Group Decision and Negotiation **9**: 109–127, 2000

Facilitation Methods for Collaborative Modeling Tools

DOUGLAS L. DEAN
Center for the Management of Information, 430 McClelland Hall, University of Arizona, Tucson, AZ 85721, USA

RICHARD E. ORWIG
Washington State University, 14204 NE Salmon Creek Ave, Vancouver, WA 98686, USA

DOUGLAS R. VOGEL
Department of Information Systems, City University of Hong Kong, China

Abstract

This paper presents results of an ongoing research effort to support effective user involvement during modeling and analysis meetings. Productivity and user participation of traditional group meetings have been limited by chauffeured facilitation and single-user tools. These tools have been designed to be used by analysts rather than for direct use by non-analyst users. Recently, electronic meeting systems (EMS) modeling tools that allow users to work in parallel to contribute directly during meetings have been developed. Such tools allow more domain experts to participate directly and productively during model development meetings than is possible using the traditional approach. Although previous research has demonstrated that EMS modeling tools may be used to develop some model content, little research had been done on collaborative facilitation methods that support these tools. This paper presents a comparison of modeling approaches for use with EMS modeling tools and proposes an approach that overcomes significant problems inherent in other approaches. It leverages the productivity enhancement afforded by direct group access and still results in production of complete, integrated, high quality models. This approach allows models to be developed two to four times faster than with traditional modeling support and yet avoids model ambiguities and inconsistencies.

Key words: facilitation, electronic meeting systems, group support systems, groupware, enterprise analysis, IDEF, activity modeling, information systems requirements, JAD

1. Introduction

Models support conceptualization, communication, analysis, and design of business processes and information systems. Involvement of key personnel during model development and analysis is important for model accuracy as well as for political ramifications.

Nevertheless, models have traditionally been developed by analysts who perform serial interviews with single users or small groups. This approach is used because of the complexities and difficulties involved when larger groups participate. Large groups lack the means to effectively combine and reconcile their knowledge into a model. As a result, models are often developed slowly with limited participation.

A number of researchers (Brown 1988; Johnson and Lofgren 1994; Suri and Diehl 1987) have noted the difficulties of completing non-trivial models in timely fashion. Completion often takes so long that model-based recommendations come too late to influence major business and system design decisions.

Traditional model development meetings have been supported by single-user tools designed for use by analysts rather than non-expert meeting participants. Recently researchers at the University of Arizona (Dean et al. 1994; Dean et al. 1995) have developed an Electronic Meeting System (EMS) designed to support construction of IDEF0 activity models. Groups of subject matter experts (SMEs), supported by this tool and a modeling expert, are able to participate actively and productively during model development and analysis. Prior to the research presented in this paper, little research has been conducted on the effects that different collaborative modeling approaches have on modeling productivity and quality. The research reported here describes the creation and testing of such meeting methods.

This paper will address a number of related questions: Given a collaborative modeling tool, is it possible to orchestrate the behavior of a group of non-modeling experts in a way that will result in the rapid creation of high quality models? How much parallelism is possible while still achieving coordination of people working on the model? How are productivity and quality impacted by parallelism and convergence strategies? How do modeling productivity and model quality resulting from collaborative modeling meetings compare with outcomes from traditional chauffeured meetings supported with single-user modeling tools?

The paper is organized as follows. First, the background for the study is presented. Next, the research questions and methods are described. Finally, the results are then presented and discussed.

2. Background

2.1. The importance of models

Models are important to business process improvement and information systems development because they facilitate understanding of complex phenomena (Curtis, Kellner and Over 1992; Kowal 1988). Appropriate process models help users bound the domain, identify the parts that make up the whole, and comprehend relationships among business activities. Many traditional organizations have divided work along traditional business function lines such as purchasing or accounts payable. Line authority and incentive structures are often aligned with these departments, but business processes often span traditional departments (Harrington 1991). Thus, individuals in different departments may perform a small part of the total process and not see clearly how their part of the work relates to the whole (Schnitt 1993). Work performed under these conditions may suffer from communication breakdowns, errors, and lack of accountability. By modeling business activities and relationships among activities, it is easier to obtain a macro view of the components making up the work. Viewed from a broader perspective, work steps can often be integrated, simplified, and streamlined (Hammer and Champy 1993; Schnitt 1993).

2.2. *Benefits of participation*

Effective stakeholder participation is essential during model development and analysis for two principal reasons. First, although analysts and facilitators generally play a key role in the collection, synthesis, and analysis of models, it is typically individuals within the organization who best understand the requirements (Curtis, Krasner and Iscoe 1988; Mirhram 1972). Moreover, no one person typically understands all of the requirements and understanding tends to be distributed across a number of individuals. The second primary reason for stakeholder participation is that it can increase the likelihood that participants will both understand and "buy in" to the proposed design (Alter 1978; Baroudi, Olson and Ives 1986; Franz and Robey 1986). In relation to reengineering efforts, Davenport and Stoddard (1994) note that they have observed many stakeholders who paid little attention to business change efforts because they were not involved in the formulation of those changes. Involvement is important because it increases the likelihood of buy-in. If key stakeholders have a hand in defining the requirements and designing the solution, they are more likely to become part of – instead of resistors to – change (Alter 1978; Davenport and Stoddard 1994; Hall, Rosenthal and Wade 1993).

2.3. *The IDEF0 method*

There are a variety of methods for modeling business processes. IDEF0, which had its origin in the Air Force Integrated Computer Aided Manufacturing project, is one that is commonly used to develop business activity models. It is used to define a functional model of what an organization does. The term "IDEF" comes from ICAM (Integrated Computer-Aided Manufacturing) DEFinition language (UM 1981). An IDEF0 model consists of an activity hierarchy with the attending constraints on the component activities at multiple levels of decomposition. Activities are bounded by Inputs, Controls, Outputs, and Mechanisms (referred to in aggregate as ICOMs). ICOMs show the information and physical objects that link activities. When viewed in diagrams, activities are represented as boxes and ICOMs are represented as arrows. Inputs enter to the left of activities, controls enter at the top, outputs exit from the right, and mechanisms enter from the bottom. Activities and ICOMs are defined textually in a glossary. Figure 1 shows an example of an IDEF0 diagram.

