CONCURRENT ENGINEERING: Research and Applications

# Modeling and Implementing Concurrent Engineering in a Virtual Collaborative Environment

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**Abstract:** Many companies are creating interdisciplinary concurrent engineering teams to collaborate on product development projects from dispersed locations. The problems these companies face stem from the lack of understanding of technical, organizational, and procedural requirements for such activities to take place effectively. This paper proposes an integrated conceptual model of the product life cycle, and a virtual collaborative environment to support concurrent engineering. The product life cycle model features the life cycle process itself, but also highlights the corresponding people and technology required for each phase. The virtual collaborative environment framework models the activities that occur, and the underlying infrastructure that must be present for collaboration to be effective. A simple prototype of the model is implemented, and an exploratory study is conducted to gain insight into the issues of concurrent engineering in a virtual collaborative environment, and to identify future research directions.

**Key Words:** virtual collaboration, concurrent engineering, modeling, groupware, product life cycle, design, computer-supported cooperative work, CSCW.

## 1. Introduction

In recent years, the traditional sequential approach to product development has given way to concurrent engineering. However, the fundamental activities that take place remain the same. Many different models of the product development process exist [1–5], but the general concepts are consistent. In a concurrent engineering environment, many of these activities are carried out by multidisciplinary teams working in a collaborative manner. The process involves communication, negotiation and team learning [7] and must be supported by the organizational infrastructure in which it takes place.

Ion and Neilson [7] identify some of the inefficiencies that can impair effective collaboration in a dispersed team setting. First, designers normally record background information results of reasoning and calculations in private notebooks, which is not easily shared. Second, although design information in the form of text and graphics is recorded and can be captured electronically, much of the design intent in the form of dialog and face-to-face interaction is lost. Third, meetings are the main method of resolving inconsistencies and design conflicts; thus, when misunderstandings occur during meetings, they can lead to increases in development time and design costs. Fourth, time delays resulting from asynchronous communication (voicemail, fax, memos) can result in delayed product development and also lead to a lack of ownership of design decisions. In developing an infrastructure to support concurrent engineering in a virtual collaborative environment, these issues need to be addressed and integrated solutions identified for capturing and recording design rationale.

Any proposed technical infrastructure must support and complement the emerging Sociotechnical Model of Organization [6], which stresses importance and value of people. As a result of a recent study sponsored by the United Kingdom Design Council to investigate the use of shared workspace in the design process, Ion and Neilson [7] propose that "... research priority should be placed on issues relating to the implementation of cooperative working systems in design and management." The researchers go on to say that "Research related to technological issues, which has been the focus of activity in recent research, is still required but should now take second priority as working systems are now commercially available."

A survey of the concurrent engineering literature reveals that few controlled experiments with collaboration tools and environments have been done. Most of the research-oriented implementations of concurrent engineering and virtual collaboration involve single case studies of how the system worked within a certain company [8–10].

The Madefast project [11] was a large-scale implementation of concurrent engineering using the World Wide Web to support a virtual collaborative environment. It involved many teams of participants from across the United States working on developing a military quality optical seeker in six

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months. Although the project was large and used sophisticated and expensive support systems, it did demonstrate that rapid engineering development of complex products is possible in a virtual collaborative environment. Some of the issues that this project encountered were the need for strong synchronous communications tools, the need for open access to design information, and the need for inexpensive systems so that small and medium-sized companies can become a part of the collaborative network.

In another study, researchers looked at the difference in design semantics (design rationale) using computer application when designing alone as compared to designing collaboratively [12]. The researchers observed that three types of collaboration took place. In mutual collaboration, designers worked together closely during the entire session, but very little semantics were documented. Exclusive collaboration involved the designers working on separate parts of the design and collaborating periodically to inform and negotiate. The participants in this type of collaboration produced more design semantics than when working individually. In the third type, dictator collaboration, one designer took charge and made all of the design decisions at the beginning, and from then on, the two designers worked independently, producing less documented semantics than when working individually. The researchers also noted that it was very difficult for designers to document design semantics during the collaborative sessions because designers were focused on negotiating instead of documentation. The study indicated that the transparency of a tool (the ability for a user to focus on the task instead of the tool) is a key factor in the development of a successful and effective system.

In a third study looking at the use of a prototype networked collaborative design environment to support learning about engineering design, researchers reported the following observation [13]:

> In addition to the technical design challenges of collaborative and information systems, researchers should also address the social and psychological aspects of using on-line resources and collaboration. The ideal collaboration system would support the advantages of social, psychological and technological information resources, including communication and data access tools, on-line mentoring and experts, multiple representations for clarity, and archived exchanges and records.

