97%	22	5	97%
120000	4	98%	24	7	98%
130000	5	98%	26	3	98%
140000	1	99%	28	3	99%
150000	3	99%	30	3	99%
160000	3	100%	32	1	100%
170000	2	100%	34	3	100%
180000	0	100%	36	0	100%
190000	0	100%	38	0	100%
200000	0	100%	40	0	100%

* NV is the number of values falling into the cluster

** CP is cumulative probability

TABLE 22. Cumulative Probability for the Activity Time and Number of Flags (Molecular Model)

Activity Time			Number of Items Processed		
CLUSTER	NV	CP	CLUSTER	NV	CP
10000	223	38%	2	237	38%
20000	152	64%	4	116	57%
30000	78	77%	6	110	75%
40000	55	86%	8	52	83%
50000	33	92%	10	35	89%
60000	24	96%	12	26	93%
70000	13	98%	14	12	95%
80000	4	99%	16	8	97%
90000	1	99%	18	15	99%
100000	4	100%	20	2	99%
110000	0	100%	22	0	99%
120000	0	100%	24	1	100%
130000	1	100%	26	2	100%
140000	0	100%	28	0	100%
150000	0	100%	30	0	100%
160000	0	100%	32	1	100%
170000	1	100%	34	0	100%
180000	0	100%	36	0	100%
190000	0	100%	38	0	100%
200000	0	100%	40	0	100%

TABLE 23. Cumulative Probability for the Activity Time and Number of Flags (Planet Model)

Activity Time			Number of Items Processed		
CLUSTER	NV	CP	CLUSTER	NV	CP
10000	250	43%	2	238	40%
20000	139	66%	4	140	63%
30000	83	80%	6	93	78%
40000	46	88%	8	56	88%
50000	31	94%	10	36	94%
60000	12	96%	12	14	96%
70000	6	97%	14	8	97%
80000	7	98%	16	3	98%
90000	2	98%	18	4	98%
100000	4	99%	20	4	99%
110000	2	99%	22	3	100%
120000	2	99%	24	2	100%
130000	1	100%	26	0	100%
140000	0	100%	28	0	100%
150000	1	100%	30	0	100%
160000	0	100%	32	0	100%
170000	1	100%	34	1	100%
180000	0	100%	36	0	100%
190000	0	100%	38	0	100%
200000	0	100%	40	0	100%

TABLE 24. Cumulative Probability for the Activity Time and Number of Flags (Orbit Model)

Activity Time			Number of Items Processed		
CLUSTER	NV	CP	CLUSTER	NV	CP
10000	244	41%	2	250	42%
20000	142	64%	4	140	66%
30000	77	77%	6	76	79%
40000	51	85%	8	55	88%
50000	31	91%	10	23	92%
60000	24	95%	12	21	96%
70000	11	96%	14	14	98%
80000	4	97%	16	0	98%
90000	4	98%	18	4	99%
100000	3	98%	20	4	100%
110000	8	100%	22	2	100%
120000	2	100%	24	0	100%
130000	0	100%	26	0	100%
140000	0	100%	28	0	100%
150000	1	100%	30	0	100%
160000	0	100%	32	0	100%
170000	0	100%	34	0	100%
180000	0	100%	36	0	100%
190000	0	100%	38	0	100%
200000	0	100%	40	0	100%

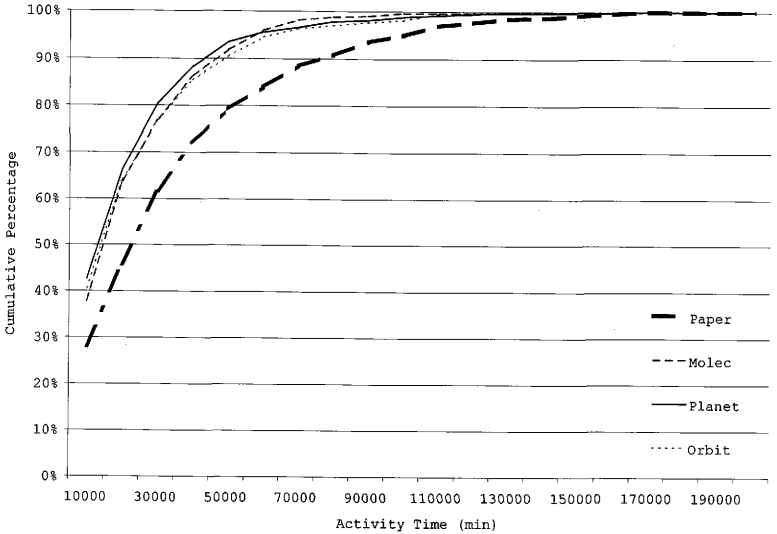

FIG. 42. Activity Time

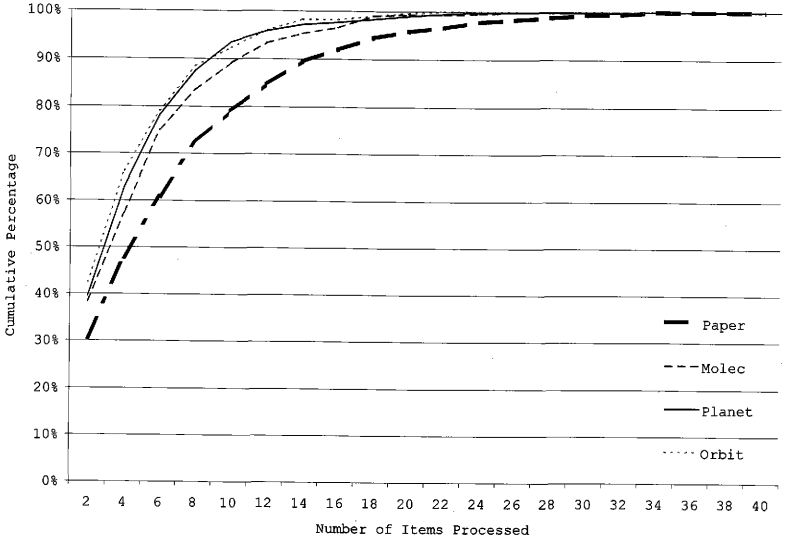

FIG. 43. Number of Items Processed

Statistical Analysis

Since Figure 42 clearly shows that the Paperless models are more efficient than the Paper-based model and thus answers the first question (or hypothesis) stated in the beginning of the research, the statistical analysis is needed only to answer the third question/hypothesis of this study.

