AN ABSTRACT OF THE THESIS OF

Andis M. Zarins for the degree of Master of Science in Mechanical Engineering presented on March 22, 2007.

Title: Engineering Design Knowledge Management and Capture Using a Process Overview Document.

Abstract approved:

Robert K. Paasch

An experiment was conducted to examine the possible impact of an engineering design and problem solving process overview document on knowledge management and capture. A process overview document was first created. Next, two multi-disciplinary design teams worked over a two-week span to develop concepts to address a problematic opportunity. One group had access to the overview document, while the control group did not. Two hypotheses, related to the number of times individuals checked available reference material, were tested. In particular, groups that had access to the overview document were expected to have more reference acts. Results of the hypotheses tests found an absence of statistical significance. Additionally, data gathered to answer five research questions indicate some favorable characteristics to the overview document's diffusion as an innovation. An experimental model was established upon which future generalizable experiments can be based, and a second design process model was developed for further study.

Engineering Design Knowledge Management and Capture Using a Process Overview Document

by

Andis M. Zarins

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APPROVED:

Major Professor, representing Mechanical Engineering

Head of the Department of Mechanical Engineering

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Andis M. Zarins, Author

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Chapter 1 ─ Introduction

Knowledge management and capture using a process overview document during the engineering design and problem solving process was examined experimentally. Three primary products resulted from these efforts: 1) a process overview document, 2) an experimental model, and 3) a model of the engineering design process that includes inputs, process paths, and outputs. Each product involves some innovation.

A process overview document did not exist prior to the experiment, and one was created. The document has two main purposes. First, it is intended to help reduce procedural uncertainty experienced by a design team. Second, the document attempts to place more emphasis on problem or opportunity definition at the start of the design process.

The developed experimental model is intended provide a base upon which future generalizable experiments can be built. In particular, two multi-disciplinary design teams, of three people each, worked over a two-week period to develop concepts to address a problematic opportunity. One group had access to a process overview document, while the other group did not. Two hypotheses, related to the number of times individuals checked available reference material, were tested. More specifically, the group that had access to the overview document was expected to have more communicative acts (i.e., acts to check a reference source). Previously, in a naturalistic study of small group problem solving, the greater number of communicative acts to help both clarify procedures and analyze the problem or task were found to yield solutions of greater utility (Propp & Nelson, 1996). The results of the hypotheses tests found an absence of statistical significance. Five research questions related to the diffusion of innovations were also asked. The experimental data indicates that the overview document might have some characteristics favorable to its diffusion.

Another model of the engineering design process was the third major product of the thesis work. Unlike the overview document, this second model had not been planned. The model's development was triggered by the efforts to complete this paper. It resulted from the attempt to describe the intended effect the overview document is supposed to have on those involved in a design team effort. The model also characterizes the consequences of different problem definition strategies.

This paper has six sections, or chapters. The introductory section itself has three more parts. First, the problem that this thesis attempts to address is clarified. Second, a definition of a possible tool to address the problem – the process overview document – is provided. Some project motivation completes the section.

The remaining paper sections begin with a review of literature relevant to the thesis work. Next, the experimental materials and methods are described in the third section. Fourth, the results are presented. Discussion of the results, limitations, lessons learned, and implications, occurs in the fifth section. Finally, there is a brief conclusion.

1.1 A Problem with Multi-Disciplinary Engineering Design Teams

The results of the engineering design and problem solving process routinely make possible that which previously was not possible. *Engineering* can be generally defined as the application of science and mathematics to useful purpose in the form of machines, structures, and/or systems (Merriam-Webster, 2004). Three types of particular knowledge needed in engineering are *general* knowledge, *domain-specific* knowledge, and *procedural* knowledge (Ullman, 2003). An engineer has two places to which to turn for this knowledge: 1) the engineer's own mind and memory, or 2) some external information source.

In response to rising demand for increasingly complex products, structures, and systems, engineering design and problem solving now, most often, requires the knowledge of more than one person. The involvement of multi-disciplinary experts, or the use of a concurrent design team, significantly increases the domain-specific specialty knowledge being applied during design. General knowledge also increases, as does specialty procedural knowledge. However, adding the knowledge of multi-disciplinary experts, while addressing the limits of individual knowledge, introduces a new problem. That problem partially offsets the realized benefits of such design teams. The further clarification of this problem is aided by the introduction of a design process model.

A simple model of the design process, that includes inputs and outputs, is presented in Figure 1 (on the next page). The inputs are a problem or an opportunity, and the knowledge of whomever is doing the design. Materials and energy needed to produce the product, structure, or system can be considered as part of the problem or opportunity. One particular problem or opportunity can be processed many different ways to output many different possible solutions or responses.

