Workflow and Cooperative Problem Solving in Civil Infrastructure Management

P. M. Jones[1], N. S. Contractor[2], and B. J. O'Keefe[2]
University of Illinois at Urbana-Champaign
[1]Dept. of Mechanical and Industrial Engineering, 1206 W. Green St. Urbana IL 61801
[2]Dept. of Speech Communication, 702 S. Wright St. Champaign IL 61820

S. C-Y. Lu
University of Southern California
IMPACT Laboratory, Los Angeles, California 90089-1450

M. Case, P. Lawrence, and F. Grobler
U. S. Army Construction Engineering Research Laboratories
Planning and Management Laboratory, P.O. Box 9005, Champaign IL 61826-9005

ABSTRACT. The goals of Project CITY (Civil Infostructure TechnologY) are to provide a technology demonstration of information infrastructure for civil infrastructure management and to demonstrate the Team Engineering Analysis and Modeling (TEAM) methodology in the analysis, design, and evaluation of that information infrastructure. The community of practice of Project CITY is the Public Works Division at a major Army installation. This paper focuses on three concurrent aspects of the project: 1) Task analyses and knowledge requirements of the community; 2) Systematic surveys of the community with respect to inter-dependence,workflow, coordination, and technology use; and 3) Candidate technologies for coordination and information sharing in distributed systems (e.g., SWIFT, ACE, and ISAM).

I. INTRODUCTION

The management of civil infrastructure systems is a complex process that involves distributed decision making and negotiation among people with heterogeneous agendas, activities, and expertise. Project CITY (Civil Infostructure TechnologY) is a research project intended to support and facilitate public works activities (within the Public Works Division of a major Army installation) via collaborative information technology. The Team Engineering Analysis and Modeling (TEAM) methodology is applied systematically to the study of individual work practices, group meetings, and organizational communication and workflow (Case et al., 1992; Jones et al., 1994). The methodology in turn informs the choice of scenarios and requirements for technology demonstration prototypes.

Thus far, the TEAM method has focused on (1) systematic surveys of communication and workflow networks and attitudes and use of current technology and (2) fieldwork that has included informal interviews, "shadowing" various members of the organization, attending meetings, and collecting documentation and artifacts used in the work. These complementary methods have been effective forms of "triangulation" in data collection; findings in one method are reinforced and corroborated by the other.

In this paper we describe results of our first two months of data collection: an emerging picture of organizational communication and activity relationships with insights into requirements for a "first wave" technology demonstration.

II. INITIAL SCENARIO: WORK REQUESTS

The first example of the mutual reinforcement of the fieldwork and survey efforts is the choice of scenario to guide the initial technology demonstration. Both efforts indicated strongly that handling work requests (i.e., the reception and processing of "4283s") was the most prominent and wide-spanning field of activity. 4283s were the most frequently encountered object of work in our field data and was the form that the most people "touch" according to the survey data.

The 4283 is a standard Department of the Army form that defines a "work request", defined as the need for construction, repair, and/or maintenance activity that requires more than 40 hours of work or over $1000 (DEH TN 420-10-01). As shown in Figure 1, when received by the PWD, the 4283 states the requester of the work, a brief work description, and the consequences if the work is not done. Within the PWD, a routing slip (a local form 167, "Record of Action for a 4283") is attached to the form. As the 4283 moves throughout the organization, it "gets heavier" -- it acquires annotations and attached information such as cost estimates and design drawings.

DEH TN 420-10-01 defines the nominal handling of a 4283. Not surprisingly, in actual practice we find a number of interesting deviations from this process. This "as-is" process is described below.