The Planet model plays the role of a standard system, as opposed to the Molecular and, to some extent, the Orbit models. The main standardizing feature of the Planet model is the Information Center that processes, directs, and controls all the data traffic. In the range of approximately 43^{rd} to 95^{th} percentile (Figure 42), the Planet model seems to perform slightly better than the other models. However, for the probability higher than 95% the Molecular model moves to the leading position.

It is assumed that a normal distribution is valid to describe the simulation outputs. The results of the simulation of the Molecular, Planet, and Orbit models will serve as independent samples. Three combinations of the samples will be tested:

1. Molecular and Planet;

2. Molecular and Orbit;

3. Planet and Orbit.

Since the pairs of samples will be analyzed, a statistical test for μ_1-μ_2 (independent samples) is chosen as the appropriate method. The procedure for the test is presented below (Ott 1993):

H_0: $\mu_1 - \mu_2 = D_0$ (D_0 is specified)

H_a: 1. $\mu_1 - \mu_2 > D_0$

2. $\mu_1 - \mu_2 < D_0$

3. $\mu_1 - \mu_2 \neq D_0$

T.S.: $$t = \frac{\bar{y}_1 - \bar{y}_2 - D_0}{s_p\sqrt{1/n_1 + 1/n_2}}$$

R.R.: For a Type I error α and df = $n_1 + n_2 - 2$

1. reject H_0 if $t > t_\alpha$

2. reject H_0 if $t < -t_\alpha$

3. reject H_0 if $|t| > t_{\alpha/2}$

The statistical test for the outputs of the Molecular and Planet models is presented in Table 25.

TABLE 25. Statistical test for the outputs of the Molecular and Planet models

Parameters	Samples	
	a) Molecular	b) Planet
Σy	12878458	12096744
Σy^2	5.43536E+11	5.35607E+11
$\bar{y}$	21393	20094
s^2	445973585	486741529
s_p	21595	
H_0:	$\mu_a - \mu_b = 0$	
H_a:	$\mu_a - \mu_b > 0$	
T.S.:	1.043 (df=1202)	
t_a:	1.645 (α=0.05)	
R.R.:	Reject H_0 if $t > t_\alpha$	
Since the observed value of t=1.043 does not fall into rejection region, there is insufficient evidence to reject the hypothesis that there is no difference in the mean activity duration of the Molecular and Planet models.		

The statistical test for the outputs of the Molecular and Orbit models is presented in Table 26.

TABLE 26. Statistical test for the outputs of the Molecular and Orbit models

Parameters	Samples	
	a) Molecular	b) Orbit
Σy	12878458	12335462
Σy^2	5.43536E+11	5.35678E+11
$\bar{y}$	21393	20491
s^2	445973585	470739413
s_p	21409	
H_0:	$\mu_a - \mu_b = 0$	

TABLE 26. Continued

Parameters	Samples	
	a) Molecular	b) Orbit
H_a:	$\mu_a - \mu_b > 0$	
T.S.:	0.731 (df=1202)	
t_a:	1.645 (α=0.05)	
R.R.:	Reject H_0 if $t > t_\alpha$	
Since the observed value of t=0.731 does not fall into rejection region, there is insufficient evidence to reject the hypothesis that there is no difference in the mean activity duration of the Molecular and Orbit models.		

The statistical test for the outputs of the Planet and Orbit models is presented in Table 27.

TABLE 27. Statistical test for the outputs of the Planet and Orbit models

Parameters	Samples	
	a) Planet	b) Orbit
Σy	12096744	12335462
Σy^2	5.35607E+11	5.35678E+11
$\bar{y}$	20094	20491
s^2	486741529	470739413
s_p	21880	
H_0:	$\mu_a - \mu_b = 0$	
H_a:	$\mu_a - \mu_b < 0$	
T.S.:	-0.314 (df=1202)	
t_a:	1.645 (α=0.05)	
R.R.:	Reject H_0 if $t < -t_\alpha$	
Since the observed value of t= -0.314 does not fall into rejection region, there is insufficient evidence to reject the hypothesis that there is no difference in the mean activity duration of the Planet and Orbit models.		

CHAPTER IV

SUMMARY AND CONCLUSIONS

Conclusions

Answers to the following questions (hypotheses) that were identified in the beginning of the study follow:

Question #1: are there good reasons to think that paperless communications are more efficient than paper-based? Yes. Based on the simulation results there is a significant difference between the performance of a paper-based communication model and the performance of paperless communication models. This is reflected in the time duration needed to complete communication cycles. For 90-95% probability, paperless models allow almost twice as fast communication as a paper-based model (Figure 42).

Question #2: is it possible to find a common procedure for the development of a standard information system? Yes. The proposed common procedure includes the following steps:

1. Identification of the involved parties;
2. Assignment of access levels these parties;
3. Analysis of the information traffic between the involved parties based on the contractual arrangements;

4. Selection of a network topology;

5. Physical development of the network.

Question #3: are there good reasons to think that a standard information system allows better communications for construction management than a non-standard one? Given the results of the simulation, which was based on the data obtained from the students at Texas A&M University, there is insufficient evidence to say that a standard communication system is more efficient than a non-standard.

In general this research resembles the pre-project planning phase approach, which uses preliminary rough estimates and conceptual studies with very few or no details. This caused several limitations the most important of which is the data gathered for the simulation.

The number of the survey participants is another limitation. Although the modes of the data samples were used for the models, there is still a chance that with a larger group of participants the values might be different.