IDEF0 is based largely on a well-established graphical language known as Structured Analysis and Design Technique (SADT)(Ross 1977; Ross 1985). Parent and child diagrams within the IDEF0 method should be balanced. That is, ICOM arrows that bound a particular activity also bound its corresponding decomposition diagram. ICOMs that enter or exit an activity should be, with rare exceptions, reflected as boundary arrows in the decomposition of that activity. Exceptions become tunneled arrows. A tunneled arrow is either (1) a boundary arrow on the decomposition diagram that did not appear as an arrow on the parent diagram, leaving open the question as to whether the arrow connects to another part of the model at the parent level or leaves the model entirely, or (2) an arrow which attaches to a parent activity but does not appear as a boundary arrow in the decomposition of that activity (i.e., it has a hidden destination in that it enters a parent activity but is not used by a child activity of the parent). Marca and McGowan (1988, p. 24) point out that there are certain instances where a tunneled arrow can reduce the complexity of a model. However, such instances are rare. Tunnels used inappropriately can be crutches for bad modeling. Tunnels can be indicators of omitted connections that should exist in the model. Thus, tunnels may signify model ambiguity and incompleteness.

Within the IDEF0 method, logical classes of ICOM connections can be bundled together into more general ICOMs that enter or exit a decomposition, and therefore the parent. Bundling allows more generalized inputs, outputs, controls, and mechanisms to be shown on a parent diagram, which reduces the complexity of the more abstract parent view.

The basic concepts of IDEF0 are simple enough to be grasped quickly by non-modeling experts, but the development of integrated, parsimonious models is best performed with the assistance of someone who understands the modeling process and the reasons for the

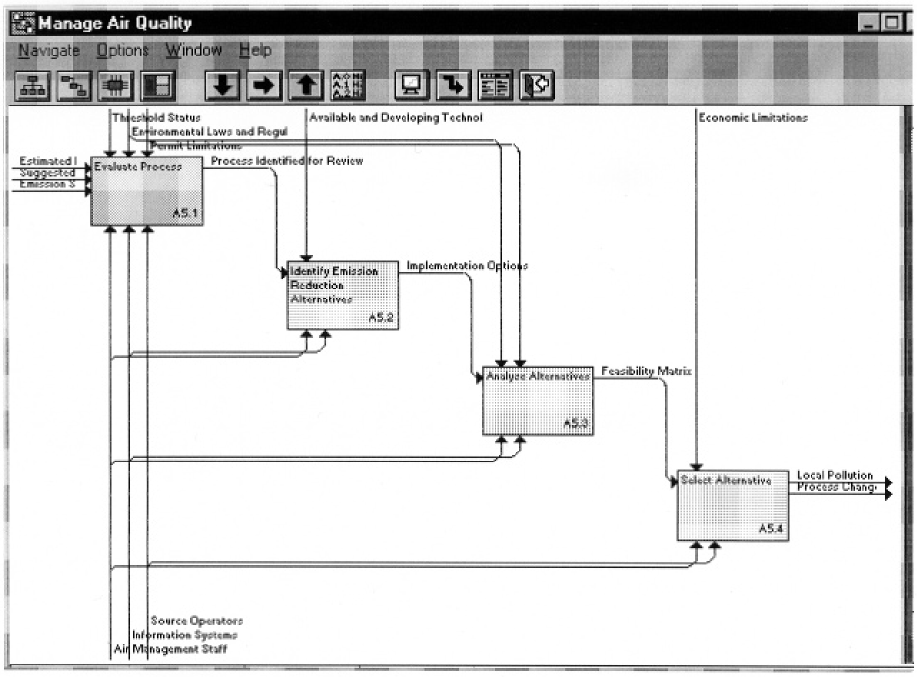

Figure 1. Example IDEF0 diagram.

IDEF0 conventions. Developing large, complex models requires much more training than it is practical to provide to session participants. To produce high quality models, subject matter experts (SMEs) therefore may be given limited training and then be led through the model development process by IDEF0 experts.

The features of balancing, bundling, and multiple levels of abstraction and other provisions within the IDEF0 method represent structure that gives IDEF0 exposition power and rigor not available in many less-structured modeling methods. However, since abstractions are nested and linked together by explicit relationships, the IDEF0 modeling task represents a work coordination challenge when it is defined by multiple individuals.

2.4. Traditional and EMS modeling support

Notwithstanding the need for participation by more than a few stakeholders, traditional IDEF0 modeling meetings have usually been conducted with small groups of three to nine people because it is difficult to keep a larger group productive. Traditional tool support has not allowed large numbers of individuals to conveniently contribute to a model, so modeling has generally been conducted with a small-group in a chauffeured manner (Dean et al. 1994; Nunamaker et al. 1991) – that is, only one person, usually the facilitator or scribe, enters data into a single-workstation IDEF0 tool while the facilitator elicits input from participants. The group uses flip charts, white boards, or pencil and paper to define the objects and descriptions. Diagrams are typically drawn on white boards or transparencies. Often, a second shift of modelers transcribes this information into the single-user tool so that time to do this is not taken during active modeling. The group reviews the model via printouts or directly on the computer screen as the facilitator leads the group through model development and review.

In contrast, the electronic meeting systems (EMS) modeling environment includes a combination of general EMS tools (GroupSystems) and an IDEF0-specific EMS tool call Activity Modeler (hereafter referred to as "AM"). AM, like GroupSystems was developed initially at the University of Arizona. Dean, et al. (1995) and Pendergast et al. (1996) review the evolution of AM and provide detailed descriptions of tool features that aid the group modeling process.

Briefly, AM allows multiple users to enter model content directly into a common model repository. The tool provides a shared work environment that includes concurrency control so that, although only one workstation can edit a specific activity or ICOM at a time, individual meeting participants can view all activities and ICOMs.

The main screen of the EMS IDEF0 tool presents two windows to SMEs (see Figure 2). On the left is the activity list, presented in hierarchical form. On the right is the ICOM list, presented in alphabetical order. A page symbol is presented on the left of each activity and ICOM that has been defined.

AM captures data in appropriately structured fields and provides views that manage complexity. As shown in Figure 1, AM also allows participants to easily and rapidly invoke graphical views of a model. AM also provides real-time feedback on IDEF0 modeling syntax and rules violations.