Of the three types of knowledge needed in engineering design, procedural knowledge and domain-specific knowledge are the two that receive the most attention in engineering education. Procedural and domain-specific knowledge are shown as two specific knowledge

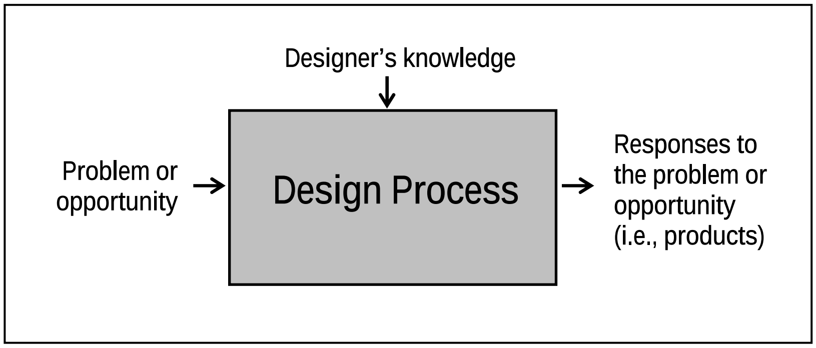


Figure 1: A simple input/output design process model

inputs into the design process in Figure 2, below.

Knowledge varies by individual. Figure 3 (on the next page) shows a design process being done by a hypothetical mechanical design engineer. Further, a well-educated and experienced mechanical design engineer has a good understanding of the design process. Plus, he or she also has significant knowledge related to other mechanical engineering topics (e.g., kinematics, fluids, materials, etc.). The same engineer also has varying lower levels of other types of domain-specific knowledge. Examples of these other domains include electrical engineering, manufacturing, and marketing. Figure 4 (also on the next page) presents a column chart indicating the various levels of knowledge that the hypothetical engineer brings to the design process. The levels of procedural knowledge and domain-specific knowledge that are brought to a given design situation are each inversely related to two types of uncertainty that a designer confronts. First, *procedural uncertainty* decreases as procedural knowledge increases.

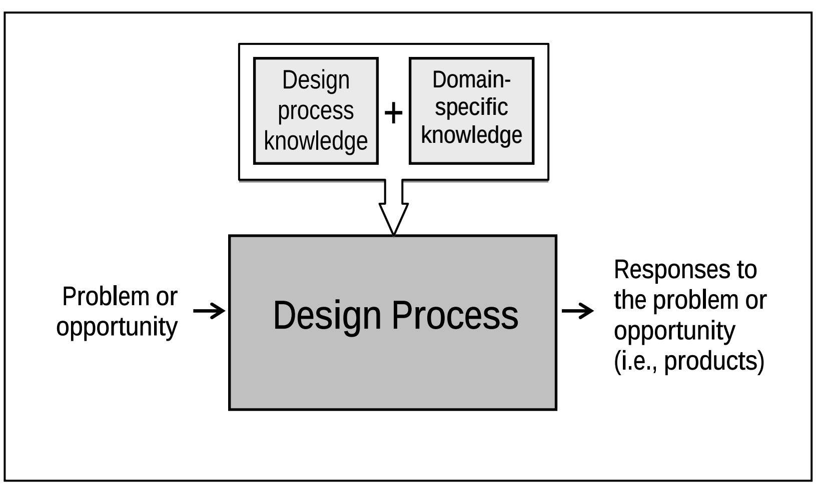


Figure 2: Two types of knowledge input into the design process

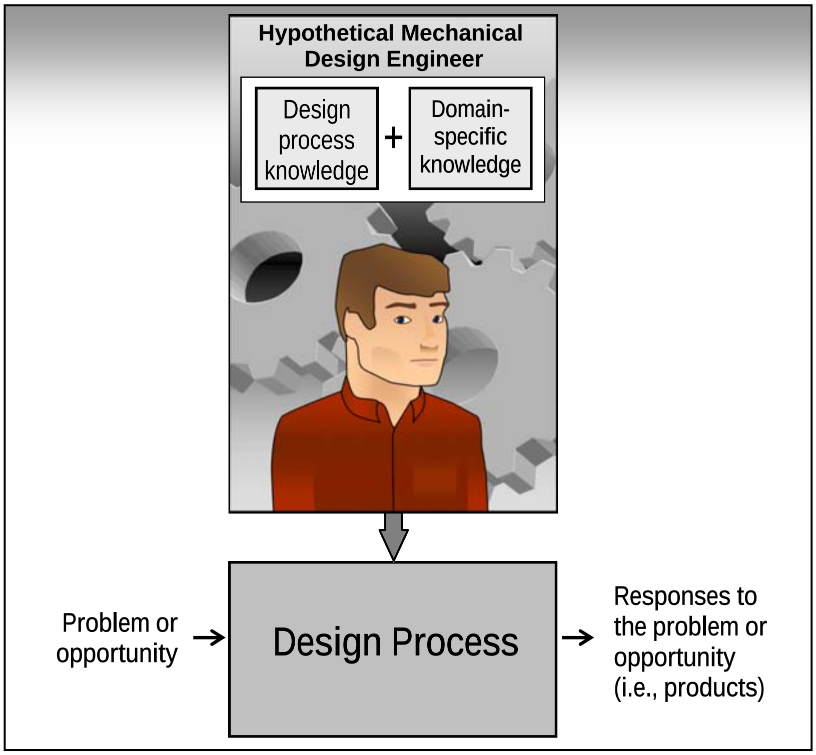


Figure 3: Knowledge input into the design process by one hypothetical mechanical design engineer