One more limitation is the clustering of the data. Only one value out of a range was entered into the models, while the rest of the cluster was neglected. One of the reasons behind this was the assumption that a triangular distribution is accurate enough for this study.

Implications

If the study is continued and a standard information system is determined and proven to be more efficient than scattered "islands of automation", then such a system could be used in the construction industry providing more efficient management of information resources and leading to the overall reengineering philosophy.

The concept of the determination of network configuration to enhance the performance of an information system is an abstract idea. This concept could be applied not only to construction project management, but also to other areas and even other industries.

Recommendations

A more detailed study could be recommended to differentiate the efficiency of the paperless models. This may include more accurate data for the simulation, and more sophisticated models.

It also could be beneficial to compare the models from the economical point of view, or in other words to consider cost as one of the selection criteria. The ABC-SIM software allows using of cost distributions for the models.

Summary

The study included the following steps:

1. Analysis of organizational structures of construction projects based on the main categories of contractual arrangements;
2. Development of a network configuration for each category of contractual arrangements;
3. Analysis of the developed configurations and identification of a common procedure;

4. Development of a standard information system's alternatives;
5. Representation of the project delivery process as a logical model;
6. Distinguishing of communication activities among the project delivery activities;
7. Representation of communication processes as a logical model;
8. Development of a paper-based communication model;
9. Development of a non-standard paperless communication model;
10. Development of standard paperless communication models based on the standard information system alternatives;
11. Gathering data for the paper-based and paperless simulation models;
12. Simulation of the models;
13. Statistical analysis of the simulation results;
14. Explanation of the study findings.

The finding of the research can be described as follows:

1. Paperless communication models are more efficient than a paper-based one;

2. A common procedure for the development of an information system has been proposed;
3. A more advanced study is needed to prove that standard models are more efficient than non-standard models.

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APPENDIX A

PILOT SURVEY

PAPER-BASED COMMUNICATIONS
TABLE A1. Paper-Based Communication Process (Part I)

Please, check the boxes below.

#	Question	No	Not likely	Maybe	Most likely	Yes
1.	If you need to communicate with another organization, would contact them by phone (vs. send a letter, fax, or email)?	☐	☐	☐	☐	☐
2.	When you call another organization, do you usually reach the person you need to talk to at the first time?	☐	☐	☐	☐	☐
3.	When you do not reach the person you need to talk to, would you wait and call him/her again (vs. send a letter, fax, or email)?	☐	☐	☐	☐	☐
4.	When you need to send a document to another organization, would it be					
	A letter	☐	☐	☐	☐	☐
	Specifications, reports, etc.	☐	☐	☐	☐	☐
	An engineering/architectural drawing?	☐	☐	☐	☐	☐
5.	Does a document get approved at the first time, if it is					
	A letter	☐	☐	☐	☐	☐
	Specifications, reports, etc.	☐	☐	☐	☐	☐
	An engineering/architectural drawing?	☐	☐	☐	☐	☐
6.	If you need to send a document, would you send a document by					
	Mail	☐	☐	☐	☐	☐
	Fax	☐	☐	☐	☐	☐
	Email?	☐	☐	☐	☐	☐
7.	Do you often send documents to other countries?	☐	☐	☐	☐	☐
8.	After you received information from another organization, would you need to consult with somebody else before you make a decision?	☐	☐	☐	☐	☐
9.	When you send a document, does it get lost or sent to the wrong address?	☐	☐	☐	☐	☐
10.	When you receive a document, does it need to be forwarded to another person or department?	☐	☐	☐	☐	☐
11.	Is it likely that you cannot read the document (for example, foreign language, or unknown format)?	☐	☐	☐	☐	☐
12.	If you cannot read a document, would you ask the sender to send another one (vs. throw it in the trash)?	☐	☐	☐	☐	☐

TABLE A2. Paper-Based Communication Process (Part II)
Please, provide approximate numbers. If you are not sure what number to put, make the best guess.

#	Question	Minimum	Most Likely	Maximum
1.	How many times do you usually contact other organizations (the owner, designer, etc.) a day?	_____	_____	_____
2.	How long would you talk on the phone with someone from another organization?	min _____	min _____	min _____
3.	If you did not reach someone by phone at the first time, how long would you wait before you call again? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____
4.	When you need to send a document, how long does it take to prepare the document (for example, print out and get signed), if it is A letter Specifications, reports, etc. An engineering/architectural drawing? Please, circle minutes or hours.	min hrs _____ _____ _____	min hrs _____ _____ _____	min hrs _____ _____ _____
5.	When you need to send a document, how long does it take to approve it (if you do not need to approve it, please, put zero), if it is A letter Specifications, reports, etc. An engineering/architectural drawing? Please, circle minutes or hours.	min hrs _____ _____ _____	min hrs _____ _____ _____	min hrs _____ _____ _____
6.	How long do you have to wait until a document is actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____
7.	How long does it take to forward a document (for example, through the internal mail system)? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____
8.	How long does it take to read a document (which might be a letter, a report, or An engineering/architectural drawing)? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____
9.	If you decide to consult first, how long does it take? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____
10.	How long does it take you to make a decision? Please, circle minutes or hours.	min hrs _____	min hrs _____	min hrs _____

PAPERLESS COMMUNICATIONS
TABLE A3. Paperless Communication Process (Part I)

Please, check the boxes below.
Note: all documents are sent and processed ELECTRONICALLY.