Use of an EMS-IDEF0 tool provides capabilities not available with single-user tools. All information need not be channeled through a scribe to become part of the model. This reduces a significant bottleneck that has existed in the traditional modeling process. Similarly, multiple participants may access model information without being restricted to the specific information being shown by a facilitator. Such direct access can aid in model conceptualization and review. Group access also makes it possible for parts of a model to be worked on in parallel, accelerating model development and making it more efficient (Dean et al. 1995; Dean et al. 1998; Dennis, Hayes and Daniels 1994).

2.5. Modeling processes

2.5.1. Meeting processes. Effective meeting processes are essential to effective meetings (Bostrom, Anson and Clawson 1993; Fox 1995; Hirokawa and Gouran 1989). The concept of meeting process includes the sequence of, the means of, and the amount of information collected and shared, as well as the means of evaluation and other structures that impact the way tasks are achieved. Anson, Bostrom and Wynne (1995) define process structures as formal and informal procedures, techniques, skills, rules, and technologies that organize and direct group behavior processes.

Vennix (1996) notes that the goal of group model building is to create consensus after sufficient deliberation and contrasting of viewpoints has taken place in a climate in which

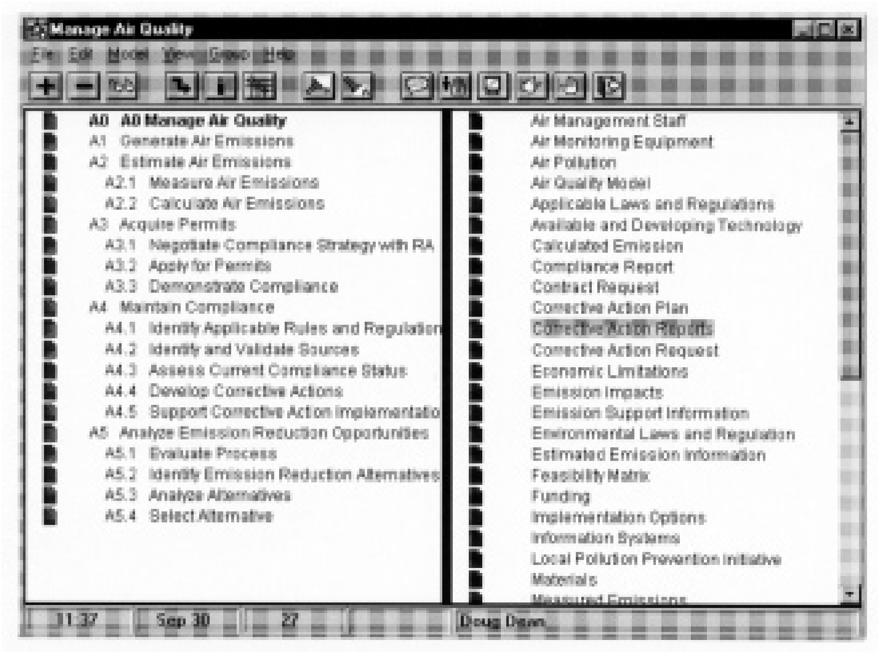

Figure 2. Activity Modeler main screen.

team learning is fostered to enhance understanding of the problem. By its nature, this process has phases of idea generation and divergence as well as convergence. Divergence and ideation are easy to achieve, relatively speaking. Convergence, on the other hand, has always been much harder to support (Clark and Brennan 1991). Nunamaker, et al. (1997) note that group support systems are excellent for ideation/divergent tasks, but appropriate meeting processes and facilitation are required to help groups come to consensus. The need for facilitation and structure becomes particularly acute for tasks that have longer durations and are complex, as is the case for activity modeling (Dean et al. 1998).

In EMS supported modeling, the complexity of the modeling task requires much verbal discussion and is likely to benefit from parallel contributions by SMEs. However, having people working in parallel on models is not enough. An effective meeting process is essential to support both parallelism and having the work culminate in a model that the group can agree upon. Such a process had not been defined prior to this study, and it was not known how groups should decompose their work to obtain parallelism without suffering from cross-defined abstractions. It was unclear how convergence should be achieved.

2.5.2. Traditional model decomposition approach. Various resources on how to conduct the traditional IDEF0 modeling process (Federal Information Processing Standards Committee; UM 1981; Marca and McGowan 1988) are available. Model development is typically conducted top-down such that ICOMs and activities at the most abstract levels are defined first. Abstract activities are decomposed in more detailed diagrams. ICOMs attached to a parent activity become boundary ICOMs to the decomposition diagram and are attached to the child activities followed by ICOMs that interconnect activities within the decomposition. Linking boundary ICOMs in the decomposition before focusing on ICOM connections between activities within the diagram decreases the likelihood that ICOMs across the levels of hierarchy will be omitted. It also increases the likelihood that ICOMs will be consistently applied. Both parent diagrams and child diagrams must be worked iteratively to achieve the best results (Federal Information Processing Standards Committee; Ross 1985).

2.5.3. Description of past EMS model decomposition approaches. This section summarizes the approach described by Dennis, Hayes and Daniels (1994, pp. 247–248; 1999, pp. 121–125), which was used to develop models with an EMS IDEF0 modeling environment. In this approach groups define activities top-down without ICOMs and then define and attach ICOMs bottom-up (this approach will hereafter be referred to as TDBU). In TDBU, the group as a whole identifies the top 3–6 activities and the facilitator acts as a scribe to record this information. Some discussion of possible sub-activities is performed. Next, the group is divided into subgroups of 3 to 5 participants. Each of these subgroups is assigned 1or more of the high-level activities and decomposes its high-level activities in a top-down fashion without defining the ICOMs associated with the activities. Once all the subgroups have finished defining the node decomposition, they review all of the nodes and participants discuss and resolve critical issues that need to be addressed by the overall group. Questions and less critical issues associated with a particular part of the model are given to the appropriate subgroup to resolve. Only after all the nodes have been defined and reviewed by the overall group are the ICOMs defined. Once again, each subgroup takes its part of the node tree and defines and attaches the ICOMs, beginning at the lowest, most detailed level of the node tree.

