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**Modeling and Implementing
Concurrent Engineering in a Virtual
Collaborative Environment**

By

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of the requirements for the degree of
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ABSTRACT

Many companies are creating interdisciplinary concurrent engineering teams to collaborate on product development projects from dispersed locations. Problems these companies face stem from the lack of understanding of technical, organizational, and procedural requirements for such activities to take place effectively. This thesis addresses the people, process and technology problems by drawing on the research of multiple disciplines, and developing integrated conceptual models of the product life cycle, and the virtual collaborative environment. 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. Implementing the two models in a simple prototype architecture, an exploratory study is then used to gain insight into the issues of concurrent engineering in a virtual collaborative environment, and to identify future research directions.

Keywords: virtual collaboration, concurrent engineering, modeling, groupware, product life cycle, design, computer-supported cooperative work, CSCW

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NOMENCLATURE

ATM – Asynchronous Transfer Mode

ADSL – Asymmetric Digital Subscriber Line

CAD – Computer Aided Design

CAE – Computer Aided Engineering

CAM – Computer Aided Manufacture

CAPP – Computer Aided Process Planning

CE – Concurrent Engineering

CNC – Computer Numerical Controlled

CPM – Critical Path Method

FEA – Finite Element Analysis

GUI – Graphical User Interface

IMS – Information Management System

ISDN - Integrated Service Digital Network

PDM – Product Data Management

PERT – Program Evaluation and Review Technique

QFD – Quality Functional Deployment

STEP - STandard for Exchange of Product data

TEAM – Technologies Enabling Agile Manufacturing

VRML – Virtual Reality Modeling Language

URL – Uniform Resource Locator

HTML – Hypertext Markup Language

1 INTRODUCTION

1.1 OVERVIEW

Globally Competitive Environment

Global competitiveness is one of the most important issues in manufacturing business today. There is hardly a manufacturing company in the world that will not be affected, and many are looking for new ways to stay competitive. The problem is that competitiveness no longer hinges on a single solution. Changing elements of the technology, the process, or the people alone will not stabilize a company's competitive edge for long, in a market where rapid and unpredictable change is the norm. Some say the answer is agile manufacturing [1].

As defined by Goldman, Nagel and Preiss [1], to be agile is "...to be capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities". In a general sense, agile manufacturing puts the focus on building a customer base by providing valued products in a very dynamic global market [2]. In the past, manufacturing companies could successfully compete in their local market either by being the only company to supply a particular product, or by producing products cheaper through the optimization of mass production. These companies typically focused on reducing price as a means of maintaining market share. In contrast, a company successfully competing in the current global market often has the following characteristics [3]:

- Focus on the customers
- Quality-driven (as opposed to cost or schedule driven)
- Elimination of waste (time, materials & resources)
- Significant employee involvement
- Continuous improvement of product and process

Industry leaders and the United States Government have created a program called TEAM (Technologies Enabling Agile Manufacturing). The purpose of this program is to “...develop, integrate, and deploy leap-ahead technologies enhancing the responsiveness, flexibility, and cost-effectiveness of U.S. industry” [4]. The TEAM program identifies thrust areas that are the backbone of an Integrated Agile Enterprise [4]. This thesis focuses on two concepts that support elements of these thrust areas, namely: concurrent engineering and virtual collaboration.

Concurrent Engineering was first defined by the Institute for Defense Analyses in report R-338 published in 1986 as follows [5]:

Concurrent Engineering is the systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support. This approach is intended to cause the developers to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.

Concurrent engineering principles are a vital part of a company competing in the global market because they embed agile manufacturing characteristics into the product life cycle. Concurrent engineering encourages designers and engineers to focus on the customer by placing sales, marketing, and even the customer on the product development team. It allows product development to be quality driven by creating integrated feedback loops throughout the company and its market. It eliminates waste by providing an infrastructure to support work in parallel, and the information to track time, material and resources. It forces a company to consider employees as valuable resources as opposed to dispensable assets. Finally, concurrent engineering enables continuous improvement of product and process by creating interdisciplinary teams of people who can optimize the product and process together while satisfying all of the customer requirements.

Virtual collaboration occurs when two or more people who are in geographically different locations work together on an activity. It allows individuals and companies around the globe to join forces in order to eliminate redundancy, minimize waste, and maximize agility in response to market changes and customer needs. Using virtual collaboration, two or more companies can collaborate for the life of a product, then

dissolve the relationship once the product has matured. Combined, concurrent engineering and virtual collaboration allows companies to develop a larger range of better products faster and cheaper than ever before. Coupled with other technologies and methods identified by TEAM, they enable an agile enterprise to exist and thrive.

Research Issues

Understanding the issues of concurrent engineering in a virtual collaborative environment requires surveying a broad range of disciplines from computer science through engineering design and production management to industrial/organizational psychology. Research in the engineering domain alone fails to capture the essence of the global product development process because the literature is based on one perspective: engineering. In order to expand our understanding of concurrent engineering and virtual collaboration, areas on the fringe of engineering science must be considered. To this end, a number of issues on the borders between the engineering realm and other realms are investigated and described. These include the people issues examined in industrial and organizational psychology, the business issues examined by business management and the machine intelligence issues examined by computer science.

1.2 OBJECTIVE AND METHODOLOGY

The objective of this thesis is to develop models for both the product life cycle process and a virtual collaborative environment, and then implement and study them in a simple test architecture. There is a dual purpose to this objective. The main purpose is to develop two models that clearly show how the people, process, and technology fit into both a product life cycle and a virtual collaborative environment. The secondary purpose is to highlight the issues that an organization may face in using the models, and suggest methods of addressing them.

Development of the first model is achieved by looking at the people, process and technology issues involved in the product life cycle. In doing so, a holistic view of concurrent engineering is generated and discussed, and a comprehensive model of the

product life cycle is produced. The framework to support the product life cycle in a virtual collaborative environment is then generated based on the requirements of the process and an understanding of the technological and people issues that are involved in the changing organizational climate. The framework is designed to be scalable so that large multinational companies as well as small and medium-sized manufacturers can use it.

To implement the framework, current off-the-shelf technology is used to produce a working model for an exploratory study. The importance of using off-the-shelf technology is that it represents what small and medium sized companies can reasonably obtain. The working model is used in a study involving teams working on a simulated product development project. Conclusions and future work focus on the strengths and weaknesses of the model, suggest areas of improvement for the technology implemented, and identify areas of future research.

Outline

This outline is followed by a discussion of the issues addressed in the thesis, and a list of related issues that are beyond the scope of this work but important to be aware of. Also included is a discussion of the special needs of small and medium sized manufacturers.

Chapter two focuses on generating a comprehensive understanding of important issues in creating a virtual collaborative environment for concurrent engineering. First, a process model of the product life cycle is developed based on common themes of the many different versions cited in the literature. Next, product development tools, concurrent engineering, virtual collaboration, and the organizational setting are studied in depth based on the research literature that has been produced in the past. A snapshot view of the current technology to support this environment in industry is then discussed. In the last section, experimental studies are reviewed.

In chapter three, a holistic view of concurrent engineering in a virtual collaborative environment is developed. The first section focuses on the product life cycle activities, and looks at how these activities can be performed in a virtual collaborative environment.

The second section focuses on the concepts of communication and archiving. It looks at how computers have changed the way people work, and offers a view of how work may be done in the future.

In chapter four, the two models developed in this thesis are presented and explained. The first is a model of the product life cycle for new products, which incorporates the process, the people, the technology, and the formal output. The second model is a framework for a virtual collaborative environment, which includes four organizational layers.

Chapter five describes the elements of a simple working model that was developed and implemented using off-the-shelf software products, and based on concurrent engineering principles. In the second section, there is an explanation of how the working model maps to the virtual collaborative framework, and a description of the tools used within it. The third section explains the hardware architecture for the working model.

In chapter six, an exploratory study using the working model is described. The first section presents an overview of the study, and the next four sections discuss how the study was conducted, with the last section giving an overview of the product that was developed by the participants in the study.

Chapter seven presents a summary of the results obtained and observations made during the study. It also includes a discussion of the issues that surfaced. The results and observations are laid out in categories relating to the participants' reaction to the environment, the process that was followed to develop the product, and the technology that was used to collaborate.

Finally, in chapter eight, some conclusions are presented and directions for future work are recommended.

Issues Addressed

The focus of this research is on the development and implementation of scaleable models that address many of the current research issues (listed in the next section). The models are based on the process of bringing a new product to market using concurrent

engineering principles and in a virtual collaborative environment. The issues addressed are of a general nature relating to the process and the types of tools that are used within that process. This approach is an alternative to the large amounts of research into specific tools that are being developed for particular applications. In other words, the purpose of this research is not to investigate or develop specific software tools such as CAD data exchange systems, but to develop a models into which companies can plug off-the-shelf support tools that are available now or in the future. In order to implement the model, however, a sample of available simple support tools are investigated, implemented, and discussed.

1.3 RELATED ISSUES

In choosing the research focus, a large number of recent concurrent engineering books, research and industry journals, and local industry representatives were consulted. After compiling the information gathered, it became apparent that a number of issues still need to be addressed before concurrent engineering in a virtual collaborative environment can become a reality for most organizations. The main issues that surfaced again and again were: simplifying product data exchange, creating intuitive technology interfaces, changing corporate culture, and providing integrated solutions. Although a review of these issues is beyond the scope of this work, knowledge of the state of the research in these areas was an important part of the literature survey, and key to the development of a product life cycle model and virtual collaborative environment framework.

Special Needs of Small and Medium Sized Manufacturers

Small and medium sized manufacturing companies usually have limited capital and human resources available to dedicate to implementing concurrent engineering and maintaining an organizational framework to support it. Thus, the systems developed to enhance concurrent engineering and intra-company networking capabilities must take this into account. A framework should be simple enough for diverse disciplines to understand, general enough to accommodate most manufacturing operations, and specific

enough to be of value to an organization wanting to utilize it. The system of integrated tools used or developed to plug into the framework should be simple to use, easy to maintain, easily integrated, and above all, inexpensive. The system should also be robust enough to handle inadvertent misuse by inexperienced employees, as training time and budgets are often limited in these operations.

In an article on the future of manufacturing firms, Ashley [6] indicates that small and medium sized companies will become integral parts of a global manufacturing network by forming and dissolving partnerships with companies having different core competencies. The key enabler to the collaboration is interoperable business, engineering, and manufacturing hardware and information systems that will allow concurrency in the product development process. By initiating the move to concurrent engineering in a virtual collaborative environment now, small and medium sized manufacturing firms will be prepared for the future.

2 LITERATURE SURVEY

2.1 THE PRODUCT LIFE CYCLE

The way the product development process is executed has changed dramatically over the last few decades, although the basic process itself has not. In the past, the bulk of product development was performed by designers and engineers working with a clearly defined set of constraints set out by some higher authority within the company. Usually, the design was based on solving a specific problem, whether it is to improve an existing product, or create a product to fill some need [7]. Currently, teams comprised of designers, engineers from multiple disciplines, and representatives from many other divisions of a company take part in the product development process. Most times it is the customer that specifies the requirements, which are then translated into functional, engineering and product requirements by the product development team. The result of more diverse involvement and communication in the process is the ability to generate more integrated and complex products as well as to respond to the customer's needs more effectively.

Although the way in which the product development process is carried out has changed, the fundamental activities that take place remain the same. In the concurrent engineering approach, for example, many activities are undertaken simultaneously as opposed to sequentially, but they are essentially the same activities regardless of order. As well, each company involved in the product development process may use different terminology or a slightly different version [7][8][9][2] [10], but in general the product development process proceeds as shown in Figure 1.

In a concurrent engineering environment, product realization is carried out by multidisciplinary teams working in a collaborative manner. The process involves communication, negotiation and team learning [22] and must be supported by the organizational infrastructure in which it takes place. Individuals from different disciplines

must have the ability to work autonomously, as well as access to the information needed to make good decisions. Efficient communication is key to successful coordination among team members.

Figure 1 – The New Product Life Cycle

In general, studies show that over 70% of the cost of a product is determined in the design phase of product life cycle while the cost of design is often less than 20% of the total cost of the product [11][12][2]. This factor alone should give manufacturing organizations the motivation to make efficient and effective use of resources in order to ensure that the design is optimized, and it satisfies all of the customer's requirements. The best way to do this is to include many of the people who will be involved with the product (production, sales, customer support etc.) in the product development process. In this way, problems are worked out early in the product development process, and the number of refinements late in the process can be minimized. This is a vital element of concurrent engineering.