## 2. Product Life Cycle Activities

The product life cycle requires a number of activities that occur concurrently and repeatedly. Synthesizing the work of a number of researchers [1,14–16], these activities can be grouped into six categories, namely, information gathering (IG), drawing and design (DD), analysis and evaluation (AE), general documentation (GD), planning and scheduling (PS) and synchronous workspace sharing (WS). Each activity has numerous tools associated with it that are used to assist people in completing that activity in an efficient manner. Underlying all of these activities is an information management system, which supplies the storage, searching, and retrieval functions as well as asynchronous workspace sharing. A discussion of the activities and their associated tools follows.

## 3. The New Product Life Cycle

The development of the New Product Life Cycle model shown in Figure 1 draws largely on the efforts of Skalak, Kemser and Ter-Minassian [17], but includes views of product development presented by others [18–21]. The view presented by Skalak et al. is especially useful because it focuses on small and medium-sized companies and includes many aspects of the product development process. Most other descriptions of product development and new product life cycle exhibit similar features, and collectively cover a wide range of industry and company standard practices. The main feature that separates this model from others that have been developed is the fact that it integrates people and technology as well as defined outputs into the process.

The column under the heading "people" in Figure 1 identifies the major disciplines involved in each phase of the new product life cycle, and to what extent they are involved. This is a generalization, but it is useful to consider who should be involved in the different phases and why.

A host of tools are available to support the product development activities. Some examples are listed below.

**Information Gathering (IG):** search engines, web browsers, knowledge-based systems.
**Drawing and Design (DD):** CAD systems, rapid prototyping, reverse engineering, sketch and drawing software.
**Analysis and Evaluation (AE):** finite element analysis tools, electronics simulation packages, decision support tools, spreadsheets, mathematics packages.
**General Documentation (GD):** word processors, object editing packages, message editors.
**Planning and Scheduling (PS):** meeting schedulers, personal planners, material requirement planning systems, project planning software (PERT, CPM), Computer Aided Process Planning (CAPP).
**Synchronous Workspace Sharing (WS):** shared whiteboards, communication systems (text based, voice based or video conferencing), application sharing tools.

The formal outputs are often used to mark and measure milestone achievements. They are considered to be the formal documentation for a particular life cycle phase, and become part of the product development file. The formal outputs listed in Figure 1 are suggested as the major documents of each new product life cycle phase.