#	Question	No	Not likely	Maybe	Most likely	Yes
1.	If you need to communicate with another organization, would you contact them by phone (vs. contact them electronically)?	☐	☐	☐	☐	☐
2.	If you need to send a document electronically, would you send it through					
	Local network (LAN)	☐	☐	☐	☐	☐
	Secure Internet network (VPN)	☐	☐	☐	☐	☐
	Network between partners (VAN)?	☐	☐	☐	☐	☐
3.	If you have an Information Center that stores and processes all the data, would it go down every time you send information?	☐	☐	☐	☐	☐
4.	If the Information Center is down will the following events happen?					
	Data is recovered/saved	☐	☐	☐	☐	☐
	Data is not saved and you need to send your document again	☐	☐	☐	☐	☐
	All the data is lost	☐	☐	☐	☐	☐
5.	When you receive a document electronically, do you					
	Forward it electronically	☐	☐	☐	☐	☐
	Read and do not forward it	☐	☐	☐	☐	☐
	First print it out, then forward it (because the person it is addressed to does not have a computer)?	☐	☐	☐	☐	☐
6.	When you send a document electronically, does it get lost or sent to the wrong address?	☐	☐	☐	☐	☐
7.	When you receive a document electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	☐	☐	☐	☐	☐
8.	If you cannot read a document, what is the probability that you ask the sender to send another one (vs. delete it)?	☐	☐	☐	☐	☐

TABLE A4. Paperless Communication Process (Part II)

Please, provide approximate numbers. If you are not sure what number to put, make the best guess.
Note: all documents are sent and processed ELECTRONICALLY.

#	Question	Minimum	Most Likely	Maximum
1.	When you need to send a document electronically, how long does it take to prepare one (for example, scan it or copy the file), if it is A letter Specifications, reports, etc. An engineering/architectural drawing?	min hrs _____ _____ _____	min hrs _____ _____ _____	min hrs _____ _____ _____
2.	When you need to send a document electronically, how long does it take to approve it (if you do not need to approve it, put zero), if it is A letter Specifications, reports, etc. An engineering/architectural drawing?	min hrs _____ _____ _____	min hrs _____ _____ _____	min hrs _____ _____ _____
3.	If you send a document electronically, how long would it take to encode the data?	min hrs _____	min hrs _____	min hrs _____
4.	If you decide to consult with somebody else after you receive information electronically from another organization, how long would it take?	min hrs _____	min hrs _____	min hrs _____

APPENDIX B

SURVEY

PAPER-BASED COMMUNICATIONS

TABLE B1. Paper-Based Communication Process (Part I)

Please, check the boxes below.

#	Question	Never	Rarely	Some-times	Often	Always
1.	Do you have partnering organizations (for example, the owner, designers, vendors, etc.) outside the US?	☐	☐	☐	☐	☐
2.	Do you have partnering organizations outside your state?	☐	☐	☐	☐	☐
3.	When you contact a partnering organization, do you use verbal communications (for, example, phone calls or meetings)?	☐	☐	☐	☐	☐
4.	When you contact a partnering organization, do you use written communications (for, example, emails, letters, drawings, etc.)?	☐	☐	☐	☐	☐
5.	When you need to communicate with someone from a partnering organization, do you contact him/her by phone (vs. send a letter, fax, or email)?	☐	☐	☐	☐	☐
6.	When you need to communicate with someone from a partnering organization, do you meet with him/her?	☐	☐	☐	☐	☐
7.	When you need to communicate with someone from a partnering organization, do you participate in a conference session (for, example, phone, video, or web conferences) with him/her?	☐	☐	☐	☐	☐
8.	When you call another organization, do you reach the person you need to talk to at the first time?	☐	☐	☐	☐	☐
9.	When you do not reach the person you need to talk to, do you usually wait and call him/her again?	☐	☐	☐	☐	☐
10.	When you do not reach the person you need to talk to do you usually try to reach him/her by mail, fax, or email?	☐	☐	☐	☐	☐
11.	Do meetings with people from partnering organizations get rescheduled?	☐	☐	☐	☐	☐
12.	Do conference sessions with people from partnering organizations get rescheduled?	☐	☐	☐	☐	☐
13.	Do you send letters to partnering organizations?	☐	☐	☐	☐	☐
14.	Do you send sets of documents like reports and specifications to partnering organizations?	☐	☐	☐	☐	☐
15.	Do you send engineering/architectural drawings to partnering organizations?	☐	☐	☐	☐	☐

TABLE B1. Continued

#	Question	Never	Rarely	Some-times	Often	Always
16.	Do you send letters to your partners via postal mail?	☐	☐	☐	☐	☐
17.	Do you send letters via fax?	☐	☐	☐	☐	☐
18.	Do you send letters via email?	☐	☐	☐	☐	☐
19.	Do you send sets of documents like reports and specifications via postal mail?	☐	☐	☐	☐	☐
20.	Do you send sets of documents via fax?	☐	☐	☐	☐	☐
21.	Do you send sets of documents via email?	☐	☐	☐	☐	☐
22.	Do you send engineering/architectural drawings via postal mail?	☐	☐	☐	☐	☐
23.	Do you send engineering/architectural drawings via fax?	☐	☐	☐	☐	☐
24.	Do you send engineering/architectural drawings via email?	☐	☐	☐	☐	☐
25.	When you send a letter, does it get lost?	☐	☐	☐	☐	☐
26.	When you send a set of documents, does it get lost?	☐	☐	☐	☐	☐
27.	When you send an engineering/architectural drawing, does it get lost?	☐	☐	☐	☐	☐
28.	When you receive a letter, does it need to be forwarded to another person or department?	☐	☐	☐	☐	☐
29.	When you receive a set of documents, does it need to be forwarded to another person or department?	☐	☐	☐	☐	☐
30.	When you receive an engineering/architectural drawing, does it need to be forwarded to another person or department?	☐	☐	☐	☐	☐
31.	After you received a letter from another organization, do you need to consult with someone else before you make a decision?	☐	☐	☐	☐	☐
32.	After you received a set of documents from another organization, do you need to consult with someone else before you make a decision?	☐	☐	☐	☐	☐
33.	After you received an engineering/architectural drawing from another organization, do you need to consult with someone else before you make a decision?	☐	☐	☐	☐	☐
34.	After you received a letter, does it happen to be unreadable (for example, foreign language, or unknown format)?	☐	☐	☐	☐	☐
35.	After you received a set of documents, does it happen to be unreadable?	☐	☐	☐	☐	☐
36.	After you received an engineering/architectural drawing, does it happen to be unreadable?	☐	☐	☐	☐	☐

TABLE B2. Paper-Based Communication Process (Part II)

Please circle numbers below.
Please keep in mind that all the questions are asked about average values.