2.2 PRODUCT DEVELOPMENT TOOLS

When developing new design tools, one should be aware of the current practices of the design engineer in order to aid in the understanding of the design environment. Ion and Neilson [22] 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. 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. To this end, a systematic approach has been used to identify how tools are used to support the product life cycle.

According to Tsai, Chiou and Hsu [13] there are four major groups of software tools used to support the design process in a virtual design environment. First, drafting and drawing tools are necessary to create representations of the product. Analysis and evaluation tools are used to test and verify the attributes of the design. Communication tools are implemented to facilitate discussions among the design team as well as store information gathered and generated during the process. Finally, information converting tools are used to translate product specifications into the format required by the different design tools.

Many engineering researchers are developing software tools to assist an engineering designer in the various stages of design process from conceptual design [14], to design review meetings [15]. Work is also being done to develop knowledge based engineering systems that will help designers use information from previous experiences for continuous improvement of products [16]. The objective of this research initiative is to identify what tools are required and when, by looking at the activities carried out within a new product development life cycle.

2.3 CONCURRENT ENGINEERING

In their description of concurrent engineering, Negele, Fricke, and Wenzel [17] highlight seventeen essential components for successful product development environments. Interestingly, most of the components are people centered, focussing on the attitudes, communication, responsibility and competence of the members of the design team. In his book on concurrent engineering, Prasad [2] identifies eight fundamental principles of concurrent engineering. These principles cover a broader range of activities and again are focused on the people and process aspects of product development. A list of the elements of concurrent engineering compared to traditional product development is shown in Table 1. The list is not exhaustive but serves to generate an understanding of some of the effects concurrent engineering has on an organization.

Element	Traditional product development	Concurrent engineering product development
Knowledge distribution	Departmentalized	Distributed and available to all involved
Communication	Slow, official, over-the-wall	Rapid, informal, distributed
Customer relationship	Consulted	Part of product development team
Product development goals	Broken down into individual goals	One clear goal shared by individuals
Innovation achievement	Through technical development and advancement	Through creative and holistic design
Product life	Long	Short
Decisions made	Dictated by overseeing executives	Negotiated by empowered teams
Working style	Individuals cooperating	Team collaborating
Reward system	Based on individual achievement	Based on team achievement

Table 1 - Elements of Concurrent Engineering

Once all the elements of concurrent engineering are in place, the organizational and personal rewards are extensive. Benefits for the organization include improved quality, improved production processes, greater cash flows, more profitability and reduced time to market [18]. All of these factors are intertwined with the increased integration of resources and the time saving attribute of the concurrent engineering process as outlined in Figure 2. Benefits for the employee can include greater autonomy, more flexibility and increased worker satisfaction.

Figure 2 – Time Saving Benefits of Concurrent Engineering

2.4 VIRTUAL COLLABORATION

Virtual collaboration occurs when two or more entities that are not collocated must work together to accomplish a common goal. This can occur within an organization, when multiple corporate divisions located in different cities collaborate to develop a new product, or between organizations, when a supplier and an assembler work together to optimize a product's design for assembly.

With the emergence of the global marketplace, virtual collaboration has almost become a necessity among large organizations and is now being explored by many small and medium sized organizations as well. The driving force behind this trend is the need for faster and more integrated solutions to problems that are common to multiple organizations or divisions. When one person alone does not have the resources to solve a problem effectively, collaboration is necessary. When the people who must collaborate are not in the same building, or even in the same country, virtual collaboration provides

the means. The enabler is new technology that allows access to information and shared workspace, and the Internet is a big part of this technology [19].

Virtual collaboration technology includes a wide variety of hardware and software systems and has existed in evolving forms since the beginning of organizations. From the postal service which provides a means of communication and document sharing that is asynchronous and extremely slow, to the collaborative workspace software that provides real time synchronous communication and document sharing over the Internet, these systems enable people to work together on a task toward a common goal.

Paul Kidd [20] refers to virtual collaboration in the agile manufacturing realm as being a joint venture between corporations with complementary core competencies. He sees the corporations being linked together electronically to share information and facilitate team collaboration activities. The proposed benefits are that companies can focus on their core competencies and still respond to rapid market changes and developments by forming and dissolving joint ventures with each other.

Virtual collaboration within an organization has far reaching benefits. Besides providing the means to work toward a common goal, virtual collaboration allows the capture of information that is often lost in face-to-face meetings. During virtual collaboration, information transferred asynchronously (such as electronic messages) can be captured as well as work being performed synchronously (such as electronic whiteboard files). Design rationale, which is often lost once a design is complete, may now be captured and used for developing updated versions of the same design, or new products that have similar features.

In a study on electronic meeting rooms [15] researchers found that groups creating documents using hypermedia in these rooms were more likely to break up tasks and work in parallel. Also, groups were more likely to use a ‘top down strategy’ in planning, and submit proposals on how to divide up and carry through their work. They found that, “in this context, parallel work may offer advantages since the hypermedia documents were also found to be more deeply elaborated.” This provides additional evidence that virtual

collaboration infrastructure can be used in collocated group work as well to enhance the process and outcome.

2.5 THE ORGANIZATIONAL SETTING

Global competition has forced company executives to rethink their values and redevelop their corporate culture. In order to compete successfully, executives are finding that it is necessary to tap into previously unused resources: people. People throughout a company have far more potential to help a company grow and be profitable than they have previously been encouraged to. Table 2 [21] offers some insight into a proposed organizational model called the Sociotechnical Model of Organization . Many forward-thinking companies have been using ideas from the new model for years, while other companies are just beginning to look at it.

Traditional Model	Sociotechnical Model
Technology first	Joint optimization of social/technical systems
People as extensions of machines	Machines as complements to people
People as expendable spare parts	People as resources to be developed
Maximum task breakdown, simple, narrow skills	Optimal tasks grouping, multiple broad skills
External controls: Procedures, supervisors, specialist staffs	Internal controls: Self-regulating subsystems
More organization levels, autocratic style: Unilateral goal setting, assignment of workers	Fewer levels, participative style: Bilateral goal setting, selection of workers
Competitive gamesmanship	Collaboration, collegiality
Organization's purpose only (often with poor understanding/acceptance at lower levels)	Members' and society's purpose also (with good understanding/acceptance at lower levels): Shared vision and philosophy
Frequent alienation: "it's only a job"	Commitment "It's my job, group, and organization"
Tendency toward low risk taking, maladaptation	Tendency toward innovation, adaptation
Less individual development opportunity and employment security	More individual development opportunity and employment security

Table 2- Traditional vs Sociotechnical Model of Organization

Although corporate culture is outside the realm of the engineering discipline, engineers implementing concurrent engineering need to be aware of the issues in order to develop an effective system. 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 [22] 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."

In an article describing the future of manufacturing firms, Steven Ashley [6] describes seven important factors that will affect an organization's ability to compete in the near future. These factors are listed below:

- **Extensive Teaming** is required because companies will not be able to afford to maintain all of their needed skill sets. Teaming improves quality, speed, and cost requirements with the realization that companies cannot afford to work in a decoupled way.
- **Future Firms** will look substantially different than they did in the past. Large companies will be distributed globally, while small and medium sized firms will become an integral part of a global network. Each company will learn to effectively control and leverage their core competencies.
- **Individual Work** will be performed on networked systems and be available to the rest of the organization(s) instantly and dynamically for synchronous or asynchronous collaboration.
- **Internationalization of Expertise** has evolved to the point where every country has capable, clever engineers who can develop products. Thus, the focus of future organizations will be on customized production tailored to customer preferences.
- **Future Manufacturing Methods** will leverage intelligent processes, flexible modular equipment, knowledge based systems, and human wisdom to create agile enterprises that can respond quickly to market changes.
- **Continuous Lifelong Training** continues to be a part of human resource management and will grow in importance as companies require people who are able

to understand a large range of issues and make good judgement decisions based on their knowledge.

- **New Organizational Structures** will emerge that are set up to address market niches. Moving away from the standard hierarchical structure, organizations will progress toward flat, matrix, and fractal structures that enable more agility within the organization.

An integral part of all of the changes that companies must make in order to compete globally is the concept of people working closely together toward a common goal. This is commonly known as group work or teamwork. Before going further, it may be useful to establish a common understanding of the three levels of group or teamwork within an organization. Although workers may have the same overall goal in mind in all three cases, important attributes distinguish between collaboration, coordination and individual work [23]. In collaboration mode, people leverage each other's skills and are working synchronously on the same task. In coordination mode, people are using their particular skills to complete a certain part of a task asynchronously. The work is passed from one person to the next or merged during development until the task is complete. Working in an individual mode, people are individually responsible for the completion of a task, and only seek other's input if needed.

In Table 3, the Arizona Groupware Grid [23] shows the relationship between the productivity processes and the mode of work. Using the grid, and knowing the mode of work desired, an organization can then look at the types of tools that may be required to support the work process productively. An organization that overlooks the relationship between productivity processes and work modes is bound to encounter many difficulties along the way.

	Communication	Thought	Information Access
Collaboration	Parallel Contribution Anonymity	Structured and Focused Processes	Session Transcripts, Automatic Concept Classification
Coordination	Asynchronous Communication	Team Scheduling, Automated Workflow, Project Management	Shared Data Stores
Individual	Presentation Tools	Modeling, Simulation	Information Filtering, Local Data Stores

Table 3 - Arizona Groupware Grid [23]

2.6 TECHNICAL READINESS

A glimpse at the current technology and emerging trends is taken here in order to see how companies might embrace a virtual collaboration infrastructure both now and in the future. There are three main technologies that support the infrastructure: computers, software tools and communication. As well, a number of key drivers in the manufacturing environment are influencing the formation of the next generation manufacturing enterprise.

Computers

By the end of the year 2000 it is estimated that between 400 and 580 million computers will be in use world wide, with 250 to 300 million of those having access to the Internet. [24]. This creates an enormous opportunity for information to be stored and shared in electronic form between and within organizations. Companies must embrace computer technology and exploit its knowledge maintenance and distribution capabilities to stay competitive in the long run. Small and medium sized companies using electronic storage and sharing can leverage the Internet and form virtual enterprises to effectively compete with the large multinational corporations.

The cost of powerful and high-speed computers is being reduced at the same time as software capabilities are expanding to help increase productivity in all realms of business.

These two factors enable small and medium size companies to use sophisticated systems and techniques to enhance their capabilities and exploit their core competencies.

Software

Software systems and tools are being introduced at an incredible rate. The need for integration of these systems and tools has become apparent to software developers and is now beginning to be addressed. According to Trlica [25]:

Engineers these days are able to integrate their other job responsibilities with engineering. They do design, schematic capture, and simulation on the same desktop on which they write reports, do budgeting, and schedule projects. This is made possible by the growing interoperability of engineering tools with programs such as Microsoft's Excel and Microsoft Project.

With the increase integration of software tools, small and medium sized companies will be able to assemble and use powerful information systems with off-the-shelf products available at reasonable prices. Integrated user friendly tools means that companies can spend less time training employees on the computer systems and more time reaping the results of productive work. Also, with the development of intelligent computer agents that perform software tasks on the users' behalf, monotonous chores such as searching through supplier catalogs for a part that has certain characteristics will no longer require as much of a design engineer's time.

Communication

The World Wide Web is expanding at an exponential rate from just 130 sites by the middle of 1993 to over 230 thousand sites by the middle of 1996 [26]. This has created a communication infrastructure that has great potential to enable small and medium sized manufacturing enterprises to develop and use communication and collaboration strategies to compete against larger corporations.

Two of the major inhibitors to the early adoption of the Internet for business communication have been a lack of bandwidth (network speed) needed for effective collaboration, and the issues related to security. There is currently an extensive amount

of work being done to address both of these problems, and acceptable solutions are presently available. New communication technologies such as Asynchronous Transfer Mode (ATM), cable modems, and increased use of Integrated Service Digital Network (ISDN) are bringing the data transfer rate to levels where businesses can effectively collaborate using the Internet. Also, a number of encryption techniques and electronic security schemes have been proposed and developed to address the business security issues [27].