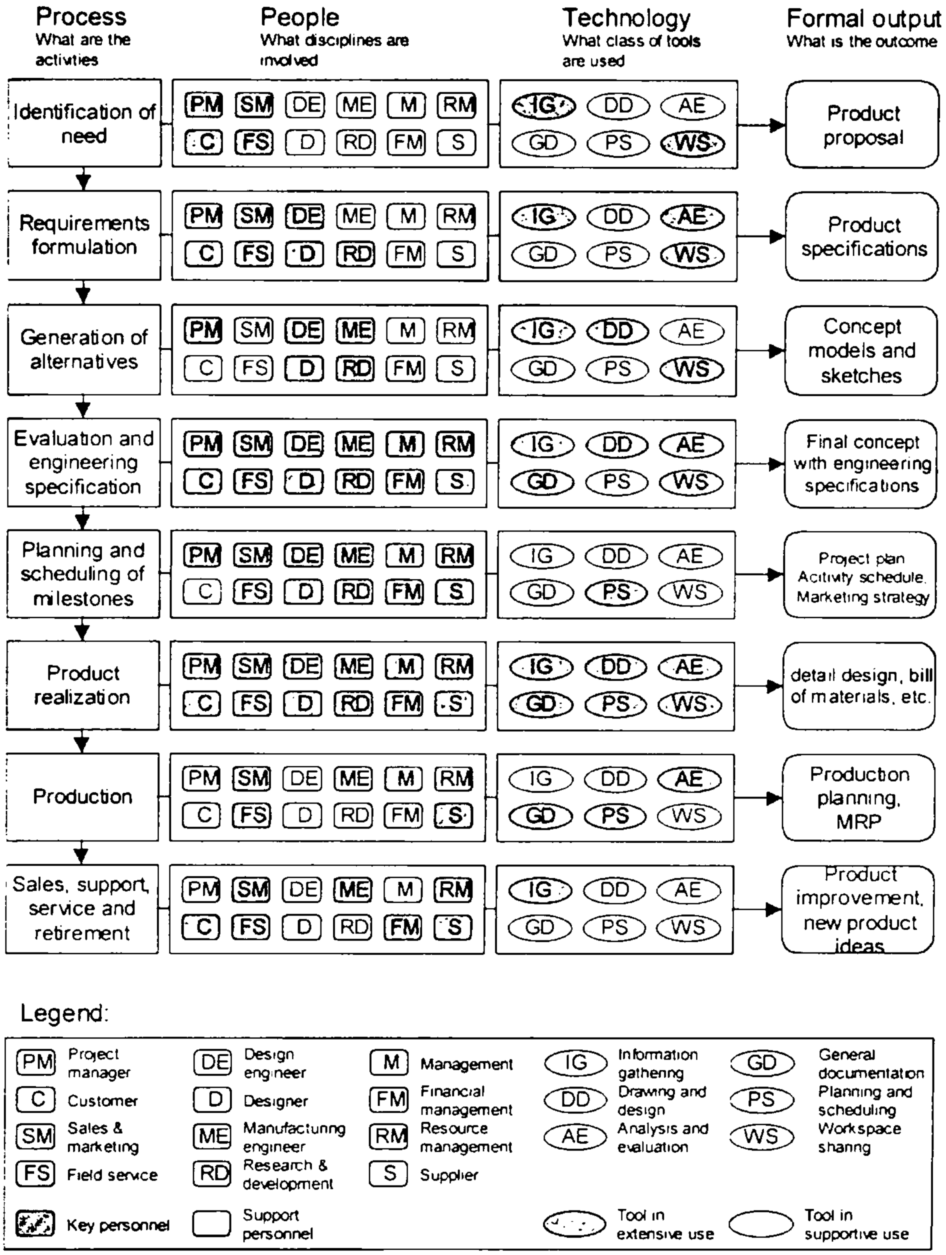


**Figure 1.** New product life cycle model.

## 4. The Collaborative Environment Framework

Based on the requirements of a new product life cycle, the framework shown in Figure 2 has been developed to support concurrent engineering in a virtual collaborative environment. The framework is the synthesis of a number of concepts found in the research literature [1,7,9,22,23]. Following this framework, a working system can be implemented using off-the-shelf and custom software technology available today. The framework is most useful, however, for generating a common understanding of the product life cycle environment for the purposes of discussing issues that an organization might face when implementing a collaborative environment architecture.

The framework in Figure 2 has been broken down into four different layers. Working downward, each layer must have its components compatible with the previous layer such that, for example, all of the application tools are compatible with the information management and storage systems. The components within a layer should complement each other without a great deal of functionality overlap. The whole system must also be designed to support the humans in performing value-added services for the organization. A detailed description of the framework layers follows.

### 4.1 Organizational Knowledge Layer

In the framework presented, the organizational knowledge layer is at the core, providing intelligent storage and retrieval services to the other layers. It is also known as organizational memory [24], and consists of an information storage system and an information management system that can be thought of as a library and a sophisticated librarian.

Other functions of the knowledge layer include the ability to intelligently assist in, or independently work at, bringing new knowledge into the organization from, for example, a network of other organizations using the World Wide Web. The information management system would also look after the routing, posting and storage of e-mail, newsgroups and threaded discussions.

### 4.2 Application Layer

The application layer provides the tools with which the engineers and others perform their tasks. The tools are used to transform information coming from the wisdom layer (the people) into information objects (documents, design drawings, analysis data, etc.), and to modify and view the information stored in the knowledge layer. The tools should be complementary and use common functions where possible [25].

The tool categories identified in this layer provide support for recurring activities within the product life cycle as outlined in Section 2. These categories cover most types of tools and provide a useful generalization for discussing the framework.

### 4.3 User Interface Layer

The user interface layer should provide a common "look and feel" to the different tools, and launch the appropriate application for the task at hand [23]. The user interface layer also provides the real time collaboration capabilities through a workspace sharing application, which can include text based chat, audio communication, video conferencing, whiteboards and more. The user interface should make the use of tools transparent and intuitive so users can focus on the task at hand instead of fumbling with the tools used to assist them.