FACILITIES ENGINEERING WORK REQUEST

DOCUMENT NUMBER — REQ ID SERIAL # FY TYPE
BLDG/FACILITY — NUMBER SUFFIX
DATE — YR MO DA

SHORT JOB DESCRIPTION

DESCRIPTION AND JUSTIFICATION FOR THE WORK TO BE ACCOMPLISHED

DESCRIBE WHAT WILL HAPPEN IF WORK IS NOT ACCOMPLISHED

REQUESTER INFORMATION — NAME, ORG, TELEPHONE, SIGNATURE
PERSON TO CALL FOR ADDITIONAL INFO — NAME, ORG, TELEPHONE

FORWARD FOR APPROVAL
slots for To:, From:, Date, Recommended Action (Approve, Disapprove), Environmental Impact, Estimated Cost, (classification of) Work To Be Performed

APPROVED FOR DESIGN
slots for Signature, Date, Source Of Funds, and Remarks

APPROVAL ACTION
slots for Document Number, Action Taken (Approved, Disapproved), Date, Signature of Approval Authority, Forwarded To:

Figure 1. Sketch of the general layout and information required for DA Form 4283. The Environmental Impact section is three "Yes/No" checkbox items: Environmental Consideration, EIS/EIA Initiated, and EIS/EIA Approved. EIS is Environmental Impact Statement; EIA is Environmental Impact Assessment. Both of these are serious long-term processes; normally, simply a Record of Environmental Consideration (REC) is done by the Environmental office at the installation. The Estimated Cost section has five spaces for putting in dollar amounts: Funded, WC [Work Category] K, WC L, WC, and Unfunded, and Total. K work is maintenance and repair; L work is new construction. The Work To Be Performed has four checkbox items: In-house, Self-help, Contract, and Troop.

A. Fieldwork: Abstraction Hierarchy and IDEF Descriptions

Based on informal interviews, observation, and analysis of documentation collected from the PWD, we have constructed several representations of the current structure of the work organization. An obvious starting point is the organization chart itself; a simplified sketch of it as of April 1995 is shown in Figure 2.

Our first effort to obtain "the big picture" of the PWD utilized Rasmussen's work domain analysis technique to derive an abstraction hierarchy [5]. The abstraction hierarchy provides a means-ends description of why the organization functions as it does and how it carries out those functions. For example, the overall goal of "Engineer Resources Management" can be described by a collection of abstraction functions that include the Real Property Maintenance Activity, Work Management, Environmental Compliance, and Energy Conservation.

More specific to questions of workflow for handling of a 4283 is the IDEF representation. IDEF is a standard notation for processes that focuses on activities and their inputs, controls (e.g., regulations), mechanisms (e.g., manpower, computers), and outputs. Briefly, this analysis shows that the 4283 process is to some extent circular and involves a high degree of on-the-fly contingent decision making.

- DIRECTORATE OF PUBLIC WORKS
  - ENVIRONMENTAL OFFICE
  - PUBLIC WORKS DIVISION (PWD)
    - ENGINEERING PLANS & SERVICES
      - Master Planner
      - Real Property
      - Space Management
      - Architects/Engineers
      - Inspectors
      - CAD Technicians
    - FACILITIES MANAGEMENT
      - Energy and Utilties Manager
      - BUSINESS MANAGEMENT
        - IFS-M System Administration
        - EMCS
        - Production Control
      - CONTRACT SURVEILLANCE
        - Inspectors
    - HOUSING

Figure 2. Simplified sketch of the organization of the Directorate of Public Works, which includes the Public Works Division (PWD), the focus of our study.

In particular, the following is a rough verbal description of the 4283 process:

1. Certain designated persons on the installation submit a 4283 to the PWD (the PWD can also generate these themselves).
2. The Production Controller enters this information into the IFS-M database and often makes preliminary decisions about where it should go (e.g., the project requires input from Safety or Environmental). This decision is sometimes made in consultation with the Business Manager and Desk Estimator, though at times the Desk Estimator re-routes the 4283 himself before performing the preliminary estimate. At this point, the decision is made as to how the work would be accomplished, i.e. through the Base Contractor or the Job Order Contractor (JOC). If the 4283 does go to these places, it cycles back to Production Control.
3. Production Control passes the 4283 to the Desk Estimator for a preliminary or "desk" cost estimate. In doing so, the 4283 may turn into another type of project (i.e., if less than $1000 or 40 hours of work, will become a 4287; if a major construction project, will become a 1391). The 4283 comes back to Production Control.
4. When it is JOC work, the Desk Estimator sends the 4283 to the Engineering Plans & Services branch for preliminary design and a detailed estimate (which includes the use of CAD tools, standard tables for costs, etc.). The 4283 then comes back to Production Control.
5. After "prescreening" by the Business Manager and possibly others, some 4283s may be put on hold or disapproved.
6. Approved 4283s are either executed by the Base Contractor (maintenance and repair work under $25,000), the Job Order Contractor (design work between $25,000 and $125,000) or go out for bid (over $125,000). From there, a set of new records are used to keep track of the work actually being done, billing, etc. The IFS-M database is used for contract administration and work status reporting functions.

B. Communication and Workflow Surveys

A second major outcome of the TEAM methodology is ongoing social network analysis. Based on survey data collected in March and May 1995, a network map is being constructed to indicate the extent to which personnel in PWD interact with each other on task related matters. Sixty-five people (a 100% response rate) in the PWD were interviewed to obtain data on task-related interactions within the PWD and with units outside the PWD. The analysis of this network data indicates (i) the extent of task interdependence among PWD personnel, (ii) the existence of relatively autonomous cliques (or subgroups) in the work flow, (iii) the criticality (or alternatively, the redundancy) of individuals who serve as liaisons in the workflow, as well as (iv) the presence of individuals who are either isolated or overloaded. This information serves as a diagnostic tool in considerations about re-configuring the workflow and in the design and specification of information-sharing and collaboration tools among the PWD personnel. Figure 3 illustrates one result of the communication network surveys.

Furthermore, two PWD-specific surveys were conducted in May: one on workflow organized around the standard records used by the PWD and the other on attitudes and use of technologies in the PWD. These surveys will provide insights into the details of workflow organized into substantive categories that are already relevant to the community, with additional information on what kinds of technological support are already in use. Appendix 1 shows portions of the survey instruments used to elicit these data.

C. Analysis of IFS-M Database Records

The Integrated Facility Systems-Mini/Micro (IFS-M) is a centralized database structure defined by the Army. The installation has a UNISYS 5000 machine for the management and maintenance of its own IFS-M records. IFS-M is tremendously complex; some of its modules include Real Property, Customer Service, Work Estimation, and Contract Administration. It is intended to be the central repository for information related to the management and tracking of work for organizations such as the PWD.

The local IFS-M records are useful because much of the work status history is recorded there (usually by the Production Controller). This representation is only partial, however; for example, within the Engineering Plans and Services branch, a 4283 may be routed to several engineers for comments and design, but in IFS-M only its duration within that branch is recorded.

We have obtained work status history data on all 4283s for October 1994 and May 1 - June 14, 1995. Some preliminary data are shown in Table 1. One prominent point to note is the Production Controller's ubiquitous presence, largely due to the practice of routing 4283s back to him at every stage of the process so that he can enter the work status history updates into IFS-M.

Table 1. Most common work status codes in IFS-M work history data set (868 projects, 5815 total work status history items)

Work Status Code	**Frequency**
PC (Production Control)	1717
CS (Customer Service)	496
APV (Approved)	479
CA (Contract Awarded)	432
CDE (Completed Detailed Estimate)	429
CMP (Complete)	397
Other	1865
Total	5815

D. Additional Findings

Based on the fieldwork and surveys, we have identified a number of issues related to the 4283. Some units felt that their input was needed earlier in the process and that sometimes they were ignored altogether. Many members of the community described, and we observed, the great deal of work that was necessary to obtain a sufficiently detailed and correct scope of work. Issues related to funding (especially if a reimbursable customer tries to avoid paying) were also important. Also, it should be noted that there is greater fluidity in characterizing work than might be supposed at first. Some projects start as service orders (4287s) and become work requests (4283s); some evolve in the opposite direction, and some are not defined formally at all until a fair amount of work on design and estimation has been done. Finally, while IFS-M itself provides a centralized representation which could be used to support collaboration directly, its complexity, difficulty of use, and lack of integration with other work activities have led to its disuse among several parts of the PWD. These sub-communities have instead evolved their own activity tracking mechanisms that rely largely on simple word processing and local database systems.