Key Drivers

In an effort to forecast manufacturing business conditions, the US government helped form and fund a group of almost 500 experts from many sources to present a vision of the future manufacturing environment. The effort was called the Next Generation Manufacturing Project, and it identified several key drivers of change that would help shape the manufacturing industry over the next 10 to 15 years [6]. These key drivers included:

- great improvements in computer and communication systems along with distributed information available anywhere,
- increased acceleration of technology change and rapid expansion of technology access,
- globalization of markets and business competition along with global shifts in wage and job skills,
- greater environmental responsibility and limitations on resources, and
- increased customer expectations.

2.7 EXPERIMENTAL STUDIES

A survey of the concurrent engineering literature reveals that few studies of controlled experiments 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 [42][28][29]. There are a few, however, that are useful for illuminating some of the issues that may present themselves in the exploratory study part of this research. The next few paragraphs describe three of them.

The Madefast project [30] 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 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 [31]. 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 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 [32]:

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.

The issues that these researchers identify are important to consider when designing and conducting a study of a collaborative environment. In developing the support system and the study characteristics, these issues are addressed where possible. The main feature that sets the study documented in this thesis apart from others, is that the support system is built using inexpensive off-the-shelf hardware and software, and was developed based on a framework that is scaleable. Thus the system can be used to demonstrate that any individual, or any sized organization can become part of a virtual collaborative environment that supports concurrent engineering activities.

3 DEVELOPING A HOLISTIC VIEW

Concurrent engineering involves much more than changing the product development process from working serially to working in parallel. It also does not just involve engineering. It involves almost every aspect of a company, from its people and corporate culture to the way the company uses its financial and physical resources to generate a profit. A collaborative framework from which a successful architecture can be built must consider all of these factors and develop them into a big picture of how an organization should look. Thus, a holistic view is needed to see how all of the pieces of concurrent engineering fit together to make an integrated environment in which a product can be developed competitively.

Many frameworks for concurrent engineering and virtual collaboration have been proposed over the years [17][33][34]. In their description of the collaborative product development framework, Roy et al include eight dedicated product design services along with a commercial CAD/CAM system [35]. The design services include a concept generation tool, geometric modeling tool, VRML model generating service, feature extraction service, product design database, casting analysis service, process planning service, NC path planning service, and a rapid prototyping slicing service. Frameworks such as these, although well developed, are too specific to be useful for a wide spectrum of industries. What is needed is a general framework that is applicable to any industry from which a custom architecture can be generated and tailored to specific business operations. With this in mind, the approach taken is to look for common elements used in product development across different industries and assemble them into one general framework.

One of the key components of concurrent engineering and virtual collaboration in any industry is communication. Without good communication important information does not get to where it should be in a timely manner. In an organization where people are not collocated, a solid infrastructure is needed to help make sure information is stored and

distributed effectively. Given an appropriate and well-designed communication infrastructure, benefits should include [22]:

- reduced product development lead times,
- reduced level of rework due to communication errors between team members,
- improved documentation of design decisions,
- improved team understanding and ownership of design problems, and
- improved documentation of the design decision making process.

3.1 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 [2][13][17][25], 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. Below is a discussion of the activities and their associated tools.

Information Gathering

Information gathering involves bringing new knowledge, data, or any other type of information into the organization. It is estimated that between 39 and 55 percent of an engineer's time is spent on information gathering and documenting [36] [37]. In this age of information, one would think that effective information gathering tool development would be widespread. In fact, there are many systems and tools developed for gathering

data (statistical process control, test systems, etc.), but few tools are available for gathering intelligible information. The tools that are currently being used (web search engines, CD ROM abstract searches, etc.) have a long way to go in terms of user friendliness and search intelligence.

Technical information used to develop a design usually comes from a variety of sources including engineering handbooks, product catalogs, component libraries and product models of similar designs. New information systems such as the MEchanical Design Information System (MEDIS), use web based technology to produce an information tool to assist people in their design tasks. The system allows design engineers to browse graphics and text showing introduction to a mechanical system (such as gears), as well as details about suggested use, applications, selection, catalog items, and manufacturers [13]. Tools such as this demonstrate a step forward in simplifying the information gathering process.

In a true multidisciplinary collaborative environment, information comes from a variety of sources but must be shared by everyone on the collaborative team. In Table 4, Ion and Nielson [22] highlight some of the design process stages, citing examples of the information that is generated and shared in each stage.

Design Process Stage	Examples of Information Generated/Shared
Market	reports on current market situation, meeting notes, brainstorming notes/sketches
Specification	specification documents, internal and client meeting notes, sketches, drawings, rough calculations, general communications
Concept Generation	brainstorming meeting notes/sketches, meeting notes, sketches, drawings, rough calculations, general communications
Concept Evaluation	Internal and client meeting notes, sketches, drawings, rough mock-ups and physical models, cost evaluation calculations, general communications
Detail Design	Meeting notes, detail drawings and design calculations, final costing calculations, 3-D solid models, detailed mathematical and numerical models, general communications
Manufacture	Final product documentation – manufacturing drawings, bill of materials, test specifications
Sell	Sales presentations, demonstrations, photographs, artwork, presentation graphics etc.

Table 4 - Information used in the design process [22]

Drawing & Design

Drawing and design activities have traditionally been the backbone of the designer's and engineer's visible output. The goal of these activities is to record and convey design ideas in a convenient and consistent manner so that they can be used by other disciplines involved in the product life cycle. There are many drawing and design tools that are currently available, with modern CAD systems being the most highly developed example. New CAD tools have become very powerful, allowing for a great deal of information to be captured in a single design. The problem with these tools is in transferring the information from the software tool that generates it, to other software tools that can use it. The STEP standard for product data exchange is one attempt to overcome this problem by using a vendor neutral format for the exchange of product data. Meanwhile, the software vendors are taking the approach of attempting to incorporate into their software packages all of the software tools that might use design information. For instance, many CAD programs now have Finite Element Analysis (FEA) tools, 3-D viewing tools, work scheduling tools, and more. This approach,

however, forces organizations to standardize on one system and inhibits collaboration between and within organizations using different systems. In their paper on integrated engineering environments Lander, Corkill and Staley [38] point out that of the numerous design-to-manufacture tools, many are incompatible in various technical ways. They suggest that the use of integrated concurrent engineering environments, such as the prototype developed at Ford using blackboard based design and analysis tools, should increase productivity and ease the workload on engineers and designers.

Drawing and design tools also include equipment used to create physical models that help people to visualize the product under development. In the past this was done either manually or with a Computer Numerical Controlled (CNC) machining center. With the advent of free form fabrication, however, engineers and designers now have a new way to create, capture and convey their design ideas.

Virtual Prototyping is another new and emerging method of demonstrating and testing a design. With a virtual prototype, no physical model is ever created. Instead, the design information from a CAD system is passed to an analysis or simulation system that uses the virtual model. Pilot projects have shown successful use of this technology in the area of vehicle design, but suggest that some extensions in simulation tools are needed, as well as a unified product design representation [39].

Analysis and Evaluation

Analysis and evaluation covers a wide variety of activities that take place during a product life cycle. It covers everything from evaluating the customers' response to a new product, to analyzing the strength of material of a certain component. No matter what the specific activity involves, the goal of performing analysis and evaluation is to find either the best solution or the optimum balance of conflicting alternatives. Sometimes the analysis is straightforward with a single solution, as in the maximum stress of a component, and other times it may require judgement as in choosing between functionality and compactness of a device. Whatever the analysis and evaluation activity involves, software tools are often valuable in assisting a person in generating a solution.

The number of analysis and evaluation software tools available is enormous, from general tools such as spreadsheets or even programming languages, to specific tools such as Finite Element Analysis (FEA). Many of the specific tools require some expertise to use them effectively or to interpret the results. A key consideration in selecting or developing analysis and evaluation tools is how to distribute and archive the knowledge gained from these activities in a way that can be easily understood by others who are not experts in that particular domain.

One of the most important evaluation activities that take place in the product life cycle is Quality Functional Deployment [40]. Quality Functional Deployment (QFD) is a formalized process of converting customer requirements into product design parameters [3]. This process is usually performed using a “house of quality” chart that can map the requirements to the design parameters and include a relative weight for each factor. QFD is important because it allows engineering designers to capture the customer’s needs in a way that can be translated directly into engineering requirements.

Design for X is another important tool used in concurrent engineering. It includes design for assembly, design for reliability, design for serviceability, design for quality, and many other aspects of the product design and life cycle. New software tools in this area are making it easier for engineers to consider many aspects of a product in a more convenient way. George Huang, for example, describes a framework and software developed for implementing concurrent engineering by using design for X tools [41].

General Documentation

General documentation is the activity of capturing knowledge in an intelligible form for distribution or for later use. It includes everything from messaging to generating a product development file and can be in the form of graphics, text, audio, video, or any other form of communication. The purpose of general documentation activities is to capture knowledge gained from the design experience in a form that can be easily located and used. Tools that can assist people in this activity range from the familiar word processors, graphics software, spreadsheet software, etc., to tools for meeting support, capture, and access [42]. Many of the new software tools developed for general

documentation are able to embed almost any type of multimedia right into the document. This allows for faster, more intelligible access to a full spectrum of information on a given subject. One of the key factors in an effective documentation system is an effective information management system. A well designed system can speed access to information and reduce the amount of redundancy in the documentation and storage of information.

Planning and Scheduling

Planning and scheduling tasks represent large portions of the activities that a supervising engineer or manager does. These activities provide the roadmap by which project goals are achieved, and involve the time-based allocation of resources [43]. Many tools exist to help people in planning and scheduling activities, from personal planning of daily events, to the planning of mega-projects. The tools range from a personal planning diary to sophisticated software systems that can schedule and track thousands of activities and resources. Even the project manager's well known Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and Precedence Diagramming Method (PDM) are available as software packages that can optimize activity sequence and resource use. A well integrated system of time management and activity scheduling tools can allow meetings to be scheduled, project progress to be tracked, and workflow to be performed, all automatically. The key to the successful implementation of such a system is the cooperation the users and their dedication to updating personal information regularly [44]. With more powerful planning and scheduling tools emerging all of the time, it appears that human ingenuity is the factor that will optimize and exploit these tools to implement concurrent engineering most efficiently.

An example can be seen at Rockwell International Corporation. Re-engineering efforts at Rockwell International Corporation have led to an effective yet simple method of monitoring progress and feasibility of a project while allocating financial resources more appropriately [45]. The company has developed a four-phase process of bringing a new product to market, which is able to speed the development process while reducing the waste on dead end products. The four stages of the project authorization request process guide and provide funding for 1) the market analysis of an idea, 2) the feasibility and

engineering requirements, 3) design and manufacturing, and 4) project postmortem.

Based on the results of each phase, management can decide whether or not to fund the next phase and continue with the product development process.

Synchronous Workspace Sharing

Workspace sharing here is considered the synchronous part of collaboration. It occurs when two or more people are working on a single activity at the same time. For example a design engineer and a production engineer may need to discuss how a product may be optimized for production. The two will need to look at the design, discuss, mark up, and make notes on revisions. With synchronous workspace sharing tools, this can be done electronically with the two engineers in different geographical locations.

Generally, synchronous workspace sharing provides one or more methods of communicating while using some shared software productivity tool synchronously. The communication can be text based, audio, video, graphical or any other electronic media, while the software productivity tool can be a CAD package, word processor, spreadsheet etc. Most synchronous workspace sharing tools also have a method of storing at least part of the collaborative dialog such that it can be used to support the design rationale of a product.

3.2 COMMUNICATION AND ARCHIVING

Information Management Systems

For the purposes of this discussion, communication occurs when the information sender knows who the information receiver(s) will be. An example is when two people have a discussion in order to clarify a design. Information storage (archiving), on the other hand, is what occurs when information is not directed toward any particular individual or group but is made available for future reference or use by others. An example of this would be if notes from a discussion to clarify a design were placed in a retrievable file system. In the past, these two types of activities were handled using different software

systems. As the importance of both activities becomes the focus of concurrent engineering efforts, however, it is apparent that they should both be handled by an integrated Information Management System (IMS).

Product Data Management systems (PDM) are an attempt to provide an integrated way of handling product information, and many systems do this quite well. The problem with these systems is that they cannot handle information that comes from other vendors' PDM systems. This is being addressed by product data exchange standards such as STEP, but seamless solutions are still to be developed. In a virtual collaborative environment where companies temporarily join forces to develop a product and then dissolve the relationship once the project is complete, a seamless information management system is required. The question, then, is what should an information management system do?