### 4.4 Organizational Wisdom Layer

The organizational wisdom layer is the group of people who make up the organization. They provide the wisdom to assimilate information into the organization, to create new products, and to generate better methods of producing products. Because people are the key to successful organizations in the future, the infrastructure should be developed

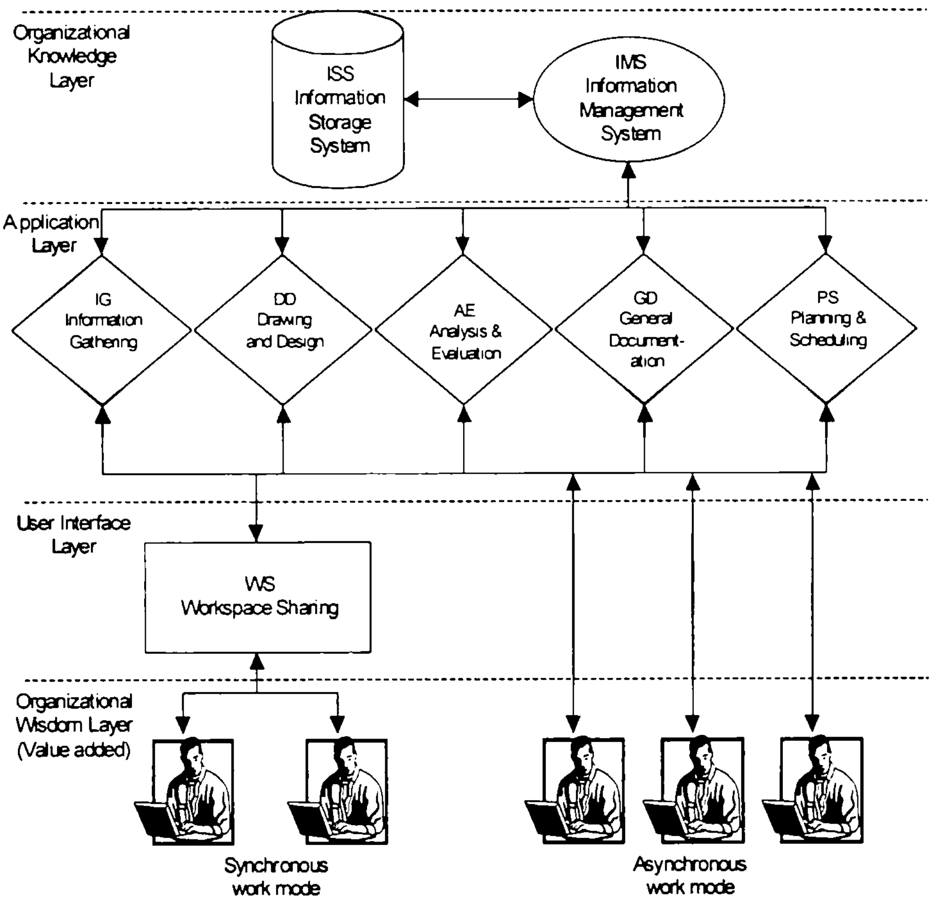


**Figure 2.** A collaborative environment framework to support a product life cycle.

as a natural extension to human capabilities, rather than using humans as an extension to the system capabilities [1,6,22].

## 5. A Prototype Implementation

A prototype implementation was developed to verify the framework, and to help further expose the real issues that people face when developing a product using concurrent engineering in a virtual collaborative environment. The prototype does not have an elaborate infrastructure to support the multitude of activities that take place in a large organizational setting, but it does contain the essential components of the framework that will allow a product development team to carry out a single design. To emphasize this difference, we will substitute "team" for "organization" in the description of the prototype implementation.

The prototype was based on standard, low cost and readily available hardware and software. The system was assembled in different rooms in the same building, connected by a LAN. This simplified testing, and eliminated current Internet bandwidth limitations as a consideration. The tools and applications used to implement the framework layers are described next.

### 5.1 Team Knowledge Layer

The repository for information gathered and produced by the team is simply a network directory on a file server. The simple prototype requires team members to directly manage the storage, indexing and retrieval of information. The software chosen for the application layer was able to assist in version control, permissions, and workflow. These functions are built into many of the Microsoft software applications, but are only capable of supporting the application within which it resides. In an ideal system, however, version control, permissions, and workflow would be left to the information management system in the knowledge layer. Commercial information management systems are available that provide this functionality.

### 5.2 Application Layer

The application layer contains the tools that the team members use in the many activities occurring during the product life cycle. Again, because of the size and scope of the planned study, the number of tools was kept to a minimum. The framework allows tools to be added incrementally as needed to support specific activities.

#### *5.2.1 INFORMATION GATHERING*

Information gathering tools included a web browser (Microsoft Internet Explorer), a scanner, and a video capture system. These tools allowed team members to gather and capture new information from the World Wide Web, from text and reference books, and from the building and testing of the product.

#### *5.2.2 DRAWING AND DESIGN*

The drawing and design activities were supported by a simple drawing program (Microsoft Draw) and a graphics tablet. Although these are very primitive tools for engineering design, they were chosen for simplicity of use. Using the tools, team members could create primitive shapes (circles, rectangles, lines) or draw freehand to convey and capture design ideas.