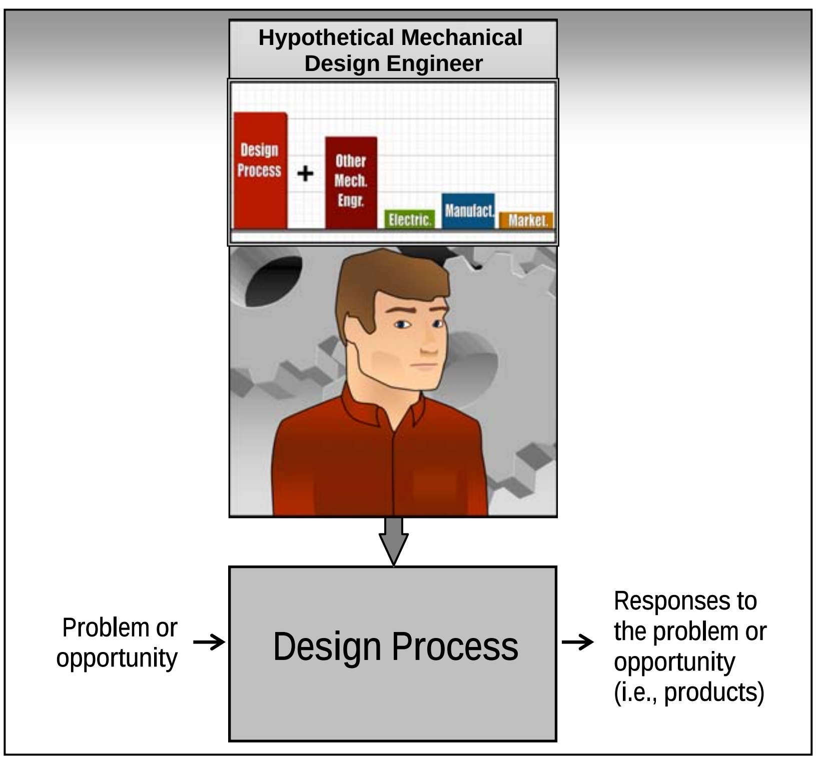


Figure 4: A hypothetical design engineer's levels of process knowledge and selected types of other domain knowledge

Second, *problem solving uncertainty* decreases as relevant domain-specific knowledge increases. Furthermore, uncertainty in communication situations with strangers has been identified as increasing anxiety and reducing mental processing capability (Gudykunst and Kim, 2003).

For relatively simple problems, a lone design engineer might have sufficient levels of procedural knowledge and needed domain-specific knowledge to successfully do design all by himself or herself. As problems or opportunities become increasing complex, the problem solving uncertainty increases, as well. As a result, for complex problems, an individual design engineer, such as the hypothetical design engineer, likely still has a low level of uncertainty with regards to the procedure by which the design is to occur. However, problem solving uncertainty is high; which is not good (see Figure 5, below).

The primary response to the problem of increased problem solving uncertainty has been to increase the domain-specific knowledge being applied to a given design situation. This has been done by introducing additional expertise, and forming a multi-disciplinary design team. Figure 6, on the next page, presents one such hypothetical team. An electrical engineer brings

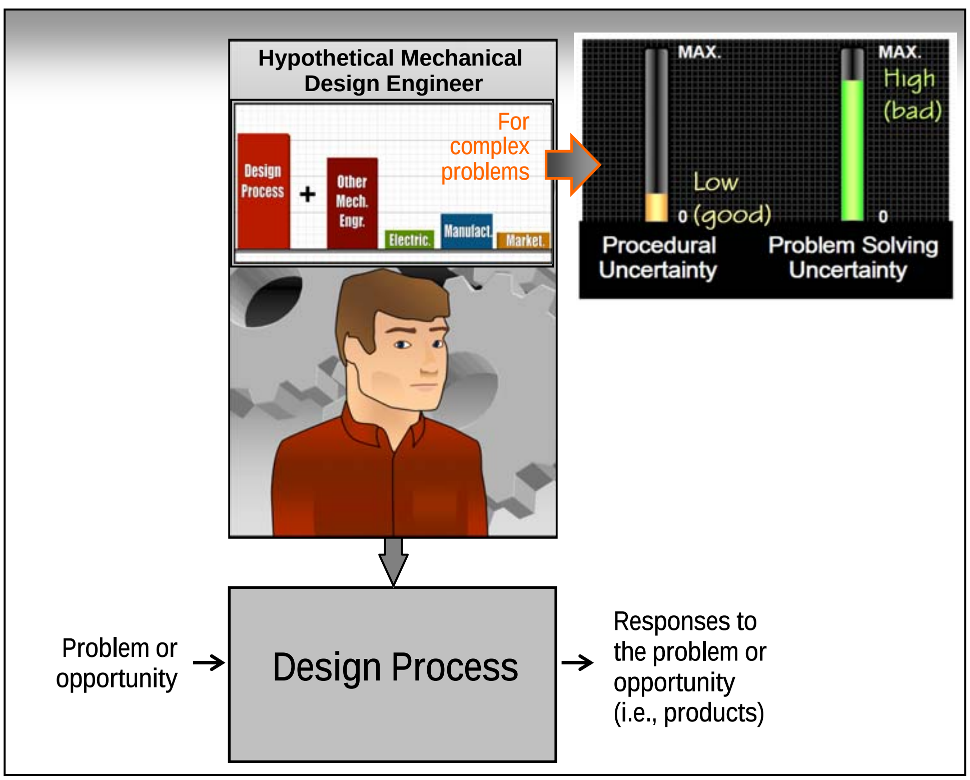


Figure 5: The hypothetical engineer's levels of procedural and problem solving uncertainty for complex problems