An effective information management system should route communication as well as archive it, provide a means of intelligently searching the storage system for information, manage document workflow, keep track of revisions, and provide security. The system should be a layer underneath and independent of the applications that generate or use the information and simply supply the storage and retrieval functionality. To date, no one software system has been observed that can support all of these functions, but the blackboard-based system described by Lander et al., which supports multiagent collaborative activities, is a step in the right direction [38].

Information Processing Levels

Before discussing communication and storage further, it may be useful to develop a common understanding of the levels of 'information' processing that can occur within and between processing systems (be they human or machine). Models that describe the levels of processing on both the machine side [46], and the human side [47] have been proposed, but one that transcends the ranges of machine and human 'information' processing could not be found in the literature. Bridging the gap between human and machine processing, a model that describes a larger range of 'information' processing was developed by the author of this thesis. This model, entitled The Hierarchy of

Processing, is used for looking at communication, storage and retrieval of data, information, knowledge etc. within and between computers and humans. Table 5 was produced to show the hierarchy of processing independent of the system involved (human or computer). It begins with the Prime level, which contains the basics of language, and builds up to the Wisdom level, which is considered to be the highest level of processing. There are no precise divisions between the levels, and even the definitions of each level require a certain amount of interpretation. Still, it is useful for discussing how ideas can be transported from one processing entity to another (communication), stored within a system (archiving), and used (processing). It is also useful for looking at the evolution of the computer from the cognitive perspective as presented below.

Processing Level	Description	Example
Prime	The most basic form of communication	Letters, numbers, words
Data	Facts and statistics	The temperature on June 12, 1967 was 25°C
Information	A collection of related data used to inform or educate	The average temperature on June 12 has fluctuated between 3°C and 38°C
Knowledge	An organized body of information	June is usually a warm month
Intelligence	The capacity to collect, organize and use knowledge for the purpose of reasoning or judgment	Most seasonal gardens in southern Ontario can be planted by June
Wisdom	The ability to use intelligence for insight	By plucking the pedals, you do not gather the beauty of the flower

Table 5 - The Hierarchy of Processing

The introduction of the computer has drastically changed the way that communication and archiving can be performed. Figure 3 shows one interpretation of how computing systems are evolving not only technologically by also how they are fundamentally implemented and used. Using the processing levels defined above, cognition is

represented from left to right while time is represented as increasing from top to bottom. The descriptions beside the time line correspond to a general era of computing evolution. As can be seen in the figure, with the introduction of the computer, storage systems were based solely on primes, and computers could only process up to the data level of understanding. Computer programmers (as indicated by the gray person symbol) had to bridge the cognitive gap [27] to interpret a user's needs into a data processing problem that could be solved by the computer. The whole interaction in this era however, was reduced to processing matters of knowledge or the lower end of intelligence as indicated by the position of the user on the cognitive scale in the figure.

Figure 3 – The Evolution of Computing Systems

As computing systems evolved they moved up the understanding ladder and as a result users could interface the systems more intelligently and with less support from computer specialists. With the introduction of the Graphical User Interface, advanced software tools, and knowledge based systems, the fundamental difference between processing and storage has become blurred and computing systems have become capable of interaction at

the knowledge level of understanding. This has allowed the users to interact even more intelligently, and with even less support from hardware and software technicians.

A system can also be envisioned in the not so distant future where a user can intelligently communicate with the computer as they do with other humans. In this case, there would be no difference in an intelligent interaction between humans and other humans, humans and machines, or machines and machines.

A system based on intelligent interactions would be capable of carrying out a complete product development, for example, without the users being aware of who is performing the services or whether they are human or machine. The concept that comes to mind when discussing these types of interactions is what the software industry calls 'Agents'. As Charles Petrie points out, however, there are a broad range of definitions of agents within the field [48], and often people will talk about agents without first defining what they mean by the term. As well, many agent and knowledge based architectures have been developed and demonstrated [34][49][50][51][52], but none of these present a high level model of a system of the future. Figure 4 shows an example of such a system.

Figure 4 – A Vision of a Service Based World

In this scenario, the end client would like to develop a product and seeks an agent (human or machine) to carry out the development. For an example, the product is a chicken feeder. The agent asks intelligent questions of a not too technical nature about the product, such as how many chickens will it feed, where will the feed be stored and delivered, what kind of facility will it be installed in, etc. The agent then acts as the project coordinator, translating the non-technical information into technical specifications, and seeks other agents and service providers to complete the product development. As the project progresses, information and knowledge is intelligently shared through clients, agents, service providers and objects in a dispersed but networked environment. In the end, a product that fulfills the needs described earlier is presented to the customer.

4 PRODUCT LIFE CYCLE AND SUPPORTING FRAMEWORK

With a holistic view of concurrent engineering in a virtual collaborative environment established and presented, it is now appropriate to introduce a model of the new product life cycle and a supporting framework. The New Product Life Cycle model integrates all three of the key components of any organizational undertaking, namely: the process, the people and the technology. Also included in this model is a list of formal outputs associated with each stage of the process. The collaborative environment framework that supports this process is a high level conceptual model. It encapsulates all of the tools and infrastructure required for concurrent engineering, and shows the relationship between them.

4.1 THE NEW PRODUCT LIFE CYCLE

The development of the New Product Life Cycle model shown in Figure 5 draws largely on the efforts of Skalak, Kemser & Ter-Minassian [53], but includes views of product development presented by others [3][54][55][56]. 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.

Figure 5 – New Product Life Cycle Model

Process

The process outlined in Figure 5 is the same as that presented earlier in Figure 1. Most product life cycles pass through each identified phase in a similar order to what is presented here. It should be noted, however, that phases are often completed in parallel and/or repeated several times in order to accommodate changes and revisions. The idea of this process model is not to lay down a strict method of completing the new product life cycle, but rather to offer a general guideline of the major activity sequence based on research and experience. With this guideline identified, the people, technology and formal outputs associated with each phase of the new product life cycle can be examined.

People

The column under the heading 'people' in Figure 5 identifies the twelve major disciplines involved in each phase of the new product life cycle, and to what extent they are involved. Again this representation is a generalization, but it is useful to consider who should be involved in the different phases and why. In some large organizations there may be a team of people working within each discipline, while in other smaller organizations a single person may have the responsibilities of more than one discipline. The point is that each phase of the product life cycle requires a different combination of efforts and expertise from different disciplines. The model distinguishes between the level of involvement by each discipline using shading. If the person(s) in a particular discipline plays a key role in a phase, then that symbol is shaded. If they play a supportive role such as in an advisory position, the symbol is not shaded. If they are not directly involved in the phase at all, then that discipline's symbol does not appear. The different disciplines and their roles within the product life cycle are defined as follows:

Project Manager (PM) is the key person associated with the new product development. The person in this role is responsible for the overall success of the project, and will spend most of their time in the planning and scheduling of activities, while making sure milestones are met on time and within the budget.

Customer (C) is an important part of the product life cycle, yet is all too often left out of the activity and decision loop. The customer can either be another manufacturer to whom

a company supplies components, or the end user of the product, or both. In the cases where there is more than one tier of suppliers, representatives at each level of 'customer' should be involved. The customer representative can supply the needs for the product and provide feedback during the many phases of the product life cycle.

Sales & Marketing (SM) provide a unique perspective on the product and where it fits into the market. They need to be involved throughout the life cycle to produce market analyses, perform benchmarking, prepare a marketing and sales strategy, and to support the product sales.

Field Service (FS) can provide valuable information on past product success and failures as well as feedback on the current product once it enters the market.

Design Engineer (DE) works out the details of how a product will function. Depending on the size of the company and the complexity of the product, there may be many design engineers from different engineering disciplines involved.

Designer (D) in general works out the form and feel of the product. Often this role is given to an experienced design engineer, but it may be useful at times to introduce a design consultant to the product development if a designer is not part of the organization.

Manufacturing Engineer (ME) looks at how the product components will be created and assembled, and provides information on the capabilities of the company. For simplicity, production engineering is included in this role.

Research & Development (RD) is responsible for bringing new technology for products and production into the organization.

Management (M) sees the new product life cycle within the corporate vision and conveys this to the rest of the team. Management is also responsible for approving the continuance of a product life as well as making sure goals are met.

Financial Management (FM) keeps track of financial resource use and allocation, and ensures financial goals are met.

Resource Management (RM) is responsible for maintaining contact with suppliers and estimating past, present and future material and component costs.

Supplier (S) can provide valuable information on their components and/or materials as well as how they can be optimized into a new product design.

Technology

The technology has been grouped into six categories of tools that support repetitive activities occurring throughout the new product life cycle. Within each category there is a wide range of tools that people can use to assist them in completing tasks productively. As well, within each tool type (word processor, for example), there are numerous off-the-shelf software packages available to choose from. It is beyond the scope of this research to evaluate and recommend particular software package brands that can fill the needs of each tool type. The approach taken here is to develop a holistic picture of the tools required, and suggests when they are required as well as their strengths and weaknesses.

In Figure 5, under the heading of technology, tools that are extensively used in a particular phase are shaded symbols, while tools that are used in a supportive manner have symbols that are not shaded. Below is a list of the tools categories based on the groupings established earlier, and examples of the types of tools used within each category:

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, PDM), Computer Aided Process Planning (CAPP)

Synchronous Workspace Sharing (WS): whiteboards, communication systems (text based, voice based or video conferencing), application sharing tools

Formal Output

The formal outputs are often used to mark and measure milestone achievement. 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 5 are suggested as the major documents of each new product life cycle phase.

4.2 THE COLLABORATIVE ENVIRONMENT FRAMEWORK

Based on the requirements of a new product life cycle, the framework shown in Figure 6 has been developed to support concurrent engineering in a virtual collaborative environment. The model framework is the synthesis of a number of concepts found in research literature [2][20][22][27][28]. Following this framework, a working architecture can be implemented using off-the-shelf and custom software technology available today. Since the framework is system independent, it can also be followed in the future to create architectures using software and systems still in development. 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.

Figure 6 – A Collaborative Environment Framework to Support a Product Life Cycle

The framework in Figure 6 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. Below is a detailed description of the framework layers.

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 [44], and consists of an information storage system and an information management system that can be thought of as a library and a sophisticated librarian. For example, if an engineer is involved in designing a new product, they could ask the librarian for information on similar products that have been developed in the past. The librarian would respond with several product development documents assembled from the library storage system, and direct the engineer to the appropriate tools to view them. The librarian would also keep track of who should have access to what information (information security), and what information is modified by who (version control).

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.

Using current technology, this layer is the most difficult to implement into an architecture because it must handle the different storage methods of the tools in the application layer, or require that those tools have a standard storage method [57]. To date, a fully functional seamless system has not been observed. The potential to create one does exist, however, by using object-oriented systems or open database middleware as the platform [57].

Application Layer

The application layer provides the tools with which the engineers and others perform their tasks. The tools are used to form 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 key issue to be aware of in developing this layer is that the tools should be complementary and use common functions where possible [58]. For example, if there is a need for drawing in a general documentation tool, it should use the functionality of the design tool as opposed to having a drawing feature built in.

The tool categories identified in this layer provide support for recurring activities within the product life cycle as outlined in section 3.1. These categories cover most types of tools and provide a useful generalization for discussing the framework.

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 [27]. For example, while documenting the description of a design rationale, an engineer may want to make a sketch of a few different component concepts. The user interface will launch the general documentation tool for the text part of the document, and then launch the drawing and design tool for the sketch. 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.

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 as a natural extension to human capabilities, rather than using humans as an extension to the system capabilities [2][21][20].

5 A SIMPLE WORKING MODEL

5.1 OVERVIEW

A simple working model was developed in part to verify the framework, but more importantly, to help further expose the real issues that people face when developing a product using concurrent engineering in a virtual collaborative environment. The working model 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 which will allow a product development team to carry out a single design.

One of the objectives in assembling the system was to keep cost down in order to meet the needs of small and-medium sized manufacturers. This was achieved by using hardware and software tools that are off-the-shelf products and require little or no customization. The total current value of the hardware is less than \$20,000 and the software was purchased for under \$2000 with much of it being downloaded from the Internet for free.