The high degree of parallelism of the TDBU Approach yielded high modeling productivity. In both studies, Dennis et al. reported that EMS supported models, when normalized by the number of activities defined per person day, were developed between 3 and 4 times faster than traditionally supported models. In the 1994 study, Dennis et al. reported models with less adherence to IDEF standards. In the later study, because of an increased emphasis on quality, the models were of comparable quality.

3. Methods

3.1. Research questions

It is easier to divide work into pieces that can be worked on by subgroups than it is to coordinate work among the subgroups so that parts of the model are intergrated and consistent. This research examines the effects of different modeling approaches on modeling productivity and quality. The main research question, is as follows: Is it possible to design a model development approach using an EMS-IDEF0 tool that will effectively support increased direct participation, be significantly faster than traditional support, and result in integrated, high quality models? This question is related to other questions. Which aspects of the traditional modeling approach suggested by IDEF0 experts should be retained or adapted for use by groups? How should task decomposition be accomplished so that divergence does not overwhelm the ability of the group to converge on quality representations? What are the tradeoffs between the conservative top-down decomposition approach currently espoused by experts and more loosely coupled approaches? The ease of work decomposition in loosely coupled approaches may allow rapid parallel content generation but may increase the model reconciliation burden later on. Is there a net gain from such a tradeoff? How will model quality and model development speed be influenced by such approaches?

To address these questions, this study examines multiple approaches for dividing work across multiple subgroups supported by an EMS-IDEF0 tool. It then compares the outcomes of these approaches with outcomes from the traditional IDEF0 modeling approach with regard to group size, development productivity, and model quality.

3.2. Modeling approach descriptions

Throughout this paper, the term E-IDEF refers to models developed with an EMS-IDEF0 modeling tool. T-IDEF refers to models developed with a traditional chauffeured approach supported by a single-user modeling tool. This section begins by briefly defining the 3 modeling approaches for use with an EMS environment that were evaluated.

Approach 1: Combination of top-down, bottom-up and the traditional approach. For this decomposition approach, a facilitator chauffeured the entire group during development of the first-level decomposition that included both activities and ICOMs relationships. Next, the larger group was broken up into subgroup, each of which worked with a facilitator to further decompose one of the sub-parts of the model. Each subgroup huddled around a few workstations. One or 2 participants usually entered information for each subgroup although the entire group could see model information. A combination of 2 decomposition approaches was taken. Some of the groups first defined all activities top-down and then defined the ICOMs bottom-up, beginning with the most detailed level of the node tree. Some of these subgroups found it impossible to define the nodes without defining the ICOMs at the same time and needed to be guided through a traditional top-down, level-by-level decomposition defining activities and ICOMs at each succeeding level of the model. Groups that had defined all of the nodes first and the ICOMs bottom-up had their lower level ICOMs bundled into more general ICOMs at a higher level to avoid having more than 6 ICOM attachments for any one activity side.

Approach 2: limited initial inter-group coordination followed by model reconciliation. Although we did not try this decomposition approach, we observed 1 set of modelers' use of the EMS-IDEF0 tool in this way. The entire group decomposed the top node into its immediate children nodes. Next, without defining the ICOMs that related the child activities of the first decomposition, the overall group was divided into 4 subgroups, each of which was supported by a facilitator and was assigned 1 or more of the child activities to decompose. While working on their part of the model, some facilitators of subgroups worked completely top-down, while others defined the activities top-down and the ICOMs bottom-up. The facilitators' initial intent was to have each subgroup observe what the other subgroups were defining in the EMS tool while defining its own particular part. Since there were too many participants to be accommodated in 1 room, participants were distributed among 3 rooms, all with workstations that enabled them to view and edit the common model. They planned to make phone calls during the day to address inter-group modeling concerns and then meet at the end of each day to perform reconciliation.

In reality, the phone calls and end-of-day reconciliation did not occur. Each group developed its part of the model and a lead modeler occasionally looked across the entire model and used the tool to post questions and suggestions. Although participants within each subgroup could see parts of the model being defined by other subgroups, they spent insufficient time addressing ICOM linkages among parts of the model. However, group members did use the activity and ICOM description fields to post questions and observations about the model to the lead modeler and to each other during the initial modeling. These comments raised some integration issues that were later used by a small set of representatives drawn from the subgroups to spend a few days integrating the model.

Approach 3: Top-down, integrated (TDI) approach. This approach was developed in an attempt to overcome some of the liabilities inherent in Approaches 1 and 2. It combined some principles of traditional, top-down model development and yet allowed participants to work in parallel to contribute textual model content. Rather than defining just the top decomposition with the entire group and then assigning parts of the model to different subgroups, the entire group defined the candidate node tree. Participants brainstormed and entered candidate activities. Next, a facilitator chauffeured the group through the process of structuring these nodes into a tentative initial node hierarchy. The overall group was then divided into smaller subgroups. The nodes in the hierarchy were allocated across subgroups for definition. After each subgroup entered the initial definitions for its assigned activities, its members reviewed all of the other activity definitions within the entire model. Alternative descriptions, suggestions for description refinement, and questions for clarification were submitted as needed. Next, the facilitator led the group through the process of selecting and refining an appropriate definition and addressing any changes to the node tree that had resulted from the discussion of the definitions. Participants were instructed that this initial node hierarchy would subsequently change when seen through the perspective of the ICOMs.

Next, the group defined the ICOMs in a top-down fashion beginning with the first activity decomposition. Participants were asked to look at the parent and child nodes to help them conceptualize the ICOMs that bounded and linked the parent activities. An ICOM list was generated and reviewed by participants to identify candidate ICOMs associated with activities. For each decomposition, the primary border ICOMs that spanned main branches of the tree were identified and entered first. After these were attached to activities and defined, the arrows internal to the decomposition were identified and attached. As new ICOMs were identified and attached, SMEs entered the ICOM definitions. The facilitator conversed with group members about candidate ICOMs and recorded the attachments while various SMEs help define the ICOMs through their workstations.

Activities were altered as necessary in light of ICOM attachments. Activities were merged or split, promoted or demoted among levels, or added or deleted as necessary to improve the logical construction of the model. Such refinements were frequently made. For example, if a particular decomposition suggested that the parent diagram should be adjusted to correspond more closely to a newly detailed decomposition, the parent diagram was modified. This parent/child/parent review and revision sequence was followed recursively throughout the model.