expertise in the area of, well, electrical engineering (see Figure 7, below). The hypothetical electrical engineer has some procedural knowledge, though not nearly as much as the

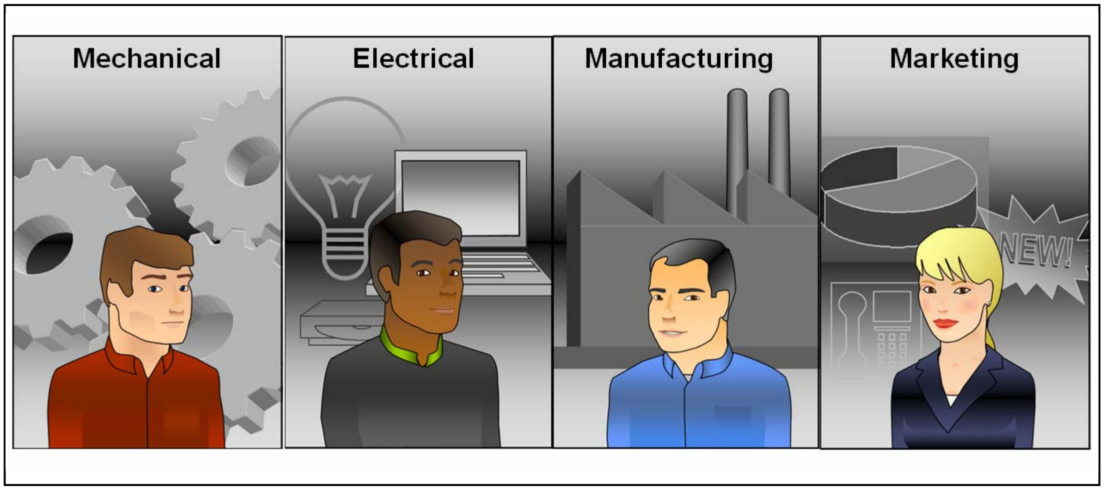


Figure 6: A hypothetical multi-disciplinary design team

mechanical design engineer. Further, the electrical engineer brings only modest understanding of other types of mechanical engineering specialties or of either manufacturing or marketing.

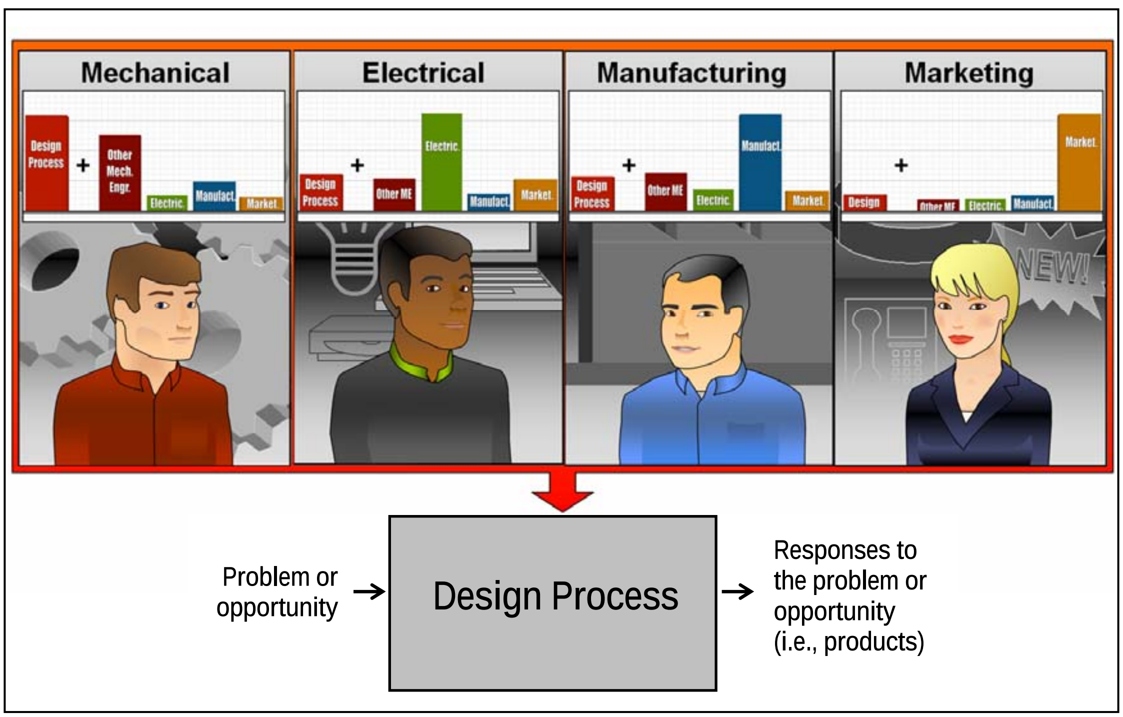


Figure 7: The increased levels of domain-specific knowledge that a hypothetical multi-disciplinary design team brings to the design process

The manufacturing expert is similarly qualified, but with a manufacturing emphasis. Finally, the marketing expert also has a high level of domain-specific knowledge, but has little knowledge of the relevant procedure or other engineering knowledge areas.