The ability to easily monitor a product development team using the system in action was an important consideration in developing the working model. To best accommodate this, the system was assembled in different rooms within a single building. It allowed the observer to easily move from room to room and to observe and address issues as they happen. It also enabled the use of a stable high-speed connection between the computing systems because they were all on the same local area network. Although the network speeds used here were not a realistic simulation of what can be achieved using much slower modems, they demonstrate what will be possible in the near future as Internet connection speeds increase using new technology such as cable modems and Asymmetric Digital Subscriber Lines (ADSL).

5.2 TOOLS AND APPLICATIONS

The tools and applications were selected based on availability, cost, and the ability for them to be integrated. The hardware was purchased from a computer supplier and retail outlet stores and represents technology that is at least one year old. The software chosen was based on the Microsoft platform because this company had the bulk of the required software in a suite of applications that are fairly well integrated. Figure 7 shows a model of how the tools and applications fit the framework in Figure 6, and below it is a description of how the system fits the four framework levels.

Figure 7 – Tools and Applications

Team Knowledge Layer

The repository for information gathered and produced by the team was simply a mapped directory called 'team design documents' on the network file server. An icon was displayed on each of the team members' user interface, which allowed them to gain direct access to any of the files contained within this folder. Because of the size and scope of the planned study, and in order to simplify the system requirements, much of the information management was handled by the team members themselves. They used file names to index the information objects, and decided themselves how to collect, store and retrieve this information. As indicated in the Figure 7, the software chosen for the application layer in this case, was able 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, and the applications would not need this functionality.

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.

Information Gathering

Tools to support information gathering activities 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.

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.

Analysis and Evaluation

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

General Documentation

General documentation activities were supported by a sophisticated word processor (Microsoft Word), and a presentation application (Microsoft PowerPoint). 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.

Planning and Scheduling

Both the word processor (Microsoft Word) and the spreadsheet application (Microsoft Excel) could be used to support planning and scheduling activities. Although neither of these tools have much functionality for resource allocation and activity tracking, a sophisticated planning and scheduling tool was not required for the study using this model.

User Interface Layer

The user interface layer was based on a Windows environment, with icons for each application tool. There was 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 could 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.

Team Wisdom Layer

The team wisdom layer is where creativity enters the product life cycle. Using information, tools, and personal experience, team members could 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 model was to allow this creativity to be exercised uninhibited by the system being used to capture it.

5.3 *HARDWARE ARCHITECTURE*

The hardware for this architecture was chosen based on availability, compatibility, and cost. All of the hardware is off-the-shelf and can be purchased at many retail outlets. This makes it possible and feasible for even the smallest of companies to assemble a similar system for use in virtual collaboration. Figure 8 shows the architecture of the hardware system assembled to create a working model. The system is simple enough to enable the research to isolate specific aspects of the virtual collaboration process, yet it can also be scaled up to support more complex and numerous processes. It essentially provides a workspace for an engineer and another for a technician with the necessary infrastructure for them to collaborate concurrently.

Figure 8 – The Architecture for a Simple Collaborative Environment

Engineering Workstation

The engineer's workstation had all of the equipment, software, and reference material to perform analysis and evaluation of the design, document the product development, and collaborate with the other team member(s). Included in this workstation were the following components:

- A personal computer (Pentium 100 MHz) running Windows 95 and color monitor (20") that are the base system for the workstation,
- A color scanner (Microtek Scanmaker X6) which allows the engineer to capture hand drawings and reference text information by scanning documents,
- An ink jet printer (Hewlett Packard 660c) that enables the printing of documents for reference or easier viewing,
- A video capture device (Snappy) connected to a video camera and a video monitor to provide video capture capabilities as well as live video image transmission using the collaboration software,
- A sound card (Soundblaster 16) with speakers and a microphone to enable audio capture and playback as well as real time audio communication,
- A 12x12 inch graphics tablet (Summagraphics Summasketch III) that allows pen like drawing, markup, and control to be performed,
- An Ethernet card that enables a maximum of 10 Mbps data transfer rate.
- Engineering reference material in the form of printed text, which contain formulas, analysis, and evaluation information.

Technical Operations Workstation

The technician's workstation was equipped with a set of hardware and software tools similar to that of the engineer's workstation, but it also had the materials, measuring devices and construction tools to allow for the building and testing of prototypes. The following components were included in the technical operations workstation:

- A personal computer (Pentium Pro 200 MHz) running Windows NT and color monitor (17") that are the base system for the workstation,
- A color scanner (Microtek Scanmaker X6) which allows the technician to capture hand drawings and printed text by scanning pages,

- A laser printer (QMS 1725) that enables the printing of documents for reference or easier viewing,
- A video capture device (Winnov Videum AV card) connected to a video camera and a video monitor to provide video capture capabilities as well as live video image transmission during collaboration sessions,
- A sound card (Soundblaster 16) with speakers and a microphone to enable audio capture and playback as well as real time audio communication,
- A 12x12 inch graphics tablet (Summagraphics Summasketch III) that allows pen like drawing, markup, and control to be performed,
- An Ethernet card that enables a maximum of 10 Mbs data transfer rate.
- A set of metal and plastic construction materials (Meccano), tools (screwdriver, wrench, scissors etc.), and test equipment (ruler, protractor, weigh scale etc.) that were used for constructing and testing prototypes of the product.

Information Management System

The information management system was basically a network directory on a file server. The server is a Pentium Pro 200 MHz computer running a Microsoft Windows NT Server operating system. This provided the team with a common place in which to store and retrieve the product development document and other related files.

World Wide Web

Access to the World Wide Web allowed both the engineer and the technician to seek the information contained there. It could be used to obtain information on similar designs done by others, formulas and calculation tools for performing analysis, ideas for methods of construction, or any other information that may be useful in the product development process. Using the World Wide Web also gave the team access to the project web page, which contains information about the product specifications and testing parameters.

6 EXPLORATORY STUDY USING THE WORKING MODEL

6.1 OVERVIEW OF THE STUDY

A simple collaborative environment was created based on a framework developed for concurrent engineering in a virtual collaborative environment. An exploratory study was conducted as a first step to confirm the framework's utility, establish any shortcomings, and observe other factors that may help or hinder the successful implementation of such an environment. The study was also used to identify areas in which more rigorous studies should be performed.

The environment was used to facilitate a product development session carried out by teams of two to four people performing different roles. The teams had access to tools, equipment, and collaborative systems needed to design and develop a prototype product with specific requirements. Participants were involved for one day, which was divided into two phases. The first phase allowed team members to learn about the tools and process used to develop a product (see Appendix A for an outline of the first phase). In the second phase, participants carried out the product development and documentation using this process and technology.

Because the study involved human subjects, it was necessary to inform participants of the study's objectives and of their right to refuse to participate. This was accomplished with a letter of information and a signed consent form (see Appendix B).

6.2 THE NATURE OF EXPLORATORY STUDIES

Exploratory studies are quite common in research that involves social phenomena. They are often used when a researcher is establishing a new research area, or when the area of research itself is new [59]. Because the topic of this research has both of these features,

the exploratory study was chosen as the method of inquiry. This type of study allows for the greatest amount of flexibility so that a researcher is able to obtain a rich overview of many aspects of the topic. Because the study is not a controlled experiment however, observations and conclusions drawn from it can only serve as a first impression of what more detailed studies can confirm or deny [60]. What the researcher is able to gain are leads from which future hypothesis and subsequent experiments can be developed. The purpose of this exploratory study is a first run evaluation of the models developed, and the identification of future research areas based on the suggestions and observations that the study generates.

6.3 METHOD USED

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 (Appendix C has a sample record sheet). 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 (see Appendix D).

6.4 PEOPLE INVOLVED

The product development was carried out in the second phase by the team of two to four people at the two different workstations in separate rooms. 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 6 shows the responsibilities, information, and tools associated with each role.

Role	Responsibilities	Information Available	Tools Available
Technicians	Component testing Prototype development Prototype testing Product Documentation	Component specifications	Test instruments, Hand tools, Building equipment, Information Gathering, General Documentation
Engineers	Product Documentation Develop tests and interpret data, Document design	Governing equations, Technical data Product performance requirements	Design documentation, Analysis and Evaluation, Information Gathering, General Documentation

Table 6 - The Roles of Participants in the Study

6.5 PROCEDURAL PROCESS OF THE STUDY

The study was divided into two phases. In the first phase an overview of the study was presented, and team members had a chance to meet and get acquainted. Also, team members familiarized themselves with the product development process and the tools needed to complete it in a geographically distributed setting. In phase two, the product development process began with the participants being given access to the information required to fulfill their roles. 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. Figure 9 shows the process that participants followed to complete their project.

In order to make it easier for the participants, and to help ensure that the product development process is followed, a template was created for the word processor that the team used. The template contained headings that match the Formal Outputs shown in Figure 9 and allowed the participants to simply ‘fill in’ the document. The template also contained notes with descriptions of the information required in each section, and

suggestions of how to get or produce this information. Appendix E shows the template with notes.

Figure 9 – Project Life Cycle for the Study of a Virtual Collaborative Environment

6.6 TECHNOLOGY IMPLEMENTED

Teams had access to all of the tools and equipment needed to carry out a product development process in a virtual collaborative environment. The computers, software and equipment provided the teams with the tools they need to fulfill their roles, and the communication infrastructure to support rich communication coupled with workspace sharing. The system was also equipped with a shared file directory that allowed all users access to the team work. A symbolic diagram of the hardware architecture layout is shown in Figure 10.

Figure 10 – Diagram of the Hardware Architecture

6.7 THE PROJECT UNDERTAKEN BY PARTICIPANTS

The aim of the project was to develop a mousetrap-powered device that can perform to certain criteria using specified construction materials and equipment. The device is required to launch a twenty-five cent Canadian coin (a quarter) into a cup that is five metres away. The device can be designed to remain stationary and launch the coin the full five metres, or move forward a maximum of four metres and launch the coin the remainder of the distance. 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. A detailed outline of the project rules given to participants can be seen in Appendix F. A printed copy of the project rules was given to each participant, and a copy was also available on the web site created for the study.

7 RESULTS, OBSERVATIONS AND DISCUSSION

7.1 RESULTS OF QUESTIONNAIRE

At the end of the study, participants were invited to fill out a questionnaire. The purpose was to identify perceived strengths and weaknesses of the working prototype, the virtual collaborative environment, and the concurrent engineering process modeled. The following tables 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.

Section A – Person 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

Table 7 – Results of Questionnaire: Part A

Section 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 you 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 our work was very interdependent so there were many interactions.	(2) 17%
	I have worked in a team before, and sometimes we worked independently while other times we had many interactions.	(4) 33%

How many times have you worked in a team including school and social settings?	1 or 2	3 to 5	6 to 8	9 or more
	(1) 8%	(3) 25%	(2) 17%	(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 8 - Results of Questionnaire: Part B

Section 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	(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%			

Table 9 - Results of Questionnaire: Part C

7.2 OBSERVATIONS OF THE PEOPLE

Participant profile

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 able to sign up for the study through either direct contact by phone, or by registering on the web site created for that purpose. Participants were given a minimal amount of information about the design project before the day when 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.

Observations

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). Nonetheless, because the design document template was laid out in the same order as the process, and could be mapped directly to the formal output shown in Figure 9, 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. Figure 11 shows some video capture images of the participants using the collaborative environment.

Participant Comments

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 between 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.

Team #1

Team #2

Team #3

Team #4

Figure 11 – Participants Using the Collaborative Environment

7.3 OBSERVATIONS OF THE PROCESS

The Nature of 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.

Observations

Following along the sequence of the project life cycle (Figure 9), a descriptive summary of the observed and documented performance of the teams during each activity is given below. Example excerpts from the documents that the teams produced can be seen in Appendix G.

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.

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.

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.

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.

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.

Product Realization

The prototype product was produced by the technicians, 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 two other 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. Figure 12 shows the final designs developed by the four teams.

Figure 12 – The Final Designs of the Four Teams

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. None of the teams were able to meet the objective of launching the coin into the cup, and only one team scored a single point for getting the coin within a metre of the cup.

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.

7.4 OBSERVATIONS OF THE TECHNOLOGY

Comments on Technology

Participants generally found the text based chat program to be most useful and reliable for communicating their ideas to one another. Some of them used the chat session records for documenting design rationale and discussions (see Appendix H for samples of

chat sessions). 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 it 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). Figure 13 shows a sample screen capture of the engineer in a collaborative session with the technician.