3.3. Sample description and measures

This paper compares eight EMS-supported sessions and 5 traditionally supported sessions. The traditionally supported sessions were selected because of the availability of reliable data regarding time spent on model development. The EMS sessions were facilitated by the authors and other facilitators. The traditional (T-IDEF) sessions were supported by a single-user IDEF tool and chauffeured facilitation. T-IDEF sessions were supported by experienced IDEF0 consultants who had demonstrated the ability to produce high quality models. SMEs from various military and other government organizations participated in model development. Summary information on development time, model size, and group size is provided in Table 1.

A number of basic model quality indicators were developed and applied to the models. Two measures of decomposition complexity were applied to determine whether decompositions were limited to 6 or fewer activities and whether more than 6 ICOMs were attached to any 1 activity side. The IDEF0 method includes these guidelines to encourage more general abstraction upward in the model hierarchy and relegation of more detail into lower levels of the model hierarchy (Federal Information Processing Standards Committee). The first measure, the complex decomposition ratio is calculated by dividing the number of decompositions having more than 6 nodes by the total number of decompositions. The over 6 attachments per side ratio divides the aggregation of attachments to boxes that exceed 6 attachments per side by the total number or ICOM attachments throughout the model.

SME appraisal of model validity was not available for the non-EMS supported sessions, but was captured for 4 of 8 EMS supported sessions.

Completeness was measured by 5 indicators. First, the IDEF0 (Federal Information Processing Standards Committee) requires that each activity have both an output and a control. The sufficiency of constraint ratio divides the number of activities that did not have at least 1 output and 1 control by the total number of activities. Second, tunnel frequency was measured by counting the number of tunnels in each model. Third, a tunnel ratio was calculated. This ratio normalizes tunnel frequency by model size. It is calculated by dividing the number of tunnels in a model by the number of activities in the model. The fourth and fifth completeness measures consisted of the number of textual lines per average ICOM definition and the number of textual lines per average activity definition. The texts in these definitions were normalized to a consistent number of 80 characters per line.

Group productivity was measured as the number of activities defined per day and the number of ICOMs defined per day. Since model and group size varied from case to case, group productivity measures were divided by the number of participants in each group to derive average individual productivity measures. Thus, activities per person per day and ICOMs per person day were calculated. For T-IDEF participants, IDEF0 training typically lasted about a day. Training typically lasted about 2 hours for the E-IDEF participants. Training time was included in productivity calculations since it represents resources expended to enable model production. Time to develop the viewpoint, context, and purpose for the models also was included in model development time.

4. Results

4.1. Observations about the respective modeling approaches

Approach 1. Although the first decomposition diagram, including both activities and ICOMs, was completed by the entire group in a chauffeured manner, each subgroup tended to focus on its own part of the model when parts of the model were decomposed by the subgroups,. When each group developed its initial activity tree, it was able to identify and remove activities that duplicated those developed by other subgroups. However, ICOM specification among groups throughout the model was more problematic. Subgroups took insufficient time to reconcile ICOM connections between their part of the model and the activities being defined by different subgroups. They frequently identified ICOMs that should link their part of the model to other parts of the model, but often failed to notify the other subgroups and negotiate an appropriate name, definition, and linkage.

Approach 2. The fact that ICOM linkages across parts of the model were not defined explicitly during model development resulted in a considerable number of redundant and partially overlapping activities and ICOMs. Homonyms and synonyms were abundant. A modeler and a representative from each subgroup met for 2 days to integrate the model, suppress the redundancy, and improve the logical structure of the model. During this model reconciliation, about one third of the ICOMs and one fifth of the activities were eliminated.

The changed model then was presented by the integration team to the larger group that had participated during the initial model development. Some non-integration team members complained that the integrators changed too much of the model – that during initial development of the partially integrated model they had chosen specific terms and concepts that had later been changed or eliminated by the integration team. Even after the integration team defended the changes and discussed the reasons they were made, some of the non-integrators voiced considerable displeasure at some model changes and claimed that some terms and logical constructs within the model no longer captured their original intent.

Observations common to approaches 1 and 2. Each subgroup was encouraged to notify other subgroups when an ICOM from its part of the model left or entered the part of the model being defined by another subgroup (or to attach the source or destination, and then notify the other subgroup). Often, however, this did not happen. Since some parts of the model tended to be defined more quickly than others, depending on size and complexity, the source or destination activity sometimes had not yet been defined by the other subgroup. Sometimes a subgroup failed to realize that another subgroup had attached an ICOM to its part of the model for quite some time. In addition, subgroups often failed to link the higher levels of the model together. ICOMs appeared as tunnels even when the same ICOM was attached to the 2 different parts of the model. Thus, ICOM linkages across the model were under-specified. For example, outputs that should have had destinations within the model were defined, but the destinations were not made explicit in the model. Likewise, an inordinate number of ICOMs were shown at 1 level of abstraction, but were not propagated to the more abstract or detailed levels of the model.

Another problem with these approaches was that ICOM homonyms and synonyms were defined differently by different subgroups and were used in different parts of the model. Homonyms and synonyms included different names for exactly the same item, items at different degrees of abstraction, and partially overlapping abstractions. The overall group reviewed and eliminated homonyms and synonyms and made modest attempts to identify sources and destinations of dangling links in the model, but there were so many tunnels that it was deemed impractical to take the time that would be required to identify all of these and to rebundle the ICOMs.

Top-down, integrated (TDI) approach. This approach suppressed ICOM homonyms and synonyms throughout the modeling process. Unlike Approaches 1 and 2, where considerable ICOM reconciliation occurred at the end, the spanning ICOMs were defined and agreed upon early. Because this process was performed top-down for all decompositions, the emphasis was on how parts of the model fitted together. Careful attention was given to avoidance of dangling ICOM attachments. Activity decompositions at each level were frequently restructured, since the ICOMs and activities were considered together during top-down model specification. This resulted in a more parsimonious, tightly integrated model than those produced by Approaches 1 and 2. Since model boundaries and inter-activity connections were brought into focus early, there was less tendency to include activities and ICOMs outside the scope of the model and to use ICOM homonyms and synonyms. Finally, the ICOMs and ICOM bundles were defined at levels of abstraction more appropriate to the activity abstractions up and down the model than resulted from Approaches 1 and 2. That is, rather than defining lower level ICOMs first and promoting them until the rule of limiting ICOM attachments to 6 forced bundling, more general ICOM names were used in the more general levels of the model. Thus, less mixing of detailed and general abstractions occurred. Consistent abstraction levels are an indication of good style (Williamson 1991). The fact that the parts of the model were linked appropriately at all of the different levels of abstraction reflected better model construction. Thus, the many omissions, errors, and ambiguities that occurred in Approaches 1 and 2 were avoided.