#	Question	Range				
1.	How many times do you usually contact partnering organizations (for example, the owner, designers, vendors etc.) a day?	<5	5-10	10-15	15-20	>20
2.	When you do not reach someone by phone at the first time, on average how long do you wait before you call again?	<5 min	5-60 min	1-4 hrs	4-8 hrs	>1 day
3.	What is the average length of your phone conversations with someone from a partnering organization?	<5 min	5-10 min	10-15 min	15-20 min	>20 min
4.	What is the average length of your conference sessions (for, example, phone, video, or web conferences)?	<5 min	5-10 min	10-15 min	15-20 min	>20 min
5.	When a conference session has to be rescheduled, on average how long does it take to agree with the involved people about the time of the next session?	<15 min	15-30 min	30-60 min	1-2 hrs	>2 hrs
6.	When the conference session is rescheduled, on average how long do you wait for the next session?	<1 hrs	1-4 hrs	4-8 hrs	1-2 day	>2 day
7.	On average how long does it take you to arrive to a meeting place if it is in the same city?	<15 min	15-30 min	30-60 min	1-2 hrs	>2 hrs
8.	What is the average length of meetings with people form a partnering organization?	<30 min	30-60 min	1-2 hrs	2-4 hrs	>4 hrs
9.	When the meeting has to be rescheduled, on average how long does it take to agree with the involved people about the time of the next meeting?	<1 hrs	1-4 hrs	4-8 hrs	1-2 day	>2 day
10.	When the meeting is rescheduled, on average how long do you wait for the next meeting?	<0.5 day	0.5-1 day	1-2 day	2-4 day	>4 day
11.	On average how long does it take to write a letter to a partnering organization?	<0.5 hrs	0.5-1 hrs	1-2 hrs	2-4 hrs	>4 hrs
12.	How long does it take to create a document like a specification, a report, etc. to send to a partnering organization?	<0.5 day	0.5-1 day	1-2 day	2-4 day	>4 day
13.	How long does it take to create an engineering/architectural drawing?	<0.5 day	0.5-1 day	1-2 day	2-4 day	>4 day
14.	How long does it take to approve a letter that is going to be sent to a partnering organization?	<0.5 hrs	0.5-4 hrs	4-8 hrs	1-2 day	>2 day
15.	How long does it take to approve a document like a specification, a report, etc. to send to a partnering organization?	<2 hrs	2-5 hrs	5-8 hrs	1-5 day	>5 day
16.	How long does it take to approve an engineering/architectural drawing?	<2 hrs	2-5 hrs	5-8 hrs	1-5 day	>5 day

TABLE B2. Continued

#	Question	Range				
17.	How long do you have to wait until a letter gets actually sent (for example, papers are stacked in an "outgoing mail" box and sent/picked up twice a day)?	<1 hrs	1-4 hrs	4-8 hrs	1-2 day	>2 day
18.	How long do you have to wait until a set of documents gets actually sent?	<1 hrs	1-4 min	4-8 hrs	1-2 day	>2 day
19.	How long do you have to wait until engineering/architectural drawings get actually sent?	<1 hrs	1-4 min	4-8 hrs	1-2 day	>2 day
20.	How long does it usually take to forward a letter (for example, through the internal mail system)?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
21.	How long does it usually take to forward a set of documents like specifications, reports, etc.?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
22.	How long does it usually take to forward an engineering/architectural drawing?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
23.	On average how long does it take to read a letter?	<10 min	10-30 min	30-60 min	1-2 hrs	>2 hrs
24.	On average how long does it take to read a set of documents like specifications, reports, etc.?	<1 hrs	1-2 hrs	2-4 hrs	4-8 hrs	>1 day
25.	On average how long does it take to read an engineering/architectural drawing?	<1 hrs	1-2 hrs	2-4 hrs	4-8 hrs	>1 day
26.	How long does it usually take to consult about a letter?	<0.5 hrs	0.5-1 hrs	1-2 hrs	2-4 hrs	>4 hrs
27.	How long does it usually take to consult about a set of documents?	<1 hrs	1-3 hrs	3-6 hrs	6-8 hrs	>1 day
28.	How long does it usually take to consult about an engineering/architectural drawing?	<1 hrs	1-3 hrs	3-6 hrs	6-8 hrs	>1 day
29.	How long does it take you to make a decision about a letter?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
30.	How long does it take you to make a decision about a set of documents?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
31.	How long does it take you to make a decision about an engineering/architectural drawing?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day

PAPERLESS COMMUNICATIONS
TABLE B3. Paperless Communication Process (Part I)

Please, check the boxes below.
Note: all documents are sent and processed ELECTRONICALLY.

#	Question	Never	Rarely	Some-times	Often	Always
1.	If you need to send a letter electronically, do you send it through a Local network (LAN)?	☐	☐	☐	☐	☐
2.	If you need to send a set of documents electronically, do you send it through a Local network (LAN)?	☐	☐	☐	☐	☐
3.	If you need to send engineering/architectural drawings electronically, do you send them through a Local network (LAN)?	☐	☐	☐	☐	☐
4.	If you need to send a letter electronically, do you send it through a secure Internet network (VPN)?	☐	☐	☐	☐	☐
5.	If you need to send a set of documents electronically, do you send it through a secure Internet network (VPN)?	☐	☐	☐	☐	☐
6.	If you need to send engineering/architectural drawings electronically, do you send them through a secure Internet network (VPN)?	☐	☐	☐	☐	☐
7.	If you need to send a letter electronically, do you send it through a network between partners (VAN)?	☐	☐	☐	☐	☐
8.	If you need to send a set of documents electronically, do you send it through a network between partners (VAN)?	☐	☐	☐	☐	☐
9.	If you need to send engineering/architectural drawings electronically, do you send them through a network between partners (VAN)?	☐	☐	☐	☐	☐
10.	If you have an Information Center that stores, sends, and processes all the data, does it stop functioning when you send information?	☐	☐	☐	☐	☐
11.	If the Information Center stops functioning, do your data get lost?	☐	☐	☐	☐	☐
12.	If the Information Center stops functioning does it save/recover your data automatically?	☐	☐	☐	☐	☐
13.	If the data is not saved in the Information Center when it stops functioning, do you need to send the data again?	☐	☐	☐	☐	☐
14.	When you send a letter electronically, does it get lost?	☐	☐	☐	☐	☐
15.	When you send a set of documents electronically, does it get lost?	☐	☐	☐	☐	☐