Figure 13 – Screen Capture of a Collaborative Session

Other comments the participants made were about equipment or systems that they didn't have use of. Some of these things were:

- a telephone,

- two computers – one for conferencing and one for working,
- a construction parts database, and
- a more sophisticated drawing program such as a CAD package.

Observations

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 working model, the lack of experience of the participants, and the techniques used to observe and record the activities, the observations recorded below (Figure 14) 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 (Figure 5) do not correspond to the last two phases of the product life cycle (Figure 9), the uses of tools are not expected to be exactly the same.

Figure 14 – Observations of the Tools Used During the Project Process

Technical Glitches

Throughout the study there were several technical glitches. The main problem that repeatedly occurred was the loss of audio communication using NetMeeting. This problem was probably a significant factor that led to the participant's poor rating of this feature and the desire to have a regular telephone.

Another problem was computer system crashes. This occurred at least once during every study session. In each case the study coordinator would inform the other team members of the computer crash and then restart the system. Fortunately because of the filing system used, little or no information was lost due of this problem.

The participants needed constant guidance from the study coordinator on how to use the system and its features. This could be expected due to the novelty of the system to the users. Other researchers have also found that it is important to have a system technician present for guidance and encouragement during the implementation of any new system [42].

7.5 DISCUSSION

Audio Communication

The audio communication part of the collaboration software (NetMeeting) was generally poor. Participants commented that the problems with echo and voice breakup made it difficult to use for anything more than short sentences. Better systems, such as teleconferencing or even a single telephone line (when working with only one other party) are certainly available, but were not used because the researchers wanted to investigate the system's capability limits. In practice, the telephone would be the best way for audio communication to take place, as it is reliable and can be used as a backup system if the computing system crashes (as it did several times).

Voice Recognition Chat

While watching the team members fumble between using the audio system and using chat, it occurred to the observers that a system capable of combining the benefits of both functions may be worth investigating. Such a system would use voice recognition software to create text based chat. Depending on the speed of the network connection, both the audio and text could be sent to the recipient, or in the case of a slow connection, just the text (as text uses far less network bandwidth). An additional advantage of using such a system is that the collaborating team could create a searchable chat archive that would contain design rationale and become part of the product development file. An audio recording indexed to the chat transcript could also be captured.

Request for Use of CAD Software

Some of the participants indicated that they would have liked to use CAD tools to develop their design. As mentioned earlier, because CAD system training was beyond the scope of this study, the researchers decided not to include it along with the other system tools. It is worth mentioning that it is possible to share a CAD application over the Internet using existing solutions like NetMeeting's Application Sharing feature. Future studies that require more complex design work may want to consider the use of CAD systems.

Screen Clutter

The issue of screen clutter was apparent throughout the design process. Teams working in collaboration mode often had many applications open at the same time as all of the communication tools. This made it difficult and awkward for the team members to work in an application (or two) and see the chat box, video conference window, and whiteboard. One solution to this problem that researchers may try in the future, is to have one computing system dedicated to the communication part of synchronous collaboration (video, audio, chat, whiteboard), and the other dedicated to application working and sharing. Having two systems would increase the viewing area, help organize the collaboration session, and potentially speed up the information transfer rate. Another solution is to incorporate a dual monitor system within a single powerful computer.

8 CONCLUSIONS AND FUTURE WORK

8.1 Conclusions

The Models

Two important models were developed in the work of this thesis. The first model is of the product life cycle, and includes elements of people, process and technology. This model has the unique feature of integrating all three of these elements. It incorporates the principles of concurrent engineering, and is useful for understanding the requirements of an organization to develop and support a new product. It is also useful in creating an infrastructure to support collaboration between people involved in a product life cycle. It was used in this thesis as a process guide for a product development study, and to develop the second model, a framework for virtual collaboration. The observations made during the exploratory study suggest that the model was valid and useful for identifying and guiding concurrent engineering project activities. The next step to verifying the model would be to perform a controlled study, and also to compare the model to leading industry current practices.

The virtual collaboration framework is a platform independent, scalable model that includes four organizational layers. These are: an organizational knowledge layer, an application layer, a user interface layer, and an organizational wisdom (people) layer. It is useful for understanding the requirements for virtual collaboration either within or between organizations that are involved in a product's life cycle. It was used in this thesis to develop a collaborative architecture (hardware and software system) to be used in an exploratory study of product development. The results of implementing the model suggest that it is a valid tool for assisting in collaborative architecture development, and that it has the essential features for allowing concurrent engineering projects to take place in a virtual collaborative environment. The next step to verifying this model would be to

use it to create an environment that will allow virtual collaboration on real world concurrent engineering projects.

The exploratory study of product development in a virtual collaborative environment was used in part to verify the product life cycle model and the virtual collaboration framework. The observations made give general support to the two models, demonstrating that they are useful for understanding the product life cycle, and for developing a simple virtual collaborative environment. The study also identifies the strengths and weaknesses of virtual collaboration, and potential problems in implementing such a system.

The Exploratory Study

This study demonstrated that an architecture based on the virtual collaboration framework provides the ability for people in different locations to effectively develop a product concurrently. What is noteworthy about the architecture is that it is built using off-the-shelf hardware and software that is available at many retail outlets, unlike other studies that use specialized hardware or software systems. This work demonstrates that virtual collaboration is attainable by almost any sized organization.

The study also highlighted some important issues to be considered in developing and implementing a virtual collaborative environment for concurrent engineering. Some of these issues are discussed below.

Based on the comments and observation of the participants, it is clear that when involved in synchronous collaboration, people prefer to work face-to-face. This is not to say that collaboration cannot be done in a virtual setting, but suggests that using current off-the-shelf technology for communication, and given the choice of discussing design issues over a network or over a conference table, people will choose the conference table. The benefits of virtual collaboration however, are the design rationale capture features embedded in the system.

Analyzing the observations made of the technology and process, 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. This was evidenced by the way participants in the study quickly became comfortable with the collaborating system, but were much less adapted to using the product development process even though both were explained extensively during the information phase of the study. The implications for this are that organizations hoping to introduce a new system such as a virtual collaborative environment need to give people time to adjust and become comfortable with the process long after they learn to use the tools.

As demonstrated by the variety of four final designs developed, it can be inferred that the virtual collaborative environment does not completely inhibit design process. In fact, because of the nature of virtual collaboration, creativity normally lost may actually be captured. In virtual collaboration, all design information must pass through the computer system at some time. If, as it passes through the system, this creative information can be captured and archived in a searchable form, it can become part of the organizational knowledge. Companies can save a lot of time and money by learning from the successes and mistakes of the past. Capturing design rationale also make revisions and redesigns much easier because engineers can be aware of why things were done a certain way in the first place. This is a key advantage, even for co-located collaboration.

The predicted use of tools in the product life cycle model generally maps well to the actual use of tools by the participants. Deviations between the predicted and the actual are expected because of the level of realism of the project, the quality of tools available, the time limits of the project duration, and the insufficient size of the user group.

Technical problems are associated with any new system implementation and the exploratory study of this virtual collaborative environment was no exception. The important consideration is to expect problems and be prepared with backup systems. In virtual collaboration, this may be as simple as having a teleconference line ready in case of computer collaboration system failure.

8.2 Future Work

The scope of this thesis can be extended in several research directions. First, using the virtual collaborative framework, more elaborate architectures can be developed to support more complex product life cycles. These architectures can be tested under controlled studies or in industry environments. Based on the results of these studies, the collaborative framework can be verified further, modified to accommodate new or different components, or rejected based on evidence that it does not apply to more complex systems.

Second, software can be developed that better meets the requirements of the collaborative framework. For example, much work is still needed in the area of storage and retrieval of organizational knowledge. If researchers can develop a way of efficiently storing the vast array of information types in a searchable form, then organizations can capture and use much more of their existing knowledge. Personnel could then spend less time recreating knowledge, and more time using it to perform value added activities.

Third, as evidenced from a survey of tools available, technical solutions for virtual collaboration (hardware and software systems) can still use improvements in the areas of user interfaces, integration of tools, reducing overlap of functionality, and standardizing of information objects. The tools don't seem to support the process as well as they should, and often they actually impose a process on the users. The tool designers must first understand the process in which the tool they design will be used, then design a tool that will transparently support that process. Also, the synchronous communication tools can be refined to make them more transparent to the user and to enable the organization to capture the creativity passing through the system.

Appendix A – Outline of Study phase I

- 1) Introduction of coordinator and participants**
- 2) Distribute letter of information and consent form**
- 3) Introduce study**
 - a) Overview of the Study
 - b) Method
 - c) People
 - d) Process
 - e) Technology
 - f) Project
- 4) Tour the Engineer's and Technician's workstations**
- 5) Introduce tools – controls and features**
 - a) Hardware
 - i) computer and user interface
 - ii) mouse and digitizing tablet
 - iii) scanner
 - iv) video monitor system
 - v) printer
 - b) Software
 - i) filing system
 - ii) word processor
 - iii) video capture software
 - iv) synchronous collaboration tool
 - v) World Wide Web resources
 - (1) the project site
 - (2) possible reference sites
 - c) Equipment
 - i) safety precautions
 - ii) measuring tools
 - iii) construction materials
- 6) Introduce project**
 - a) Objective
 - b) Method
 - c) Testing Parameters
 - d) Test Apparatus
 - e) Design Constraints
 - f) Scoring

Appendix B – Letter of Information, Consent Form, & Ethics approval

Letter of Information

The purpose of this study is to evaluate the effectiveness of a framework developed for concurrent engineering using virtual collaboration. Concurrent engineering is the process of working on many different design tasks at once as opposed to doing them in a sequential order. For example instead of designing a car and then designing an engine to fit into it, in concurrent engineering the car and engine are both designed at the same time. Thus concurrent engineering shortens the design time and produces better products. Virtual collaboration is performed when people need to work together on a project, but they are not located in the same city for example. They use the telephone, fax, and computers to communicate with each other and share information instead of meeting face-to-face. Virtual collaboration allows people to work together who would not normally be able to because of the distance between them. Combined, concurrent engineering and virtual collaboration allow people to develop a larger range of better products faster and cheaper than ever before.

For this study, we have assembled a system of computers and software that can be used for virtual collaboration. Our intention is to have participants come and use the system in a product development scenario. This will allow us to get feedback on how effectively the system supports collaboration when people in a team are physically distributed (not able to meet face-to-face).

Participants will be assigned to teams of two, and are asked to participate in the session for one day. The session is divided into two phases. In the first phase, participants will be involved in learning how to use computer equipment and software for drawing, analyzing, report writing and communication. Participants will also learn about the process of developing a product, about the tools used to design, create and test a product, and about how to collaborate effectively. In the second phase, participants will carry out the process of developing a product using the tools they learned about in the first phase. By the end of the second phase the teams of participants will have created a prototype of their design and a document of how the design was developed and how well it performed. Information on method of scoring will be given at the beginning of the second phase. Teams will be awarded points for the document that they produced, and the performance of the prototype that they developed. The team with the highest score will receive an award.

All teams will receive complementary refreshments during participation in the session.

There are no known physical or psychological risks associated with this study. Participants should not experience any discomfort due to their participation. Some participants will be using a screwdriver and wrench to assemble their prototypes but the risk of injury is minimal.

Participation in the session is strictly voluntary, and participants may refuse to participate or withdraw from the study at any time and for any reason. Participants will be asked questions in regard to their experience with the tools and equipment they used but may refuse to answer any question that they find objectionable or make them feel uncomfortable.

The names of all participants will be kept confidential in any publications of the results of observations, surveys, and any other part of the study.

Participants who have inquiries about the study or related issues can call Dr. Ralph Buchal at the University of Western Ontario: (519) 679-2111 extension 8454.

Consent Form

I have read the Letter of Information and have had any questions answered to my satisfaction. I agree to be involved in this research project.

Name of Participant

Signature

Date

If participant under the age of 18

Signature of parent or guardian

Date

The UNIVERSITY of WESTERN ONTARIO

*Vice-President (Research)
Ethics Review Board Dental Sciences Building*

REVIEW BOARD FOR NON-MEDICAL RESEARCH INVOLVING HUMAN SUBJECTS

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ALL NON-MEDICAL RESEARCH INVOLVING HUMAN SUBJECTS AT THE UNIVERSITY OF WESTERN ONTARIO IS CARRIED OUT IN COMPLIANCE WITH THE SOCIAL SCIENCES AND HUMANITIES RESEARCH COUNCIL GUIDELINES (1981).