The introduction of multi-disciplinary experts has the desired effect of reducing the uncertainty related to problem solving. However, because most of the team members have a low level of procedural understanding, the procedural uncertainty increases significantly with a multi-disciplinary design team (see Figure 8, below). This increase, of course, is bad.

1.2 A Potential Response to the Problem: The Process Overview Document

In an effort to address the new problem that arises from the use of multi-disciplinary teams, a new tool is proposed. That tool is in the form of a document that provides an overview

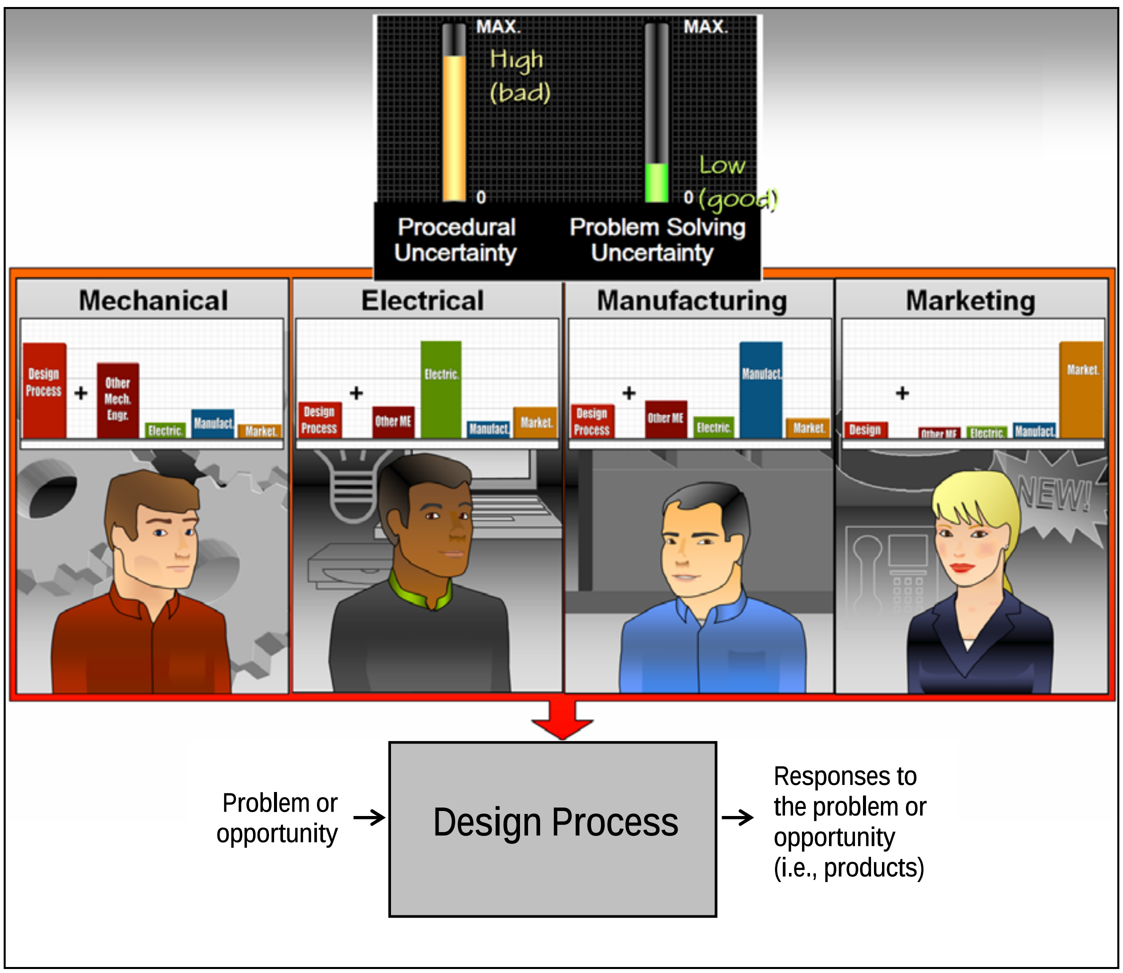


Figure 8: The decrease in problem solving uncertainty and the increase in procedural uncertainty resulting from the use of a multi-disciplinary design team

of the engineering design and problem solving process that is both accessible to all team members, and can be shared. More specifically, the process overview document is intended to increase procedural understanding and reduce uncertainty.