III. ISSUES AND REQUIREMENTS

As described in the previous section, the 4283 is a relatively impoverished form of communication among members of the PWD. Drawings, cost estimates, and other relevant information are attached to the 4283 as it moves through the organization. Telephone calls and memos are exchanged to articulate requirements, elaborate upon scope of work, and negotiate on the actual accomplishment of the work. As noted above, another issue is some groups being "left out" of the process.

Based on our analysis and on explicit ideas generated by members of the PWD, the following specific requirements appear justified: (1) Free-form annotation of electronic 4283s; (2) Attachment of CAD drawings, spreadsheet cost estimates, and other supporting documentation to 4283s; (3) Integration with email; (4) Ability to generate Gantt chart pictures of current projects divided into various classifications (e.g., by customer, by type of work (new construction or maintenance and repair)), (5) Ability to "announce" projects and seek feedback from the community at large. Currently, the latter function is largely handled in group meetings.

IV. COLLABORATIVE TECHNOLOGY INFRASTRUCTURE: CANDIDATES AND DEMONSTRATION PROTOTYPE

A. SWIFT

The System Workbench for Integrating and Facilitating Teams (SWIFT) is a collaboration infrastructure that assumes a tightly-coupled interaction among team members. It supports rich and detailed reasoning in the context of an object-oriented database.

B. ACE/CPACE

ACE (Agent Collaboration Environment) is a Lisp-based software program that is based on the Discourse Model of collaboration [1]. CPACE is a C++ reimplementation of most of the ACE functionality. The underlying model of collaboration in both systems is the sharing of interests among (software) agents and the automatic notification to the appropriate agents that relevant interests have changed in the world. The conceptual model of user-system interaction is that the user defines a collection of agents, where each agent performs a certain task as defined by its checklist(s).

C. ISAM

ISAM (Intelligent Support for Activity Management) is a blackboard architecture that provides an infrastructure for intelligent associate support [3,4].. The abstractions in ISAM are somewhat similar to those in ACE/CPACE; in particular, both emphasize activity: ISAM with Activity objects which can be hierarchically related (and also related by pre- and post-conditions) and ACE with checklists. ISAM also explicitly models Artifact, Information, and Systems objects.

D. First Technology Demonstration

The overall vision of our ultimate technology demonstration is "an ocean of ACE with islands of SWIFT". That is, our survey and field data suggest that overall, the PWD is fairly loosely coupled but that "cliques" of tightly-coupled interaction exist. Thus, overall we view ACE's model of collaboration as dominant, with subsets of people being supported with SWIFT-like functionality.

Our first demonstration focuses on 4283 processing. Given the previous discussion of requirements, it will include the ability to electronically view, annotate, and attach other media to a 4283, provide overall project status information in Gantt-chart formats, and will allow the representation and sharing of interests throughout the community. This demonstration uses ISAM as a front-end to the ACE environment; the abstractions in ISAM more naturally match the conceptual models of everyday work, and ISAM's C++ development can be viewed as contributing to CPACE evolution. This system will communicate with IFS-M; it is hoped that by supporting the work context directly and allowing IFS-M updates to be a natural side-effect of work, that we can best make use of central representations without "reinventing the wheel".

V. ACKNOWLEDGMENTS

This research is funded by Grant No. ECS94-22730 from the National Science Foundation. We gratefully acknowledge the assistance of the members of the PWD.