#### *5.2.3 ANALYSIS AND EVALUATION*

A spreadsheet tool (Microsoft Excel) was used to support the analysis and evaluation activities. With this tool, team members could perform and capture quality function deployment rationale, and generate and record test scenarios for the product as well.

#### *5.2.4 GENERAL DOCUMENTATION*

A word processor (Microsoft Word) and a presentation application (Microsoft PowerPoint) supported general documentation activities. These tools allowed team members to embed video, audio, graphics and text into a single information object. They could be used, for example, to create a product development file, which includes descriptions, pictures, drawings, audio discussions, and even full motion video of the product in action.

#### *5.2.5 PLANNING AND SCHEDULING*

Both the word processor (Microsoft Word) and the spreadsheet application (Microsoft Excel) could be used to support planning and scheduling activities. For more sophisticated planning, a tool like Microsoft Project should be used.

### 5.3 User Interface Layer

The user interface layer is based on a Microsoft Windows environment, with icons for each application tool. There is also an icon for the team design file and one to evoke a synchronous collaboration session using an Internet collaboration tool (Microsoft NetMeeting). The Internet collaboration tool allowed team members to communicate using audio, video, text-based chat, and whiteboard and also enabled application sharing. Team members can share ideas, discuss and markup design concepts, modify design sketches and drawings, view each others work space, and collaborate synchronously on a document as well as perform many other activities.

### 5.4 Team Wisdom Layer

The team wisdom layer is where creativity enters the product life cycle. Using information, tools, and personal experience, team members can generate a multitude of feasible concepts, perform a battery of analyses, discuss and evaluate design issues, and create a unique product that can perform to specifications. The key to the framework and prototype implementation is to allow this creativity to be exercised uninhibited by the system being used to capture it.

## 6. Exploratory Study

The prototype virtual collaboration environment was used to simulate four separate collaborative product development sessions. Each simulation involved a team of two to four people, located in two separate rooms. Each team received a half-day of instruction on the process and tools, followed by a half-day product development simulation. The participants performed the roles of technicians and engineers (technicians in one room, engineers in the other). Each person had access to certain information and tools that may be required or helpful in carrying out their responsibilities. Table 1 shows the responsibilities, information, and tools associated with each role. The participants were all students, ranging from high school level to engineering postgraduate level.

Information about the usefulness of the framework and the supporting collaborative environment was gathered using two methods. The first was an observational method in which an observer recorded the tools used by the participants in the different phases of the product development cycle. The observer also recorded comments made by the participants during the process. The observer sampled chat sessions, saved whiteboard sessions and obtained screen captures for further observation and analysis. The second method utilized a questionnaire given at the end of the session, which asked participants about the effectiveness of the environment and the tools that were used.

Each team was asked to develop a mousetrap-powered device satisfying specified design requirements. The materials for construction of the device consisted of a large assortment of Meccano pieces (metal plates, bars, gears, wheels, rods, nuts, bolts, etc.), an unlimited amount of fishing line and string, and a maximum of two spring-operated mousetraps. The teams were then instructed to collaborate and carry out the product development process with the final output being a product development document that includes a project plan, concepts, engineering specifications, design rationale, detailed design, a prototype, and results from testing the prototype.

### 6.1 Results of Questionnaire

The following tables (Tables 2, 3, and 4) provide a summary of the results obtained from the questionnaire given to the twelve participants. Because of the nature of the study (not a controlled experiment) and the sample size and composition, detailed statistical analysis is not appropriate. Instead, the responses documented here indicate initial support and criticism of the models, and serve to point at issues that are worth further investigation.

The tables show the number of participants who gave a particular response in brackets, and the percentage of participants who gave that response beside it.

## 7. Observations

### 7.1 The People

Participants were recruited from two places: high school students who had been involved in engineering competitions, and university engineering students both graduate and undergraduate. Participants were given a minimal amount of information about the design project the day before the study took place. Twelve people participated in the study. Their ages ranged from 17 to over 30, and their education ranged from secondary school graduates to university engineering graduate level. Eleven of the twelve participants were at least familiar with computers and a range of software, and one person knew only the basics. Most of the participants had been involved in teamwork more than three times. Few had used computer systems to collaborate before this study. Participants were assigned to the role of either engineer or technician based on their preference or by random assignment at the beginning of the session.