The following definition of a process overview document has two parts. First, how an overview document fits in with existing sources of knowledge is described. Second, six primary characteristics of an overview document are identified.

1.2.1 The Knowledge Pyramid

All knowledge that is relevant to engineering design and problem solving, much of which is academic, can be modeled as a pyramid (see Figure 9, below). At the top, the knowledge is extremely general and relatively limited in amount. Also at the top of the pyramid, all engineers (and most people, in general) have an internally accessible and simple definition of the problem solving process (i.e., identify the problem, formulate a solution, and implement the solution). Movement from the top of the knowledge pyramid to the bottom results in knowledge that is increasingly more specific and greater in quantity. On the bottom of the pyramid is highly specialized understanding. Also, reference material is available for much of the knowledge in the pyramid, including textbooks and articles (see Figure 10, on the next page).

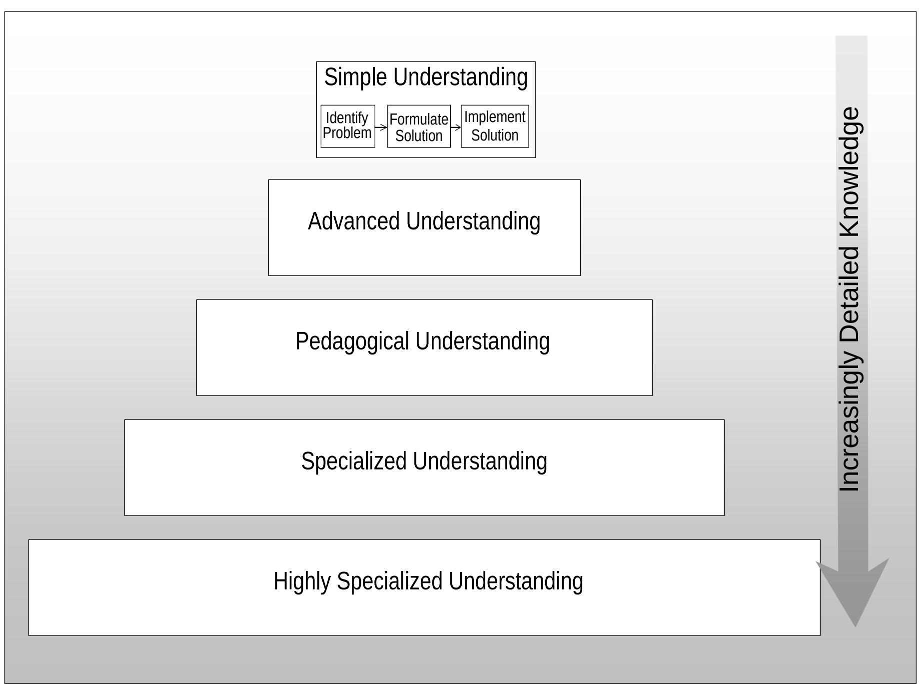


Figure 9: Engineering design and problem solving knowledge pyramid

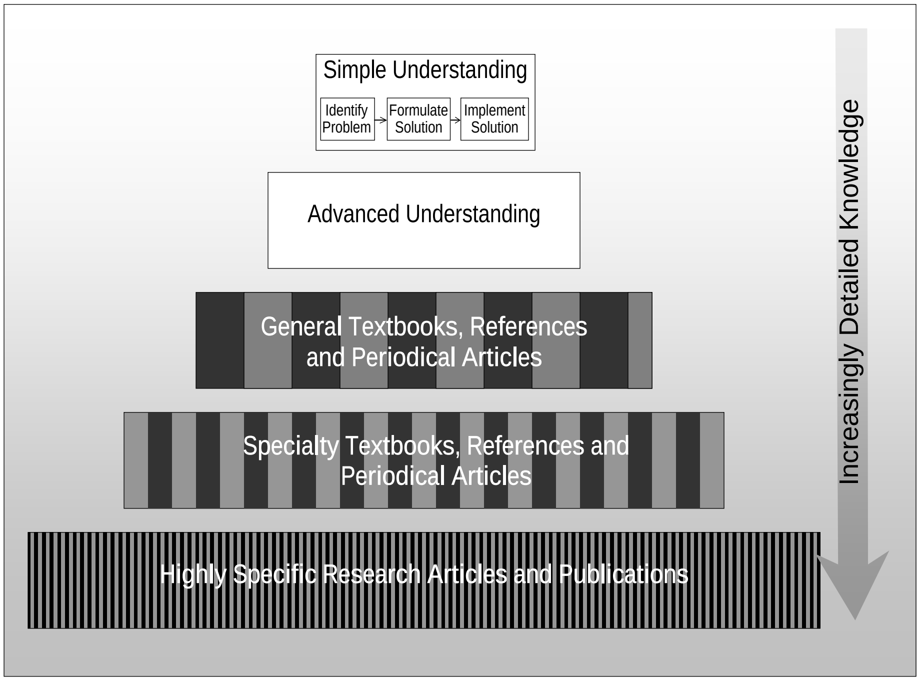


Figure 10: Available reference materials as part of the engineering design and problem solving knowledge pyramid

The percentage of knowledge committed to memory from each level of the pyramid, for a particular engineer, decreases from the top of the pyramid to the bottom (see Figure 11, on the next page). In addition to the simple problem solving process definition, a fairly inexperienced but college educated engineer has a more elaborate understanding of the design process. In addition, he or she has more domain-specific knowledge, especially of science and math, than if he or she had not been college educated. With increasing experience, an engineer increases the percentage of relevant knowledge that is available from his or her own memory. However, even highly experienced design engineers are unlikely to have a complete and correct understanding of all the procedural possibilities that could contribute to the solution of each new design problem. In other words, even highly experienced design engineers would benefit from reference material that does not have the depth that general textbooks provide.