VI. REFERENCES

[1] Case, M. (1994). The discourse model for collaborative engineering design: A distributed and

asynchronous approach. PhD Dissertation, Department of Mechanical and Industrial Engineering, UIUC.
[2] DEH Resources Management System Handbook, TN 420-10-01, 1 November 1991.
[3] Jasek, C. A. (1995). Cooperative support for supervisory control: Aiding flight operations teams in satellite ground control. MS Thesis, Department of Mechanical and Industrial Engineering, UIUC.
[4] Jones, P. M. (1995). Cooperative work in mission operations: Analysis and implications for computer support. To appear in *Computer-Supported Cooperative Work: An International Journal.*
[5] Rasmussen, J., Pejtersen, A. and Goodstein, L. (1994). *Cognitive systems engineering*. NY: Wiley.

APPENDIX 1

Questions from the 4283 Workflow Survey

2.1. My work results in the need for a DA 4283 (Y/N)
2.2. If yes, how often per week or month does your work result in the need for a DA 4283?
3.1. In my work, I have initiated a DA 4283 (Y/N)
3.2. If yes, how often per week or month have you initiated a DA 4283?
3.3. Who prompted you to initiate a DA 4283? Select all that apply. [coworker, supervisor, outside client, outside contractor, myself, other]
4.1. I work on collecting information that appears in a DA 4283. (Y/N)
4.2. I work on entering information that appears in a DA 4283. (Y/N)
4.3. If yes to either of the above two questions, please respond to the questions below:

Who do you contact to collect this info?
How long does it take to collect this info?
What sources do you consult to collect this information? [books, databases, government document, manuals, memory, other]
What media do you use to collect this info? [phone, memo, personal meeting, group meeting, computers]
What media do you use to enter this info? [paper, electronic]
How frequently do you collect this info? (/week or /month) enter this info? (/week or /month)

5.1. My work involves managing the routing of the DA 4283: (Y/N)
5.2. My work involves managing the completion of the DA 4283: (Y/N)
5.3. My work contributes to the completion of the DA 4283: (Y/N)
5.4. I make decisions about the following:
a) Tracking/Monitoring of the DA 4283. Y/N
b) Routing of the DA 4283. Y/N
c) Completion of/Resolution of the DA 4283. Y/N
d) When or if to do the job described in the DA 4283. Y/N
5.5. Who do you get the DA 4283 from:
5.6. Who do you give the DA 4283 to:
[see attached roster]

The Major Question from the Communication Network Survey

We would like to learn more about your existing task communication patterns in PWD. Attachment A is a roster of employees in the PWD. As you look over the list, identify those with whom you have had some work-related communication so far this year. In each case, estimate the average number of <u>hours per week</u> you communicated with these individuals. *Communication includes conversations in person, in meetings, by phone, via electronic mail, or by memoranda.*

Selected Questions from the Technology Use and Attitudes Surveys

(level of agreement questions use standard 7-point Likert scale]

A. When did you first use this computer software program (month/year)?
B. How much time do you spend using this computer software program in an average week?
C. For this computer software program, please indicate your level of agreement with the following statements:

The information from this program is always accurate.
The information I receive from this program is complete.
I could not get along without the use of this program.
This program tends to overload me with information.
The information contained in the program is reliable.

D. Please indicate your level of agreement with the following statements: "I would use this computer software program more often than I do today if..."

I had more training.
The quality of training was improved.
My supervisor required that I use it.
My co-workers use it.
Using it would improve the quality of my work.
The information it provided was more accurate.
It were easier to understand.
The documentation for the program was better.

IV.A. Please indicate your level of agreement with the following statements:

My supervisor thinks that this program is worth the time and effort required to use it.
The opinions of my co-workers influence how I think about this program.