4.2. Model and modeling approach statistics

Table 1 provides a summary of data on model size, validity, quality, and productivity for the different approaches. For approaches with more than 1 model, the figures reflect averages.

Table 2 shows the percentage difference resulting when the values for each approach is compared to the T-IDEF sample (Column a). The percentage difference is calculated by dividing a particular EMS-supported approach by the T-IDEF values in Column (a), subtracting 1 from the result to get a difference value, and then multiplying by 100 to convert this value to a percentage.

Group Size. Table 1 reflects that approximately twice the number of SMEs participated in the large E-IDEF sessions as in the T-IDEF sessions.

Quality. In terms of decomposition complexity, all models adhered to the rule of limiting activities per decomposition to 6. About 3% of the ICOM attachments violated the 6 attachments per side rule in the T-IDEF models, with 3 of the 5 traditionally-supported models violating this rule rarely and 2 models violating it frequently. This rule was generally not violated in the E-IDEF models. All models suppressed homonyms and synonyms.

As mentioned above, SME appraisal of model validity and completeness was not available for the non-EMS supported sessions and the Small-Group E-IDEF sessions, but was captured for the other treatments. SMEs were asked to react to the statement: “I believe that the activity model represents the functions that need to be performed in the work activity.”

Response options ranged from 1, Disagree strongly! to 5, Agree strongly! Table 1 shows the average model validity and completeness ratings from the SMEs for each E-IDEF approach. All models received relatively high ratings, with the TDI Approach being given the highest. Participation in this model development experience helped clarify the business process for the participants and the models resulting were used to identify and document a number of significant areas for improvement.

Notwithstanding the high model validity rating by SMEs for all approaches, the high number of tunnels in Approaches 1 and 2 suggests that these models were less complete and consistent than the T-IDEF and TDI models. Table 1 shows that the T-IDEF models averaged less than 3 tunnels per model. The first and second E-IDEF approaches had tunnel counts of roughly 100 per model. The number of tunnels per activity on these approaches was correspondingly high. Table 2 shows that the tunnels per activity value for

Table 1. Model statistics

		E-IDEF			
Model development approaches:	T-IDEF	Approach 1	Approach 2	Large- group E-TDI	Small- group E-TDI
Column:	a	b	c	d	e
Development time, number of models, group size, and model size					
Development days	9.5	7.75	9	3.6	2
Number of models	5	2	1	3	2
Persons per day	9.4	18.50	22	16.7	4
Nmber of activities	27.2	107	62	34	34
Number of OCOMs	86.2	227.50	239	65	60
Model quality					
Decomposition complexity:					
Complex decomposition ratio	–0–	–0–	–0–	–0–	–0–
Over six attachments per side ratio	0.03	–0–	–0–	–0–	–0–
Model parsimony:					
Homonyms/synonyms eliminated?	Yes	Yes	Yes	Yes	Yes
Validity:					
SMEs' model validity perceptions	not avail.	3.81	4.16	*4.29	not avail.
Completeness:					
Missing constraints ratio	–0–	.06	–0–	–0–	–0–
Tunnels per model	2.88	112	94	2.7	2.5
Tunnels per activity	0.10	0.92	1.52	0.09	0.09
Textual lines per ICOM	0.73	1.9	1.1	1.9	▲1.2
Textual lines per activity	1.99	2.8	3.0	2.86	1.8
Productivity					
Activites per day	2.96	14.05	6.9	9.6	16.4
ICOMs per day	9.16	29.89	26.6	18.5	29.2
Activities per person per day	.35	0.79	0.43	0.56	4.21
ICOMs per person per day	1.08	1.69	1.7	1.10	7.57

*Validity rating from 1of 3 modeling sessions

▲(Not all ICOM definitions were completed by the group

Table 2. Modeling approach comparisons: percentage differences

	a vs b	avs c	a vs d	a vs e
Activities per day	375	133	224	454
ICOMs per day	226	190	102	219
Activities per person per day	126	23	60	1103
ICOMs per person per day	56	57	2	601
Tunnels per activity	820	1420	<10>	<10>

Approach 1 was 820% higher than for the T-IDEF models. The Approach 2 value was even higher. The TDI Approach, however, averaged less than 3 tunnels, with a tunnel ratio comparable to that of the T-IDEF models.

Finally, the activity and ICOM textual descriptions in the E-IDEF models, developed by large groups, were more detailed than in the T-IDEF models, reflecting more extensive definitions.

Productivity. Approach 1 had productivity rates per day that were higher than those of the traditionally supported efforts by 375% for activities and by 226% for ICOMs. Average activities and ICOMs per subject matter expert per day were 126% and 56% higher respectively. The second column in Table 2 compares Approach 2 and the T-IDEF baseline. With Approach 2, 3 of 4 productivity measures fell markedly below those of Approach 1, although it was still higher than the T-IDEF baseline. For the Large-Group TDI Approach, activities and ICOMs per day were 224% and 102% higher than the T-IDEF baseline. Activities per SME day were 60% higher than the T-IDEF baseline, while ICOM production per SME day was comparable to the T-IDEF baseline. For the Small-Group TDI Approach, activities and ICOMs per day were 454% and 219% higher than the T-IDEF baseline. Activities per SME day were 1103% higher than the T-IDEF baseline, while ICOM production per SME day was 601% higher than the T-IDEF baseline.

5. Discussion

5.1. Group size

The fact that about twice as many participants took part in the Large-Group E-IDEF meetings as in the T-IDEF meetings means that the E-IDEF models were exposed to a broader range of contributions and review. Thus, the goal of being able to effectively support more participants was met. The small-group E-IDEF groups were smaller than the T-IDEF groups.