The importance of procedural understanding is highlighted by a study of small group problem solving in a naturalistic (i.e., in non-laboratory) setting that was done by Propp and Nelson (1996). More specifically, the problem solving of work teams at a manufacturing plant was examined. Amongst Propp and Nelson’s findings were that those groups characterized by higher frequencies of both communication to *orient the group and establish procedures*, and communication to *analyze the problem or task* arrived at decisions of greater utility. *Utility* is an evaluation considering both the benefits and costs of a decision (Propp and Nelson, 1996).

An emphasis on the understanding of processes is also reflected in quality assurance and improvement guidelines, such as those put forth by the International Standards Organization (ISO). “The supplier shall establish and maintain procedures to control and verify the design of the product in order to ensure that the specified requirements are met,” ISO states (ISO, 1992). According to Ullman (2003), the organization’s ISO 9000 quality management system is implemented by companies for, amongst other reasons, to improve product quality, reduce costs, and to heighten firm competitiveness. To receive ISO 9000 certification, a firm must describe the process by which work, such as product design, is accomplished (Ullman, 2003).

An approach similar to ISO’s emphasis on organizationally specific processes, when applied to the general design and problem solving process, may yield improvement in process results. Further, the grey area between reliable individual knowledge and knowledge that clearly requires reference to an outside source could be better addressed. At the least, a process overview document would provide designers another means by which they can double-check

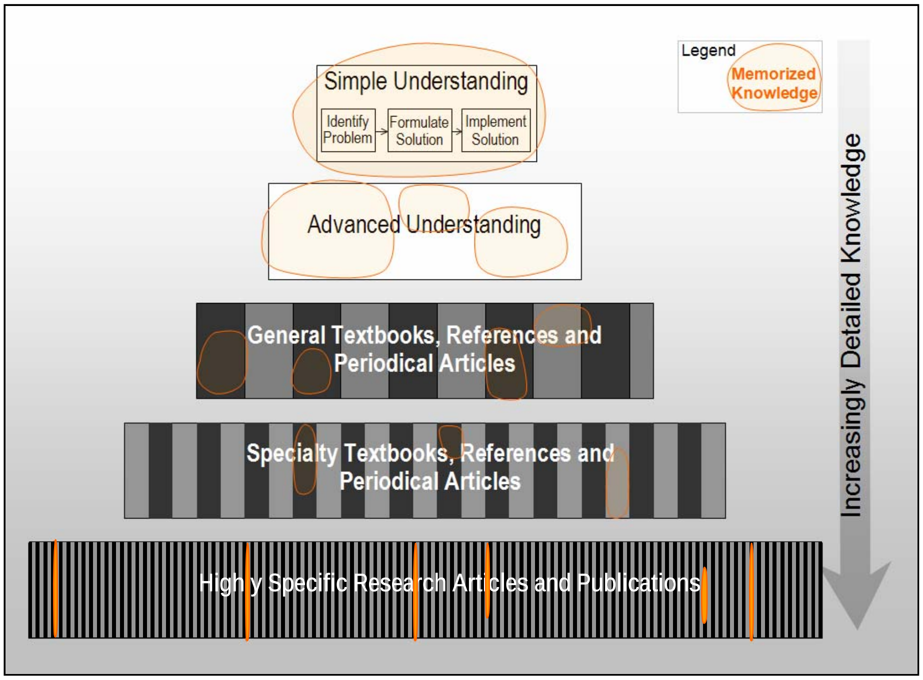


Figure 11: A graphical representation of one hypothetical design engineer’s memorized knowledge as part of the engineering design and problem solving knowledge pyramid

their understanding.

1.2.2 Primary Characteristics of a Process Overview Document

A process overview document is defined as a digest of information that is presented in more detail in other documents such as general textbooks and research articles (see Figure 12, below). The document has six primary features. First, a 'big picture' presentation of the entire design and problem solving process lays out the process in an easy to follow, left-to-right representation, and on a single page. Major process stages are identified, and questions that need to be answered are explicitly stated. A flowchart portion clarifies the procedural consequences of potential answers to questions at decision points, and shows places where stages may be repeated (i.e., feedback loops). Additionally, a Gantt chart like portion on the same page presents the sequence of procedural steps in a manner that clarifies that tasks may have varying degrees of overlap or *concurrency*. The time-dependent nature of the process is indicated by the Gantt chart representation.