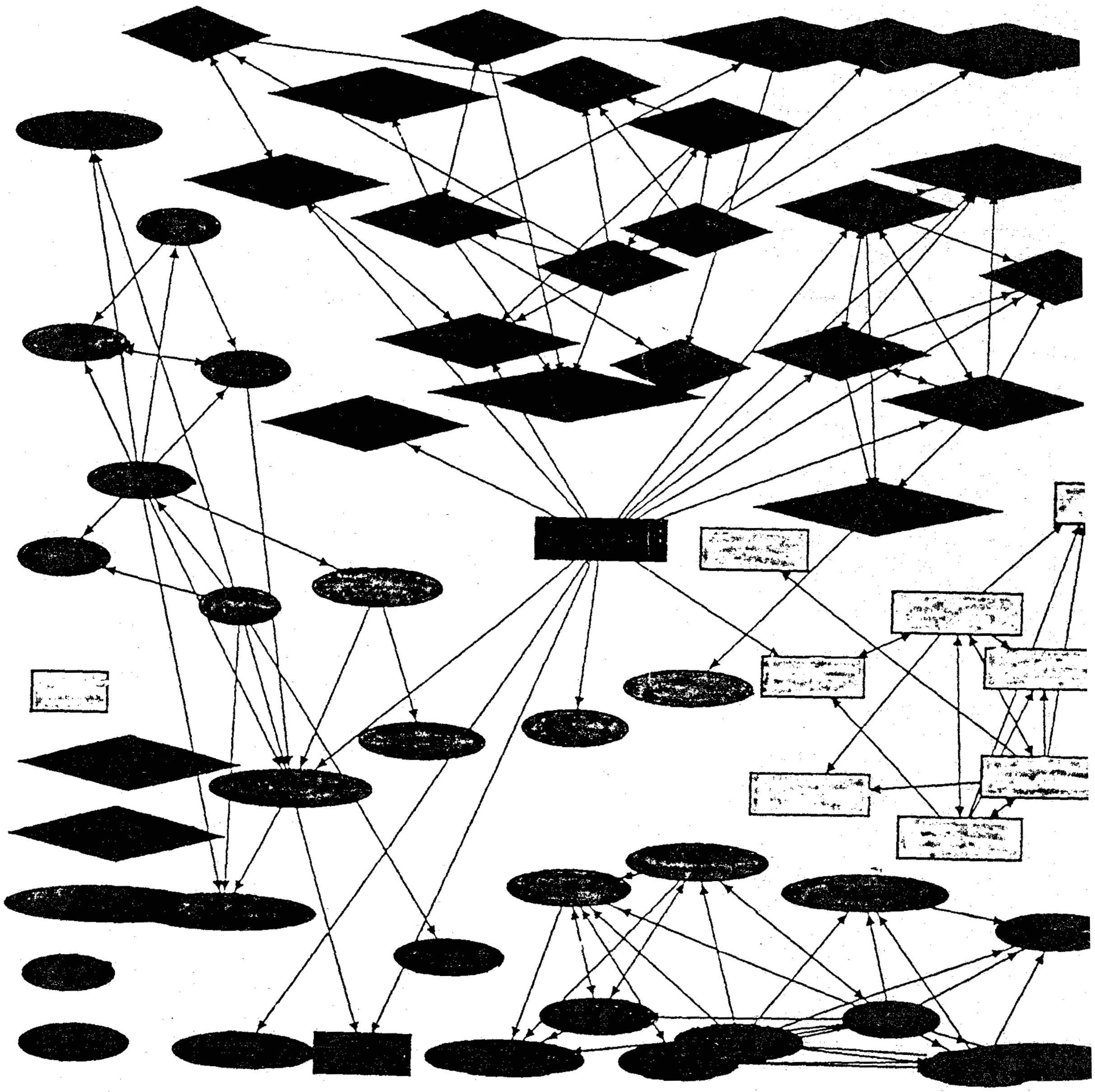

Figure 3. Initial task communication network for selected portions of the PWD.