Although none of the participants were familiar with all of the hardware and software tools used in this collaborative system, after a short (half-hour) demonstration session, they quickly became effective at using them. It also did not take long for the participants to decide on which tools they preferred to use for communication. It was much more difficult for the participants to adapt to understanding and completing activities in the design process, presumably because most of them had no previous design experience (even the graduate engineering students had limited design experience). None-

*Table 1. The roles of participants in the study.*

| Role | Responsibilities | Information Available | Tools Available |
|---|---|---|---|
| Technicians | Component testing<br>Prototype development<br>Prototype testing<br>Product documentation | Component specifications | Test instruments, hand tools, building equipment, information gathering, general documentation |
| Engineers | Product documentation<br>Develop tests and interpret data<br>Document design | Governing equations<br>Technical data<br>Product performance requirements | Design documentation, analysis and evaluation, information gathering, general documentation |

***Table 2. Results of questionnaire: Part A—participant profile.***

| Age of participants | 16–19 | 20–24 | 25–30 | 30+ |
|---|---|---|---|---|
| | (8) 67% | (1) 8% | (1) 8% | (2) 17% |

| Education level | Grade 12 | Grade 13/OAC | College/ University |
|---|---|---|---|
| | (1) 8% | (6) 50% | (5) 42% |

| Career status | Working | Unemployed | Student | Other |
|---|---|---|---|---|
| | (3) 17% | 0 | (10) 83% | 0 |

theless, because the design document template was laid out in the same order as the process, the teams generally followed the product development sequence.

Two study sessions were conducted using teams of two people (one engineer and one technician) and two other sessions used teams of four people (two engineers working in the same room and two technicians working in another room). The sessions that involved teams of two people would be best classified as mutual collaboration. Their collaboration over the network was much richer than the sessions involving teams of four. This was probably due to the fact that the teams of four could discuss designs with the other person in the room. In the two sessions with teams of four, the collaborative system was used mostly to inform rather than to work together, which would best fit the classification of exclusive collaboration.

Overall, the participants responded positively to the collaborative environment, with most of the difficulty stemming back to the lack of experience in design.

At the end of the questionnaire, participants were invited to comment on the collaborative environment and the teamwork experience. The responses could be categorized into a number of common themes. One theme was the participants' satisfaction with the activity, which is typified by the comment "I really enjoyed this experience. It was well presented and I had fun." Another theme was on the activity process, and the comments varied from "need personal contact for design beginning; project too complex for proper completion" to "I thought that the life cycle process helped very much to organize the work into easily manageable components." A third theme of the comments focused on the technical aspects of the system. These comments included "clearer audio would have helped communication; some difficulty with computers/interaction," "need better communication be-

***Table 3. Results of questionnaire: Part B—previous experience.***

| Question | Response | |
|---|---|---|
| Which statement best describes your knowledge of computers and software? | I rarely ever use computers and don't know much about them. | 0 |
| | I have used computers before but I'm not very familiar with them. | (1) 8% |
| | I sometimes use a computer and know how to work the software I use. | (3) 25% |
| | I often use a computer and am familiar with a range of software tools. | (6) 50% |
| | I have a comprehensive understanding of computers and software. | (2) 17% |
| Which statement best describes the majority of your experience with working in teams? | I have never really worked as part of a team before. | (1) 8% |
| | I have worked in a team before, and each member did mostly their own work and there were never many interactions. | (5) 42% |
| | I have worked in a team before, and sometimes we worked independently while other times we had many interactions. | (4) 33% |
| | I have worked in a team before, and our work was very interdependent so there were many interactions. | (2) 17% |
| How many times have you worked in a team including school and social settings? | 1 or 2 | (1) 8% |
| | 3 to 5 | (3) 25% |
| | 6 to 8 | (2) 17% |
| | 9 or more | (6) 50% |
| Which statement best describes how you have felt about work in teams in the past? | I mostly enjoy working in teams. | (1) 8% |
| | Sometimes I liked working in teams and other times I haven't; it depends mostly on who the other team members are. | (4) 33% |
| | Sometimes I liked working in teams and other times I haven't; it depends mostly on the task. | (6) 50% |
| | I have worked in teams before, but I prefer mostly to work on my own. | (1) 8% |
| | I have never worked on a team before. | 0 |