TABLE B3. Continued

#	Question	Never	Rarely	Some-times	Often	Always
16.	When you send an engineering/architectural drawing electronically, does it get lost or sent to the wrong address?	□	□	□	□	□
17.	When you receive a letter electronically, are you the final addressee?	□	□	□	□	□
18.	When you receive a set of documents electronically, are you the final addressee?	□	□	□	□	□
19.	When you receive an engineering/architectural drawing electronically, are you the final addressee?	□	□	□	□	□
20.	When you receive a letter electronically, do you need to forward it electronically to another person or department?	□	□	□	□	□
21.	When you receive a set of documents electronically, do you need to forward it electronically to another person or department?	□	□	□	□	□
22.	When you receive an engineering/architectural drawing electronically, do you need to forward it electronically to another person or department?	□	□	□	□	□
23.	When you receive a letter electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	□	□	□	□	□
24.	When you receive a set of documents electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	□	□	□	□	□
25.	When you receive an engineering/architectural drawing electronically, do you need to print and forward it, since the final addressee cannot receive it electronically?	□	□	□	□	□
26.	When you receive a letter electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	□	□	□	□	□
27.	When you receive a set of documents electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	□	□	□	□	□
28.	When you receive an engineering/architectural drawing electronically, is it likely that you cannot read it (for example, because of an incompatible format)?	□	□	□	□	□

TABLE B4. Paperless Communication Process (Part II)

Please, circle numbers below.
Note: all documents are sent and processed ELECTRONICALLY.
Please keep in mind that all the questions are asked about average values.

#	Question	Range				
1.	When you need to send a letter electronically, how long does it take to approve it?	<15 min	15-60 min	1-4 hrs	4-8 hrs	>1 day
2.	When you need to send a set of documents electronically, how long does it take to approve it?	<60 min	1-4 hrs	4-8 hrs	1-2 day	>2 day
3.	When you need to send an engineering/architectural drawing electronically, how long does it take to approve it?	<60 min	1-4 hrs	4-8 hrs	1-2 day	>2 day
4.	When you send a letter electronically, how long does it take to encode the data?	<5 min	5-30 min	30-60 min	1-3 hrs	>3 hrs
5.	When you send a set of documents electronically, how long does it take to encode the data?	<5 min	5-30 min	30-60 min	1-3 hrs	>3 hrs
6.	When you send an engineering/architectural drawing electronically, how long does it take to encode the data?	<5 min	5-30 min	30-60 min	1-3 hrs	>3 hrs
7.	How long does it take to consult electronically about a letter?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
8.	How long does it take to consult electronically about a set of documents?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day
9.	How long does it take to consult electronically about an engineering/architectural drawing?	<10 min	10-60 min	1-4 hrs	4-8 hrs	>1 day

EXPERIENCE DATA
TABLE B5. Past Experience Information

Please, circle options below.

#	Question	Range/Area				
1.	How many years of experience do you have?	<0.5 years	0.5-1 years	1-5 years	5-10 years	>10 years
2.	What areas (can be more than one) have you worked in?	Planning/ Cost Est.	Design	Procure	Construct	Project Mgmt

FEEDBACK

If you have any comments/suggestions about this questionnaire, please provide them here:

APPENDIX C

SURVEY RESULTS

TABLE C1. Answers for the questions in TABLE B1

#	Answers																							
1	3	3	2	3	2	4	2	5	3	2	3	4	2	1	3	4	1	2	1	4	1	1	1	-
2	2	5	4	3	4	1	2	5	3	3	4	3	2	3	3	4	1	4	3	3	2	1	2	-
3	5	4	4	4	2	4	5	4	4	4	4	3	4	3	5	5	1	4	4	4	4	1	3	3
4	3	4	4	2	3	5	4	4	4	4	4	3	4	4	5	5	1	3	4	4	2	1	3	4
5	4	4	4	2	2	4	5	4	4	4	3	3	4	3	5	5	1	3	3	3	5	1	3	5
6	3	4	3	3	4	4	2	4	4	3	3	3	3	2	4	5	1	2	2	3	2	1	2	3
7	3	4	3	4	3	5	2	4	3	3	2	3	3	1	3	5	1	2	3	3	1	1	2	2
8	3	2	4	3	3	5	2	2	3	2	2	3	3	2	2	4	1	3	4	4	3	4	2	2
9	4	3	3	2	2	3	3	5	4	3	3	3	3	4	4	4	5	5	4	4	3	3	2	4
10	5	3	4	3	5	4	4	4	3	4	4	3	4	3	4	2	5	4	3	4	4	4	3	4
11	3	4	4	2	5	5	2	3	4	4	3	3	3	2	4	3	1	2	3	4	4	1	2	4
12	3	1	4	3	5	5	2	3	4	4	3	3	3	2	4	3	1	2	3	3	3	1	2	2
13	3	4	3	2	5	5	4	5	3	4	3	3	3	2	4	2	1	3	3	5	2	1	3	4
14	3	4	3	3	5	4	4	5	3	5	4	3	3	3	5	5	1	3	2	5	4	1	2	5
15	3	4	3	2	3	3	4	5	5	5	4	3	3	4	4	5	1	3	2	4	4	1	1	5
16	3	2	4	2	4	1	3	1	5	2	3	3	1	4	3	2	1	3	3	3	2	3	3	-
17	4	3	4	3	4	3	4	4	5	4	3	4	3	4	4	4	3	3	4	4	3	3	3	4
18	3	4	4	2	4	4	2	4	4	3	4	3	3	4	4	3	5	4	4	4	4	3	2	3
19	4	2	3	2	3	3	2	1	3	5	4	3	3	2	3	2	3	5	3	4	3	4	2	-
20	3	2	3	4	4	2	1	2	4	2	3	1	3	3	2	2	3	3	3	4	4	4	3	1	5
21	3	2	3	4	4	3	1	2	4	1	3	2	2	3	4	2	4	2	4	3	4	3	1	4
22	2	2	3	3	2	3	3	1	4	5	4	3	1	4	4	2	1	4	3	4	4	3	2	3
23	2	2	2	3	2	4	1	2	4	1	3	1	4	1	2	3	3	2	3	4	3	2	1	2
24	1	2	2	3	3	3	1	2	3	1	2	1	4	3	4	3	1	2	2	4	3	3	1	4
25	2	2	2	4	1	3	2	3	2	2	2	2	3	3	2	1	1	2	2	3	1	2	1	2
26	2	2	1	3	-	3	1	3	2	2	2	2	2	3	3	1	1	3	2	3	1	2	1	2
27	2	2	1	4	-	4	1	3	2	2	2	2	2	3	3	1	1	3	2	2	1	2	1	2
28	4	2	3	3	-	2	2	4	2	3	2	2	4	2	4	3	3	3	3	4	3	3	2	5
29	3	2	4	2	2	3	2	4	2	3	2	3	4	2	4	3	3	3	3	3	3	3	1	5
30	4	1	3	2	3	4	2	4	2	3	3	3	3	2	4	2	1	3	3	3	3	3	1	3
31	3	2	3	3	2	2	4	4	3	3	2	3	4	3	4	3	4	4	4	3	4	3	2	3
32	4	2	4	4	2	3	4	4	3	3	3	3	5	3	4	3	4	4	4	3	5	3	1	3
33	4	2	4	3	4	4	4	4	2	3	3	3	4	3	4	3	4	4	3	2	5	3	1	3
34	2	2	4	4	1	3	1	4	3	2	2	3	4	1	4	2	1	1	2	2	2	3	1	2
35	2	2	4	3	2	3	2	4	3	2	2	3	3	1	4	2	1	2	2	3	3	3	1	1
36	2	2	4	3	2	4	3	4	3	2	2	3	3	1	4	1	1	3	2	3	3	3	1	1

TABLE C2. Answers for the questions in TABLE B2*

#	Answers																								
1	2	1	1	2	2	4	1	2	3	2	2	2	1	3	-	1	2	2	1	2	1	2	1	3
2	2	2	1	3	3	3	3	2	2	2	3	3	2	2	-	3	1	2	2	3	3	5	3	3
3	3	1	3	3	2	2	2	3	5	2	2	2	3	3	-	4	2	2	1	3	4	2	1	2
4	5	1	3	2	3	5	2	5	2	5	5	1	-	3	-	5	5	4	3	4	1	5	2	5
5	2	3	2	2	2	3	1	5	2	1	5	1	5	2	-	1	3	5	3	3	1	5	1	5
6	5	4	1	2	4	3	4	5	4	1	4	2	3	4	-	3	1	4	4	4	4	5	5	5
7	4	3	2	2	2	2	3	4	4	3	3	2	2	3	-	1	2	3	3	3	2	4	1	3
8	3	5	3	2	3	3	2	5	5	3	2	2	2	3	-	4	2	2	1	3	2	3	2	2
9	2	3	1	2	2	4	4	5	4	1	4	3	3	2	-	1	1	3	1	5	1	4	1	1
10	4	2	4	2	4	2	3	5	3	3	4	2	3	3	-	2	1	3	3	3	3	3	4	4
11	2	1	2	3	3	4	1	3	3	3	3	3	3	2	-	1	1	1	1	2	2	2	2	1
12	3	3	4	2	2	3	1	5	2	5	4	2	3	4	-	3	1	4	2	3	3	3	1	4
13	4	5	5	2	4	4	5	5	5	5	5	3	3	4	-	2	1	4	3	3	4	3	-	3
14	4	1	3	2	4	3	1	3	4	3	4	3	3	4	-	1	1	4	2	4	2	1	1	2
15	4	1	4	2	2	2	3	5	3	5	4	3	4	4	-	1	1	4	2	4	2	1	1	4
16	5	1	4	3	3	3	3	4	4	4	5	3	5	4	-	1	1	4	2	4	3	1	-	4
17	4	3	2	2	2	2	3	3	3	4	3	2	3	3	-	3	2	2	3	3	1	2	2	3
18	4	3	3	2	4	4	3	3	4	4	3	3	3	3	-	3	2	3	3	3	3	3	2	3
19	4	3	3	-	3	3	3	3	3	4	3	2	3	3	-	3	2	4	3	4	3	3	-	3
20	4	2	4	1	2	2	3	3	4	5	1	3	2	5	-	3	1	2	2	3	1	3	1	2
21	3	3	5	2	4	3	4	4	3	5	1	2	3	4	-	3	1	2	2	3	1	3	1	2
22	4	2	5	2	4	2	3	4	2	5	1	3	1	4	-	3	1	2	3	2	1	3	-	2
23	2	1	2	2	4	3	1	2	3	2	2	3	1	1	-	1	1	1	2	3	2	3	1	1
24	3	2	4	2	3	4	3	5	2	5	3	3	2	2	-	1	1	5	2	3	3	3	1	4
25	4	1	4	2	3	5	3	5	3	5	3	3	2	2	-	2	1	4	2	4	4	3	-	1
26	1	1	2	1	3	3	1	3	2	3	3	3	3	4	-	1	1	5	1	3	2	2	1	2
27	2	1	4	2	4	2	2	4	3	3	3	2	5	2	-	2	2	5	2	2	3	1	1	3
28	3	1	4	2	2	3	2	4	3	3	3	1	5	3	-	1	1	5	2	2	3	1	-	2
29	2	1	3	1	3	4	2	5	3	2	5	3	5	5	-	2	2	4	1	3	2	2	1	2
30	3	1	4	2	1	3	2	5	2	2	5	2	5	5	-	4	2	5	1	2	3	2	1	2
31	4	1	4	2	3	2	2	5	3	2	5	1	5	5	-	4	2	5	2	3	3	2	-	2