5.2. Model quality

The TDI and T-IDEF methods are clearly more rigorously defined than the models produced by Approaches 1 and 2 because they have less tunnels. The excessive occurrence of tunnels in the other approaches reflect ambiguities, inconsistencies, and incompleteness. Table 1 indicates that SMEs judged the models resulting from use of the Large-group TDI Approach to have higher validity than those of the 2 non-TDI E-IDEF approaches. This is consistent with the very low tunnel rate and other quality indicators. The models produced by the TDI Approach had better cohesiveness, better fit between activities and ICOMs, and better use of ICOM abstractions appropriate to the level of activity abstractions.

Although they judged the less integrated models somewhat lower than the TDI approach, the fact that SMEs still gave them reasonably high validity ratings suggests that SMEs were not highly calibrated on this measure. The more objective tunnel ratio is more sensitive to completeness and consistency. The model produced with the TDI Approach demonstrates that E-IDEF tools can be used with a large group to develop high quality models when supported by appropriate facilitation techniques. Fragmented models result when parallel work is done in ways that do not emphasizes model integration.

Although access to a shared workspace is an important group enabler, an effective modeling approach is necessary in order to prevent disjointed and redundant modeling. Performing 1 or 2 levels of decomposition together is not sufficient to allow further decomposition to be partitioned and linked adequately. The same can be said about developing a node tree top-down, followed by development of ICOMs bottom-up. When subgroups work on a part of the model for a long time without frequently reviewing other parts of the model, homonyms and synonyms naturally result. Even if sub-branches containing non-redundant activities are modeled top-down, integration into the larger model may still result in too many tunnels because the activities within each branch were not explicitly defined in light of the linkages and because consistent ICOM abstractions across parts of the model were not used.

As noted by Marca and McGowan (1988), unless common border ICOMs are defined first and connected with care, links tend to be overlooked. Subgroups tend to focus on their own parts of the model and to perform insufficient coordination with other subgroups. This tendency was exacerbated by multiple, remote locations in Approach 2, but is also common when subgroups are in the same room. The high tunnel frequency that resulted from Approaches 1 and 2 point to the ambiguity and incompleteness created by disjointed modeling approaches.

If groups invest a lot of time forming disjointed abstractions they can become frustrated when the abstractions have to be reworked to make parts of the model fit together appropriately. Analysts lack the domain knowledge required to complete unreconciled models. Reconciliation by a smaller representative group may violate the buy-in of the members of the larger group. For example, attempted model reconciliation by the small representative team in Approach 2 appears to have reduced the buy-in of the participants who were not involved in the integration. When a smaller group performs reconciliation, the larger group must be reconvened or a time-consuming post-session review must be performed. These problems are avoided when integrated, quality models are developed in the first place by the larger group through a top-down approach such as the TDI approach.

The TDI Approach employs decomposition methods more like those of traditional IDEF0 than do Approaches 1 and 2 and the TDBU Approach. This helps participants retain better understanding of the evolving model and still allows SMEs to contribute candidate activities and textual definitions in parallel. Level-by-level specification of ICOMs and attention to the boundary spanning ICOMs before defining internal ICOMs results in more cohesive, integrated, unambiguous models than models resulting from Approaches 1 and 2. This is borne out by the paucity of tunnels in the model produced by the TDI Approach. With boundary spanning ICOMs in place to form the context for parts of a model, subgroups can sometimes work in parallel effectively to decompose those parts. It is important, however, that frequent cross-subgroup review be performed and that care be taken to avoid homonyms and synonyms as well as dangling ICOMs. One conservative approach is to conduct reviews each time a subgroup has completed a decomposition.

The fact that ICOMs and activities are defined together throughout the model in the TDI Approach leads to a better fit between ICOMs and activities than results from the TDBU Approach, which assumes that activities can be defined early and in the absence of ICOMs. The TDBU Approach assumes that the activity tree is largely stable and that ICOMs at the bottom level can be specified and then mechanically bundled across higher level activities that were not formed in the presence of boundary ICOMs. This assumption is not supported by our research findings. Higher level activities are myopically formed when a node tree is constructed without ICOM relationships. Tentative node trees require substantial revision when ICOMs are taken into consideration.

Finally, the fact that SMEs can directly contribute textual definitions of activities and ICOMs is important. When definitions are not collected through a scribe, more detailed definitions can be contributed while, at the same time, oversight by the facilitator(s) ensures that a reasonable balance between definition completeness and parsimony are achieved.

5.3. Development productivity

The direct access provided by the EMS-IDEF0 environment allows models to be developed 2 to 4 times faster than when modeling is supported by the traditional chauffeured, single-tool approach. Because all content need not be channel through a facilitator, more people can productively participate. The first 2 E-IDEF approaches examined produced speed at the sacrifice of some quality. However, the TDI Approach yielded model quality comparable to that of the T-IDEF approach while completing models much faster. It appears that the group-enabled modeling environment was able to overcome production bottlenecks inherent in the traditional approach. Not only are E-IDEF approaches faster than the T-IDEF approach as a whole, individual participant productivity is also higher even when considerably more people are contributing. It should be noted here that although the measures employed in this paper adjust for group size when assessing productivity, this mathematical adjustment does not tell the whole story in comparing groups of different size. Since the comparison was made across groups of different sizes, group size should be considered in evaluating the numbers. It is likely that conflicting forces are at work. Electronic support enables more parallel contribution, but more people must be coordinated.

6. Conclusion

This study has demonstrated that EMS tools can be used to rapidly develop models of high style and quality. However, having a group-enabled tool is not enough. Facilitation methods can have a significant impact on model quality and productivity. EMS can be applied in ways that allow parallel work without sacrificing the benefits of good modeling practice. In this way, SMEs and analysts can work together to quickly develop models that are complete, integrated, and unambiguous.

Acknowledgements

An earlier version of this paper appeared in the Proceedings of the 29th Annual Hawaii International Conference on System Sciences (1996), pp. 472–481. We would like to recognize the following individuals and organizations for their vital contributions to this research: Mark Pendergast, Jim Lee, Boris Nevstrujev, Nina Katic, Bill Saints, Mark Bovelsky, Lynne Mikulich, Ventana Corporation, the U.S. Army Environmental Center, the DoD Environmental Security Corporate Information Management Program Management Office, and the U.S. Army Waterways Experimental Station. This research was sponsored by the Army Environmental Center.