***Table 4. Results of questionnaire: Part C—experience in this project.***

| Question | Response | | | | |
|---|---|---|---|---|---|
| Was the information presented in phase one clear and understandable? | Yes | No | | | |
| | (12) 100% | 0 | | | |
| Was the information given on the product life cycle helpful for this project? | Yes | No | | | |
| | (8) 67% | (4) 33% | | | |
| How would you rate the usefulness of the tools you used to collaborate? | 1—poor | 2 | 3—sat. | 4 | 5—excel. |
| | 0 | (2) 17% | (3) 25% | (6) 50% | (1) 8% |
| Which are the two tools you found most useful for communicating your ideas? | Text based chat | | | | (10) 83% |
| | Whiteboard | | | | (5) 42% |
| | Video capture/conference | | | | (5) 42% |
| | Synchronous workspace sharing (NetMeeting) | | | | (2) 17% |
| | Audio communication | | | | (2) 17% |
| Which two tools did you find most difficult to use during the project? | Audio communication | | | | (7) 58% |
| | Synchronous workspace sharing | | | | (6) 50% |
| | Whiteboard | | | | (2) 17% |
| Are there any tools or features that you did not have, that you think would have been helpful in collaborating on this project? | Conventional telephone system | | | | (7) 58% |
| | Dedicated communication computer system | | | | (4) 33% |
| | CAD software | | | | (3) 25% |

tween the engineer and the technician," and "the whole setup was great because of the sharing of information in real time allows the different software to work together. I think it is very efficient." Other comments not quoted were similar to these in nature.

### 7.2 The Process

Because of the nature of the project and the allocation of equipment, the engineers focused their efforts on documentation of the design while the technicians focused on construction of the prototype. It is interesting to note, however, that all of the participants who took on the role of engineer indicated that they found the information given about the product life cycle helpful, whereas most of the technicians indicated that they did not find it helpful. This may be due to the fact that the engineers were constantly exposed to the process while working on the document, whereas the technicians followed an ad-hoc strategy of solving technical design problems as they came up during the prototype construction.

Following along the sequence of the project life cycle, a descriptive summary of the observed and documented performance of the teams during each activity is given as follows.

#### *7.2.1 INTERPRETATION OF NEEDS*

The engineers generally completed this activity by either summarizing or cutting and pasting the project objective stated on the study web site into their document. Little discussion took place, and the team relied on their memory of reading the objective during phase 1 of the project.

#### *7.2.2 REQUIREMENTS FORMULATION*

The requirements formulation activity was handled similarly to the interpretation of needs. While the engineers were documenting the requirements, the technicians were taking inventory of the construction equipment.

#### *7.2.3 GENERATION OF ALTERNATIVES*

This activity generally involved a great deal of collaboration. Teams developed, presented and discussed ideas using the many tools available. Sometimes the teams documented their ideas and then presented them to the other member(s), while other times they would try to describe the idea as they were thinking, and then document it later.

#### *7.2.4 EVALUATION AND ENGINEERING SPECIFICATIONS*

The evaluation of the concepts was partly done through discussion among team members, but more by building and testing a simple prototype mechanism. The engineer(s) usually observed the prototype testing and documented the results, but the decision of whether or not to continue with the idea was most often made by the technician(s). Engineering specifications were generally not done.

#### *7.2.5 PLANNING AND SCHEDULING OF MILESTONES*

This activity was not done by any of the teams. Two of the teams did however keep a record of activities and their start/finish time after they had occurred.

#### *7.2.6 PRODUCT REALIZATION*

The technicians produced the prototype product, and information (video or diagrams) was passed on to the engineers for documenting a detailed design. In one case the engineers created the bill of materials based on the information provided by the technicians, in another the technicians created the bill of materials themselves. The other two teams did not create a bill of materials at all. In general, the product development rationale was not documented, although some teams directed the reader to the saved chat file where text based discussions had been recorded.

### *7.2.7 PRODUCT TESTING*

Although prototype testing by the technician(s) occurred throughout the project, the product testing discussed here refers to when the scoring was done. Technician(s) performed the testing, and the engineer(s) observed using video conferencing.

### *7.2.8 PRODUCT ENHANCEMENT DISCUSSION*

In general, discussion about product enhancement was limited. It was the engineer(s) who documented some ideas for product improvement and comments about the design.

## 7.3 The Technology

Participants generally found the text based chat program to be most useful and reliable for communicating their ideas