* "-" denotes N/A

TABLE C3. Answers for the questions in TABLE B3

#	Answers																								
1	5	3	4	1	2	2	3	5	1	3	5	2	2	5	-	1	5	2	4	3	3	3	-	-
2	5	3	4	2	3	4	1	2	2	3	5	2	2	5	-	1	4	2	4	2	3	3	-	-
3	5	3	4	3	2	3	1	2	2	3	5	3	2	5	-	1	1	2	3	2	3	3	-	-
4	4	3	4	2	4	2	3	3	3	3	3	3	1	1	-	1	1	3	4	3	4	3	-	-
5	4	3	4	2	3	3	1	2	2	3	3	3	1	1	-	1	1	3	4	3	4	3	-	-
6	4	3	4	2	2	3	1	2	3	3	3	3	1	1	-	1	1	3	3	3	4	3	-	-
7	3	3	4	2	4	2	3	1	2	3	2	3	1	1	-	1	1	3	4	2	2	3	-	-
8	3	3	3	2	3	3	1	1	3	4	2	3	1	1	-	1	1	4	4	2	2	3	-	-
9	3	3	3	3	2	4	1	1	3	4	2	2	1	1	-	1	1	4	3	2	2	3	-	-
10	3	3	2	2	4	3	-	1	3	-	3	2	1	1	-	2	1	1	3	2	1	1	-	-
11	3	3	2	3	3	2	-	1	3	-	1	2	1	1	-	2	1	1	2	2	1	2	-	-
12	3	3	2	2	2	3	-	5	2	-	1	2	1	1	-	4	5	4	4	4	1	1	-	-
13	3	3	3	3	4	4	-	4	2	-	5	3	1	1	-	5	5	4	4	3	2	2	-	-
14	2	3	2	4	1	3	1	2	2	2	2	3	1	1	-	1	1	1	2	3	2	1	2	-
15	2	3	2	3	3	2	1	2	2	2	2	3	1	1	-	1	1	1	2	2	2	1	2	-
16	2	2	2	3	2	1	1	2	1	2	2	3	1	1	-	1	1	2	2	4	2	1	1	-
17	4	4	3	3	3	4	4	4	2	3	3	3	1	5	-	4	5	3	3	3	3	3	4	-
18	3	4	3	3	2	3	4	4	3	3	3	3	1	5	-	4	5	3	3	4	3	3	4	-
19	2	4	3	4	4	2	4	4	3	3	3	3	1	5	-	4	-	3	2	3	3	3	-	-
20	4	4	2	3	2	4	2	4	3	3	3	3	1	2	-	2	1	4	3	3	4	3	2	-
21	3	4	2	3	4	3	2	4	2	3	3	3	1	2	-	2	1	4	3	3	4	3	2	-
22	3	4	2	3	4	2	2	4	3	3	3	3	1	2	-	2	-	4	2	2	4	3	-	-
23	2	4	3	2	3	3	2	2	2	2	3	3	1	1	-	1	1	2	2	2	4	3	3	-
24	4	4	3	3	2	4	2	2	2	2	3	3	1	1	-	1	1	2	2	3	4	3	3	-
25	5	4	3	3	4	3	2	2	2	2	3	3	1	1	-	1	-	2	2	2	4	3	-	-
26	2	2	3	3	2	3	1	3	3	3	3	3	1	1	-	3	1	3	2	2	3	3	2	-
27	2	2	3	3	4	2	3	3	2	3	3	3	1	1	-	3	1	3	3	3	3	3	2	-
28	4	2	3	3	2	3	3	3	3	3	3	3	1	1	-	3	-	4	3	4	3	3	-	-

TABLE C4. Answers for the questions in TABLE B4

#	Answers																								
1	1	1	2	2	3	2	1	3	5	3	2	1	-	1	-	1	1	2	1	3	2	3	1	-
2	2	1	3	3	4	3	2	5	4	3	3	1	-	1	-	1	1	2	2	2	2	2	1	-
3	3	1	3	2	2	2	2	5	-	3	3	2	-	1	-	1	-	2	2	3	3	2	-	-
4	1	1	4	2	3	4	1	1	3	2	1	2	-	1	-	1	-	4	1	4	1	3	2	-
5	1	1	4	3	-	3	1	1	3	2	2	2	-	1	-	1	-	4	2	3	1	3	3	-
6	2	1	4	2	4	3	1	2	3	2	2	2	-	1	-	1	-	5	2	4	1	3	-	-
7	1	1	4	3	3	2	2	5	2	2	3	2	-	1	-	1	2	2	1	3	2	2	1	-
8	2	1	4	3	4	4	5	5	3	2	3	3	-	1	-	3	2	2	1	4	2	2	1	-
9	4	1	4	2	1	4	5	5	4	2	3	4	-	1	-	3	-	2	2	3	2	2	-	-

TABLE C5. Answers for the questions in TABLE B5**

#	Answers																								
1	5	5	1	3	3	3	3	3	5	4	2	3	2	-	4	3	1	1	3	3	3	4	3	
2	1	1	4	-	1	5	1	1	5	5	1	1	1	5	-	2	4	2	1	1	2	3	2	1
2	2	2	-	-	5	-	2	2	-	-	2	-	4	-	-	-	5	-	4	3	-	-	4	4
2	3	3	-	-	-	-	4	4	-	-	3	-	-	-	-	-	-	-	5	4	-	-	-	5
2	4	4	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	5	-	-	-	-
2	5	5	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	-

** More than one answer was acceptable for the question #2.

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