References

Alter, S. (1978). “Development patterns for decision support systems”. *MIS Quarterly* 2, 3.

Anson, R., R. P. Bostrom, and B. Wynne. (1995). “An experiment assessing group support system and facilitator effects on meeting outcomes”. *Management Science* 41, 2, 189–208.

Baroudi, J. J., M. H. Olson, and B. Ives. (1986). “An empirical study of the impact of user involvement on system usage and user satisfaction”. *Communications of the ACM* 28, 3, 232–238.

Bostrom, R. P., R. Anson, and V. K. Clawson. (1993). “Group facilitation and group support systems”. In L. M. Jessup and J. S. Valacich (eds.), *Group Support: New Perspectives*. New York, NY: Macmillan Publishing Company, 146–168.

Brown, E. (1988). “IBM combines rapid modeling technique and simulation to design PCB factory-of-the-future”. *Industrial Engineering* 20, 6, 19–23.

Clark, H. H. and S. E. Brennan. (1991). Grounding in communication. In L. B. Resnick, J. Levine, and S. D. Teasley (eds.) *Socially Shared Cognition*. American Psychological Association, 127–149.

Curtis, B., M. I. Kellner, and J. Over. (1992). “Process modelling”. *Communications of the ACM* 35, 9, 75–90.

Curtis, B., H. Krasner, and N. Iscoe. (1988). “A field study of the software design process for large systems”. *Communications of the ACM* 31, 11.

Davenport, T. H. and D. B. Stoddard. (1994). “Reengineering: business change of mythical proportions?” *MIS Quarterly* 16, 2, 121–127.

Dean, D. L., J. D. Lee, R. E. Orwig, and D. R. Vogel. (1995). “Technological support for group process modeling”. *Journal of Management Information Systems* 11, 3, 43–64.

Dean, D. L., J. D. Lee, M. O. Pendergast, A. M. Hickey, and J. F. Nunamaker Jr. (1998). “Enabling the effective involvement of multiple users: methods and tools for collaborative software engineering”. *Journal of Management Information Systems* 14, 3.

Dean, D. L., R. E. Orwig, J. D. Lee, and D. R. Vogel. (1994). “Modeling with a group modeling tool: group support, model quality, and validation”. *Proceedings of the 27th Annual Hawaii International Conference on System Sciences*. Los Alamitos, CA: IEEE Computer Society Press.

Dennis, A. R., G. S. Hayes, and R. M. Daniels. (1999). “Business process modeling with group support systems”. *Journal of Management Information Systems* 15, 4, 115–142.
Dennis, A. R., G. S. Hayes, and R. M. Daniels. (1994). “Re-engineering business process modeling”. *Proceedings of the 27th Annual Hawaii International Conference on System Sciences*. Los Alamitos, CA: IEEE Computer Society Press.
Federal Information Processing Standards Committee. *Integration Definition for Function Modeling (IDEF0)*.
Fox, G. (1995). “The challenge of convergence”. *Proceedings of the 28th Hawaii International Conference on System Sciences*. Los Alamitos, CA: IEEE Computer Society Press.
Franz, C. R. and D. Robey. (1986). “Organizational context, user involvement, and the usefulness of information systems”. *Decision Sciences* 17, 329–356.
Hall, G., J. Rosenthal, and J. Wade. (1993). “How to make reengineering really work”. *Harvard Business Review*. 71, 6, 119–131.
Hammer, M. and J. Champy. (1993). *Reengineering the Corporation: A Manifesto for Business Revolution*. New York, NY: Harper Business.
Harrington, H. J. (1991).*Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity, and Competitiveness*. New York, NY: McGraw-Hill, Inc.
Hirokawa, R. Y. and D. S. Gouran. (1989). “Facilitation of group communication”. *Management Communication Quarterly*. 3, 1, 71–92.
Johnson, M. E. and T. Lofgren. (1994). “Model decomposition speeds distribution center design”. *Interfaces* 24, 5, 95–106.
Kowal, J. A. (1988). *Analyzing Systems*, London: Prentice-Hall.
Marca, D. A. and C. L. McGowan. (1988). *SADT: Structured Analysis and Design Techniques*. New York, NY: McGraw Hill, Inc.
Mirhram, A. (1972). “The modeling process”. *IEEE Transactions on Systems, Man, and Cybernetics* 2, 5: 621–629.
Nunamaker, J. F. Jr., R. O. Briggs, D. Mittleman, and D. R. Vogel. (1997). “Lessons from a dozen years of group support systems research: a discussion of lab and field findings”. *Journal of Management Information Systems* 13, 3, 163–207.
Nunamaker, J. F. Jr., A. R. Dennis, J. S. Valacich, D. R. Vogel, and J. F. George. (1991). “Electronic meeting systems to support group work”. *Communications of the ACM* 34, 7, 40–61.
Pendergast, M. O., D. L. Dean, J. D. Lee, B. Nevstrujev, and N. Katic. (1996). “Current advances in group supported business process reengineering”. *Proceedings of the 29th Annual Hawaii International Conference on System Sciences*. Los Alamitos, CA: IEEE Computer Society Press.
Ross, D. T. (1977). “Structured Analysis (SA). A language for communicating ideas”. *IEEE Transactions on Software Engineering* SE-3, No. 1, 16–34.
Ross, D. T. (1985). “Douglas Ross talks about Structured Analysis”. *Computer* July, 80–88.
Schnitt, D. L. (1993). “Re-engineering the organization using information technology”. *Journal of Systems Management* January, 14–20, 41–42.
Suri, R. and G. Diehl. (1987). “Rough-cut modeling: an alternative to simulation”. *CIM Review* 3, 3, 25–32.
UM (1981). *Integrated Computer-aided Manufacturing (ICAM) Function Modeling Manual (IDEF0)*, Air Force Systems Command, Wright-Patterson AFB, OH: Materials Laboratory, Air Force Wright Aeronautical Laboratories.
Vennix, J. (1996). *Group Model Building: Facilitating Team Learning Using System Dynamics*. London: Wiley.
Williamson, W. R. (1991). *Systems Analysis Quality Metrics*, Adroit Systems, Inc.