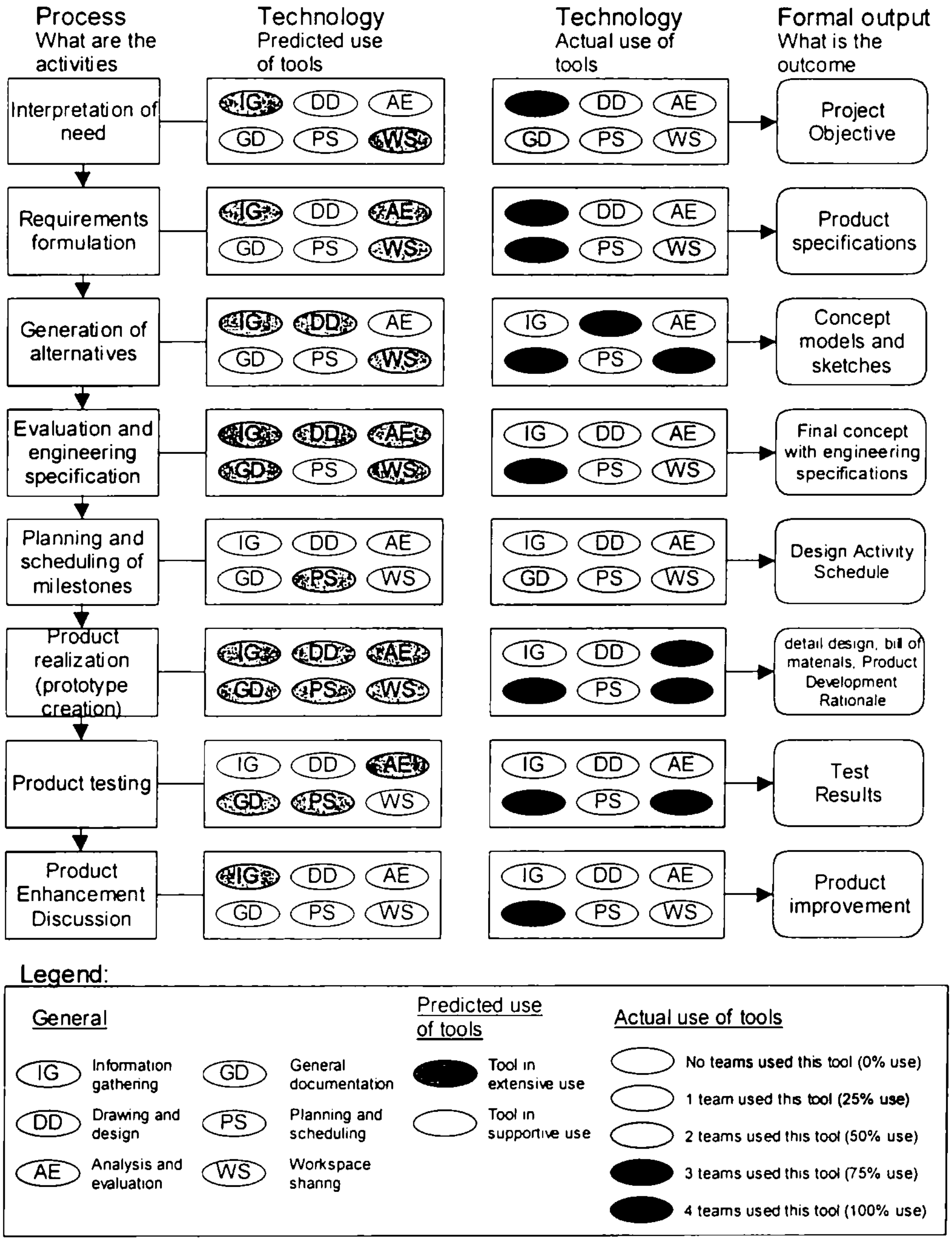


**Figure 3.** Observations of the tools used during the project process.

to one another. Some of them used the chat session records for documenting design rationale and discussions. They also found the video conferencing tool and the whiteboard equally useful as different methods for conveying design prototype ideas. Participants indicated that they found the audio communication useful, but that is was awkward because of the echoing and the two-second delay in receiving the signal. They also mentioned that the application-sharing feature of NetMeeting was slow and cumbersome and that it inhibited the use of the computer for other things. Part of the problem seemed to be attributed to screen clutter (trying to view multiple applications at once). This made it difficult to see the applications at the same time as the communication channels windows (video, chat, whiteboard).

As the participants went through the project life cycle, the tools that the teams used in each activity were recorded. Because of the simplicity of the prototype implementation, the lack of experience of the participants, and the techniques used to observe and record the activities, the observations recorded in Figure 3 simply act as a general indicator for the validity of the 'Tools Used' part of the product life cycle. Also, because the last two phases of the project life cycle do not correspond to the New Product Life Cycle Model of Figure 1, the uses of tools are not expected to be exactly the same.

## 8. Conclusions

This paper presents a product life cycle model incorporating elements of people, process and technology, and proposes a framework for virtual collaboration. An exploratory study using a prototype implementation suggests that the model and framework are effective in supporting distributed concurrent engineering teams. There is evidence that people are fairly quick to adapt to new technology but find it much more difficult to conform to a new or unfamiliar process. Finally, the virtual collaboration process captures and records design rationale that might otherwise be lost in conventional collocated collaboration.

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