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THE REVIEW BOARD HAS EXAMINED THE RESEARCH PROJECT ENTITLED:
"The study of concurrent engineering in a virtual collaborative environment."

REVIEW NO: S6488

AS SUBMITTED BY: Professor R. Buchal, Mechanical & Materials Engineering, Engineering Science Building

AND CONSIDERS IT TO BE ACCEPTABLE ON ETHICAL GROUNDS FOR RESEARCH INVOLVING HUMAN SUBJECTS UNDER THE CONDITIONS OF THE UNIVERSITY'S POLICY ON RESEARCH INVOLVING HUMAN SUBJECTS.

APPROVAL DATE: 30 June 1998 (UWO Protocol, Letter of Information & Consent)

AGENCY: NSERC Number OGP0036398 UWO#FO68A1

TITLE:

A.K. McDougall, Chair

Appendix C – Observation Record Sheet

Team #

PROCESS What are the activities	Formal Output What is documented	Tools Used Shade appropriate symbols	Notes
Interpretation of Needs	Project Objective	<div>IG DD AE</div> <div>GD PS WS</div>	
Requirements Formulation	Product Specifications	<div>IG DD AE</div> <div>GD PS WS</div>	
Generation of Alternatives	Concept Models and Sketches	<div>IG DD AE</div> <div>GD PS WS</div>	
Evaluation and Engineering Specification	Final Concept with Engineering Specifications	<div>IG DD AE</div> <div>GD PS WS</div>	
Planning and Scheduling of Milestones	Design Activity Schedule	<div>IG DD AE</div> <div>GD PS WS</div>	
Product Realization (Prototype Creation)	Detail Design Bill of Materials Product Development Rationale	<div>IG DD AE</div> <div>GD PS WS</div>	
Product Testing	Test Results	<div>IG DD AE</div> <div>GD PS WS</div>	
Product Enhancement Discussion	Product Improvement	<div>IG DD AE</div> <div>GD PS WS</div>	
<div>General Activity Sequence</div>			

Appendix D – Questionnaire for Participants in the Study

Participant Questionnaire

Section A - Person Profile

1) Team Number: _____

2) Role (circle): Technician Engineer

3) Age (circle): 16-19 20-24 25-30 30+

4) Education Level (circle): grade 12 grade 13/OAC college/university

5) Other Education:

Please list technical courses related to computers, teamwork, or design

Course description _____ Duration _____

Course description _____ Duration _____

Course description _____ Duration _____

Course description _____ Duration _____

6) Career Status (circle): working unemployed student other

7) Area of Specialization/Interest: _____

8) Additional information about education or interests:

Section B – Previous Experience

In answering the following questions, please consider your experiences before this project.

1) Which statement best describes your knowledge of computers and software?
(circle only one)

- A. I rarely ever use a computer and don't know much about them.
- B. I have used computers before but I'm not very familiar with them.
- C. I sometimes use a computer and I know how to work the software I use.
- D. I often use a computer and I am familiar with a range of software tools.
- E. I have a comprehensive understanding of computers and software.

2) Which statement best describes the majority of your experience with working in teams? (circle only one):

- A. I have never really worked as a part of a team before
- B. I have worked in a team before, and each member did mostly their own work and there were never many interactions
- C. I have worked in a team before, and our work was very interdependent so there were many interactions
- D. I have worked in a team before, and sometimes we worked independently while other times we had many interactions

3) How many times have you worked in a team including school and social settings?
(circle only one)

1 or 2 3 to 5 6 to 8 9 or more

4) Which statement best describes how you have felt about work in teams in the past?
(circle only one)

- A. I mostly enjoy working in teams
- B. Sometimes I liked working in teams and other times I haven't, it depends mostly on who the other team members are
- C. Sometimes I liked working in teams and other times I haven't, it depends mostly on the task.
- D. I have worked in teams before, but I prefer mostly to work on my own
- E. I have never worked on a team before

5) Additional information related to experience with computers, teams or design:

Section C – Experience in this Project

1) Was the information presented in phase one clear and understandable? Yes No

2) Was the information given on product life cycle helpful for the project? Yes No

3) How would you rate the usefulness of the tools you used to collaborate with the other team members? (circle the appropriate number)

1
poor

2

3
satisfactory

4

5
excellent

4) Which (of the ones you used) are the two tools you found most useful for communicating your ideas to others?

First most useful tool: _____

Second most useful tool: _____

5) Which (of the ones you used) two tools did you find most difficult to use during the project?

Tool _____ Difficulty _____

Tool _____ Difficulty _____

6) Are there any tools or features that you did not have, that you think would be helpful in collaborating on this project?

a) _____

b) _____

c) _____

7) Please write any additional comments or suggestions you may have about the collaborative environment or the teamwork experience here:

Thank you for completing this questionnaire

Appendix E – The Product Development Document Template

Product Development Document

**Developed By
Team #X
On <autodate>**

Team #X consists of:

Project Objective

***Enter a clear statement of the objective in your own words (1 point). Suggestion: open a new word document for rough work, and cut and paste into the final document. Use application sharing so that everyone can view and work on the document together.**

Product Specifications

* What is the product supposed to be able to do? Describe in your own words (2 points)

Concept Models and Sketches

***Show sketches of the component concepts and or overall feasible concepts. You should have at least 2 or 3 (10 points). Suggestion: use the NetMeeting whiteboard for sketches. Create multiple pages as necessary. Afterward, cut and paste from the whiteboard to the word document.**

Final Concept with Engineering Specifications

*A drawing of the complete concept that was chosen should go here with the engineering specifications (eg. device travel 3m, launch angle 30 degrees, coin horizontal travel 2m) below. (10 points) Suggestion: use the whiteboard. This will be the best alternative chosen, with additional details.

Final Concept

Engineering Specifications

Design Activity Schedule

* Record a short description of who will do what and when. This is a schedule of tasks that will be done individually. It will be necessary to collaborate periodically. This should be scheduled.

Detail Design

***Design drawing or video capture views with enough detail that the device could be created again using only this information and the bill of materials. (15 points) Suggestion: add annotations to identify parts in the bill of materials.**

Drawing

Description

Bill of Materials

*List the parts (make up descriptive names) and quantity you used to build the device. (5 points)
Suggestion: refer to the drawing.

[illegible]

Product Development Rationale

*Record a summary of reasons for choosing certain design features and important team decisions made. (7 points)

Test Results

*A clear description what happened with the test was performed (5 points), and fill in the table. (Testing score max 35 points)

Description

Table of Results

Test Trial #	Launch Distance	Landing Distance	Score
1			
2			
3			

Product Improvement

*A description of improvements that could be made in future designs. (5 points)

Appendix F – Design Constraints & Testing Parameters

The Coin Launcher Project

Objective

The objective of this project is to go through the process of design, building and testing of a device that will launch a coin into the air such that it lands in a cup not less than 1 metre away. The device will be scored on the product development document and the performance of the device.

Method

Using the skills, information and construction materials at hand, your team will go through the process of developing a prototype product to accomplish the objective. The device will be powered using the energy of loaded mousetraps. A maximum of two mousetraps can be used in the design.

Testing Parameters

The device your team builds will be tested and evaluated for scoring under the following conditions.

- The mousetrap(s) will be loaded and any adjustments will be completed
- The device will be placed 5 metres away from the target cup
- The mousetrap(s) will be activated using a thread that trails the device
- From this point on, the device will be autonomous
- The device may remain stationary or move forward, but can not move closer than 1 metre away from the target cup
- The device may launch the coin (a Canadian quarter) at any time following the pulling of the activation thread
- For scoring purposes the landing point will be considered the first place where the coin hit the floor, and distances will be measured in a radial direction from the target cup
- Three official test trials will be performed with the test score based on the best of the three

Test Apparatus

Design Constraints

Size and Shape

There are no restrictions on the shape of the device, but it must fit into a cube measuring 40cm X 40cm X 40cm.

Materials

The materials available for use are limited to those provided to the technicians. They include:

- two mousetraps (approximately 5cm X 10cm X 1.5 cm),
- an unlimited amount of thread,
- pulleys, wheels, gears, shafts, and drive belts,
- steel plates and links of various shapes and sizes,
- nuts and bolts for assembly.

Component Modifications

None of the components except the thread can be modified from their original size or shape (except in elastic deformation) during the construction or testing of the device. The mousetrap(s) must be used as provided and cannot be disassembled.

Target Cup

The target cup is approximately 10cm high with an opening diameter of 8cm.

Scoring

Scoring will be based on the document created during the product development process. The majority of points available are dedicated to capturing the product design rationale in the document. The documents will be judged on the creativity of the concepts, designs, and methods, and on how well the design rationale is captured. The maximum points available and a description for each section of the document are given in Table 1.

A maximum of 35 points is available for the results of the device testing. Any device that launches the coin into the cup on any of the three test trials will receive the full 35 points. Devices that do not launch the coin directly into the cup will receive points for the closest initial landing spot of the three test trials based on the following formula:

$$Score = 30 - \left(\frac{d}{3} \right)$$

Where d is the distance from the target cup in cm.

Document Section	Description	<i>Points available</i>
Project Objective	Clear statement of the objective	1
Product Specification	Summary of the product requirements	2
Concept Models and Sketches	Sketches and descriptions of several feasible concepts that are generated during discussions	10
Final Concept with Engineering Specs.	Drawing of the chosen concept with a description and a list of engineering requirements	10
Design Activity Schedule	A plan of who will do what and when it will be complete	5
Detail Design	Design drawing with sufficient detail that the product could be created again using only this information	15
Bill of Materials	A list of parts and quantity used	5
Product Development Rationale	A summary of reasons for choosing certain design features and a record of important team decisions made	7
Test Results	Clear description of the results obtained (5 points) Testing score (35 points)	40
Product Improvement	Description of improvements that could be made in future designs	5
Total Maximum Points		100

Table 1 – Scoring Description and Breakdown

Appendix G – Samples from the Product Development Documents

Project Objective – team 1

The objective of this project is to go through the process of design, building and testing of a device that will launch a coin into the air such that it lands in a cup not less than 1 metre away. The device will be scored on the product development document and the performance of the device.

Product Specifications – team 3

Size and Shape

There are no restrictions on the shape of the device, but it must fit into a cube measuring 40cm X 40cm X 40cm.

Materials

The materials available for use are limited to those provided to the technicians. They include:

two mousetraps (approximately 5cm X 10cm X 1.5 cm),
an unlimited amount of thread,
pulleys, wheels, gears, shafts, and drive belts,
steel plates and links of various shapes and sizes,
nuts and bolts for assembly.

Component Modifications

None of the components except the thread can be modified from their original size or shape (except in elastic deformation) during the construction or testing of the device. The mousetrap(s) must be used as provided and cannot be disassembled.

Target Cup

The target cup is approximately 10cm high with an opening diameter of 8cm.

Concept Models and Sketches – team 4

Catapult idea that was discarded

Idea for building a platform was conceived from this problem

Bar could fly back and disrupt path of either coin or arm

The first bit of what would be the final design. Instead of a mesh on the arm, a 'racket' was built.

Final Concept with Engineering Specifications – team 1

Final Concept

Engineering Specifications

Energy of spring (Potential Energy) = Energy at launch (Kinetic Energy)

$(\text{Force at angle 1} \times \text{Angle 1} \times \text{Arm length}) - (\text{Force at angle 2} \times \text{Angle 2} \times \text{Arm length}) = .5 \times \text{mass of coin} \times \text{velocity Squared}$

$PE = .1583J$
 $V^2 = 63.32 \text{ (m/s)}^2$
 $\text{Range} = 4.15m \quad [x = (v^2)/g * \sin(2 * \text{Angle of trajectory})]$

Design Activity Schedule – team 3

*

Time	Person	Activity
2:00pm	Karen	Writing final concept/design
	Clement	Writing schedule/scanning notes and diagrams
	Brad/Jin-Yi	Testing mousetrap coin launcher
2:50	Karen/Clement/Brad/Jin-Yi	Discuss detailed design
3:00	Karen/Clement	Work on detailed design

3:00	Brad/Jin-Yi	Continue building/testing
3:30	Karen/Clement	Write bill of materials
3:45	Karen/Clement	Write product development rationale
4:00	Brad/Jin-Yi	Testing

Detail Design – team 2

Drawing

Refer to concept D

Bill of Materials – team 4

ID	Part Name	Quantity
	Mousetrap	1

	Bolts	Many
	Nuts	Many
	Fishing Wire	Some
	5X11 mechano	4

Test Results – team 2

Test Trial #	Launch Distance	Landing Distance	Score
1	1m	3m	0
2	0.5m	1m	0
3	1.5m	2m	0

Product Development Rationale – team 3

Reasons for Coin-toss Device Design

Concept Model #2: Concept model #1 was eliminated due to the belief that we would not have sufficient power to drive the coin 5m. Concept #3 was also eliminated because a method of automated launch could not be found, while a solution to concept model #2 was found.

Ramp: The ramp was instituted into the design because we needed to optimize the amount of initial potential energy (PE) for conversion into kinetic energy (KE).

Elastic Slingshot: This was used because the “car” required more PE to decrease the distance to the goal, since the ramp would not be able to give the “car” enough energy to get it close enough to $d=1$ m. The elastic slingshot (as well as the ramp) freed up a second mousetrap, as the original design was to use one mousetrap to power the car.

Coin Launcher (the arm): We used an arm attached to the mousetrap to give the coin greater leverage to propel it further. The arm also acted as an launchpad for the coin.

Mousetraps: Two mouse traps were needed because one would not be able to give it enough energy to propel it the distance required.

String: The string was attached to the ramp so that it could go taut to enable to launch to be automated.

Product Improvement – team 1

Engineer G My calcs say that that will go 4.15m. Sound Right?
 Engineer G Why Don't you raise the m/t with stand up? We can raise it what, another 12 in?
 Engineer G Try making the angle (between M/T and base) just a little less if you can.
 Engineer G That will launch at a greater angle.

Appendix H – Sample chat session

This Sample chat session is from team #4 (two engineers and two technicians)

MS-Chat0001

```
"8/3/98 10:34:00 AM","Engineer G","Hello Guys"
"8/3/98 10:34:04 AM","Technicians G","lets try this"
"8/3/98 10:34:12 AM","Engineer G","We got the first words in!!"
"8/3/98 10:34:55 AM","Technicians G","Did you load the background?"
"8/3/98 10:35:07 AM","Engineer G","No we didn't"
"8/3/98 10:35:11 AM","Technicians G","load it now"
"8/3/98 10:35:31 AM","Engineer G","why?"
"8/3/98 10:35:39 AM","Technicians G","hold on"
"8/3/98 10:35:49 AM","Engineer G","Okay lets get started??"
"8/3/98 10:35:58 AM","Engineer G","Save the sketch, it's a preliminary
drawing"
"8/3/98 10:36:08 AM","Technicians G","I already did"
"8/3/98 10:36:10 AM","Technicians G","Anyways...."
"8/3/98 10:36:29 AM","Technicians G","can u guys get the objectives
and porject specs going? the lst two things"
"8/3/98 10:36:42 AM","Technicians G","dennis can't speel very weel!"
"8/3/98 10:36:49 AM","Technicians G","james can't either"
"8/3/98 10:36:55 AM","Engineer G","I got that from his election
campaign"
"8/3/98 10:37:00 AM","Technicians G","lol"
"8/3/98 10:37:04 AM","Technicians G","loser"
"8/3/98 10:37:14 AM","Technicians G","Okay nuff goofin around."
"8/3/98 10:37:28 AM","Technicians G","so can u guys get those lst two
going? on the document?"
"8/3/98 10:43:55 AM","Technicians G","hello?"
"8/3/98 10:46:01 AM","Engineer G","So how does that sound for a project
objective"
"8/3/98 10:46:23 AM","Engineer G","Do you think Product Specifications
has the same meaning as constraints"
"8/3/98 10:46:32 AM","Engineer G","Okay, Ignore me if you'd like"
"8/3/98 10:46:58 AM","Technicians G","umm"
"8/3/98 10:47:49 AM","Engineer G","Probably just a more defined
Objective"
"8/3/98 10:54:20 AM","Technicians G","okay hello"
"8/3/98 10:54:32 AM","Technicians G","look into the video"
"8/3/98 10:54:34 AM","Engineer G","hello hello"
"8/3/98 10:54:39 AM","Engineer G","I see the box built "
"8/3/98 10:54:43 AM","Technicians G","we have a prelim model."
"8/3/98 10:54:54 AM","Technicians G","going to fire a quarter"
"8/3/98 11:09:25 AM","Technicians G","okay we're donig test1 for the
quarter"
"8/3/98 11:09:31 AM","Technicians G","okay....."
"8/3/98 11:09:38 AM","Technicians G","watch the video"
"8/3/98 11:09:52 AM","Engineer G","What are you ding"
"8/3/98 11:10:04 AM","Technicians G","the quarter hit the ceiling"
"8/3/98 11:10:05 AM","Engineer G"," I know that but for a moment I
couldn't see anything"
"8/3/98 11:10:06 AM","Technicians G","during the test"
"8/3/98 11:10:09 AM","Technicians G","it went REALLY far"
"8/3/98 11:10:11 AM","Technicians G","or high."
"8/3/98 11:10:25 AM","Engineer G","How far did it go width wise??"
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"8/3/98 11:10:29 AM", "Engineer G", "4 meters"
 "8/3/98 11:10:44 AM", "Engineer G", "Is that 4 meters forward??"
 "8/3/98 11:11:04 AM", "Engineer G", "What did you jsut do?"
 "8/3/98 11:11:31 AM", "Engineer G", "7 meters without hitting the ceiling?"
 "8/3/98 11:11:36 AM", "Engineer G", "How di you change the angle??"
 "8/3/98 11:11:45 AM", "Engineer G", "Elevated what thing"
 "6/3/98 11:11:50 AM", "Engineer G", "I really see well"
 "8/3/98 11:11:51 AM", "Engineer G", " OKy"
 "8/3/98 11:12:19 AM", "Engineer G", "What are the dimensions of the block"
 "8/3/98 11:12:50 AM", "Technicians G", "1 cm thick"
 "8/3/98 11:12:52 AM", "Engineer G", "1 cm??"
 "8/3/98 11:12:53 AM", "Technicians G", "in height"
 "8/3/98 11:13:17 AM", "Engineer G", "Look at Chris''s diagram on the white board"
 "8/3/98 11:20:11 AM", "Engineer G", "So there was a problem that the bar on the mouse trap was sending the quarter backwards when it was released"
 "8/3/98 11:20:36 AM", "Engineer G", "And that was solved by...temporarily placing the quatered out outside the bar"
 "8/3/98 11:21:48 AM", "Engineer G", "How far is the distance from the start to the cup"
 "8/3/98 11:22:52 AM", "Engineer G", "5m"
 "8/3/98 11:23:01 AM", "Engineer G", "So you went 2m over last time?"
 "8/3/98 11:24:11 AM", "Technicians G", "we''re going to place a small platform onto the mousetrap"
 "8/3/98 11:24:30 AM", "Technicians G", "a small support beam or ledge"
 "8/3/98 11:24:47 AM", "Engineer G", "That is for the quarter??"
 "8/3/98 11:25:46 AM", "Technicians G", "changed the prajectory (angle) to get small distance"
 "8/3/98 11:26:34 AM", "Technicians G", "raising the back causes travel less... shorter LENGTH"
 "8/3/98 11:27:06 AM", "Technicians G", "arc less"
 "8/3/98 11:27:22 AM", "Technicians G", "also"
 "8/3/98 11:27:26 AM", "Technicians G", "w/ msoutrap"
 "8/3/98 11:27:40 AM", "Engineer G", "Your last few sentaces made no sense"
 "8/3/98 11:27:45 AM", "Technicians G", "when angle becomes large - quarter can''t balance"
 "8/3/98 11:27:49 AM", "Technicians G", "it''ll slip off."
 "8/3/98 11:28:01 AM", "Engineer G", "Don''t make the angle any larger then"
 "8/3/98 11:28:27 AM", "Engineer G", "Try placing the quarter, not at tle edge but closer to the fulcrum of the mousetrap"
 "8/3/98 11:29:12 AM", "Technicians G", "attaching it to the spring"
 "8/3/98 11:29:28 AM", "Technicians G", "whiteboard"
 "8/3/98 11:35:27 AM", "Engineer G", "So I take it that you have nixed the idea of moving the device, sort of as a car??"
 "8/3/98 11:35:36 AM", "Technicians G", "i think so"
 "8/3/98 11:35:37 AM", "Engineer G", "Too inaccurate...."
 "8/3/98 11:35:39 AM", "Technicians G", "what do u think?"
 "8/3/98 11:35:57 AM", "Engineer G", "I think it will be hard to direct and since there is enough"
 "8/3/98 11:36:06 AM", "Engineer G", "force to cause the quarter to pass the cup"

"8/3/98 11:36:19 AM", "Engineer G", "we should be able to get it to hit the cup with some fine tuning"
 "8/3/98 11:36:26 AM", "Engineer G", "That's what I think"
 "8/3/98 11:37:12 AM", "Technicians G", "here's the thing"
 "8/3/98 11:37:17 AM", "Technicians G", "if we're going to make it move"
 "8/3/98 11:37:27 AM", "Technicians G", "then we need to shorten the distance as much as possible"
 "8/3/98 11:37:34 AM", "Technicians G", "Firing distance"
 "8/3/98 11:37:57 AM", "Technicians G", "do u just want to conclude that moving it is pointless?"
 "8/3/98 11:37:59 AM", "Engineer G", "There is not point to moving it I think"
 "8/3/98 11:38:08 AM", "Engineer G", "I think that that is probably right"
 "8/3/98 11:38:22 AM", "Engineer G", "Since it can already shoot too far"
 "8/3/98 11:42:32 AM", "Technicians G", "okay"
 "8/3/98 11:46:45 AM", "Technicians G", "okay time is now:11:49 - within half an hour we HOPE to have some tests going on"
 "8/3/98 11:49:36 AM", "Technicians G", "okay"
 "8/3/98 11:49:42 AM", "Technicians G", "we're having problems with the platform"
 "8/3/98 11:49:46 AM", "Technicians G", "we can't really attach anything"
 "8/3/98 11:56:38 AM", "Technicians G", "condition is to have it very sturdy"
 "8/3/98 11:56:49 AM", "Technicians G", "mouse trap has a lot of energy"
 "8/3/98 11:56:59 AM", "Technicians G", "if ledge isn't stable"
 "8/3/98 11:57:07 AM", "Technicians G", "could modify each test result"
 "8/3/98 12:05:19 PM", "Technicians G", "going to draw on your white board"
 "8/3/98 12:34:07 PM", "Technicians G", "so what are you talking about the under part?"
 "8/3/98 12:34:12 PM", "Technicians G", "what do u want us to do?"
 "8/3/98 12:40:01 PM", "Engineer G", "Did you get the verbal decrption about the under part."
 "8/3/98 12:40:14 PM", "Engineer G", "Wait a minute did you just add the unter puart to the over part???"
 "8/3/98 12:40:21 PM", "Engineer G", "That wasn't what I mean."
 "8/3/98 12:40:46 PM", "Engineer G", "What I meant to say was that you didn't need to have the large contraption on top. "
 "8/3/98 12:41:22 PM", "Technicians G", "sorry, but the contraption is on already"
 "8/3/98 12:41:24 PM", "Engineer G", "If you wanted to, you could use a board under the mouse trap throwing arm"
 "8/3/98 12:41:28 PM", "Engineer G", "That's okay if it works"
 "8/3/98 12:41:37 PM", "Technicians G", "there is an arm as well"
 "8/3/98 12:41:45 PM", "Engineer G", "If it doesn't we will need to think of something else"
 "8/3/98 12:43:00 PM", "Technicians G", "hi"
 "8/3/98 12:43:08 PM", "Engineer G", "hello hello"
 "8/3/98 12:44:21 PM", "Technicians G", "hello"
 "8/3/98 12:46:39 PM", "Engineer G", "Your audio and video is gone, what happened>???"
 "8/3/98 12:47:10 PM", "Engineer G", "We have totally lost contact...guys what happened??"

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