The second primary feature of the overview document is that, for process steps and

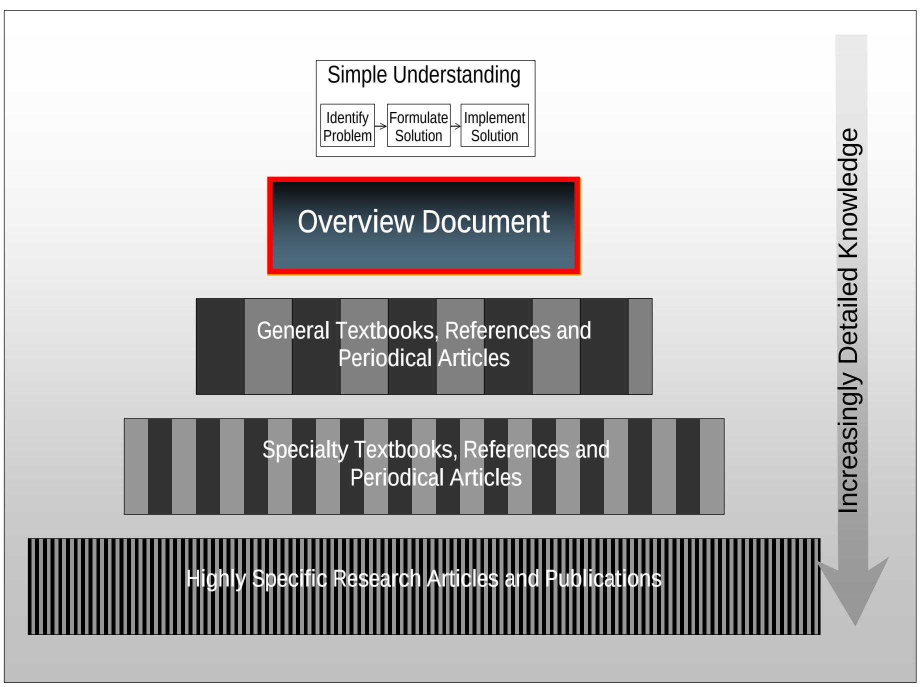


Figure 12: How an overview document fits into the engineering design and problem solving knowledge pyramid

decision points, more specific clarifying information is included. In an electronic file, the items in the flowchart are hyperlinked to the clarifying information pages. For hard copy versions of the document, these pages are also provided in the order consistent with the process, in general. Further, sources are listed at the end of each section of clarifying information. These lists direct document users to specific references for even more information and greater detail.

Third, the document can be used as a general reference, such as when learning about the process, or it can be used for specific projects. The digital file version of the document can be saved under new filenames and, then, used to manage and document particular design projects. Four features most contribute to the document's ability to do so. First, the Gantt chart portion of the procedure lay-out page can be customized to plan a project. Second, the pages that provide each step's clarifying information include places were data-in and data-out can be tracked, as well as places to input and view contact information. Also, multiple worksheets that can be used to assist in the accomplishment of various project stages are included. Lastly, for shared versions of the electronic file, changes to the file can be tracked.

A fourth primary feature of the overview document is that it has considerably less than the 100-to-1000 pages that general process textbooks have. As a result, total reading time is a few hours, as opposed to twenty-to-fifty hours.

Fifth, a completion date is clearly listed on the overview document. The date provides an indication of how up-to-date the document is. So as to represent the state-of-the-art of the design process, the document is to be revised periodically.

Finally, and as alluded to above, the document is an electronic file that is also presentable as two different hard copy versions. One such version is a hard copy three-ring binder document that can be viewed without a computer and transported readily. The other version is a poster that allows the entire main procedure lay-out page to be viewed easily.

1.3 Project Motivation

Much of the motivation for developing an engineering design and problem solving overview document arose from two sources: the author's own previous work experience, and observations of the types of problems that resist resolution.

A few years ago, the author was employed at a large aerospace manufacturing company, and did a redesign of a highly relevant federal regulatory flowchart. The redesign took what was deemed as a convoluted chart, presented on multiple pages, and clearly laid out the process from left to right on a single page. The revised diagram was built in commonly available computer software. Further, this work was done on non-company time. Additionally, it was concluded that such an easier to follow flowchart could also be potentially helpful to colleagues, as well.

Reaction to the first chart led to a request by the company for a second flowchart of a second highly relevant process. This time the work was done on company time. Eventually, this second chart too was completed. The second chart differed from the first in that it permitted those viewing it digitally the option of clicking on individual process steps to hyperlink to additional information. Both documents were well-received, and were posted and distributed as necessary.

Also, as noted previously, the engineering problem solving process routinely yields results that overcome physical constraints which humans encounter. However, many other types of constraints to human existence resist resolution. Various threats to life and health, including socio-political conflicts, have gone on for decades.

It is believed by the author that the process of engineering design and problem solving can significantly contribute to defining processes that help solve the other problems humans confront. This belief is based significantly upon two interrelated assumptions. The first assumption is that the probability of an engineering design and problem solving process generating a desired outcome is greater than the probability of most other major problem solving approaches doing the same. This greater level of outcome certainty may be, in part, the result of the second assumption. To begin with, the results of the engineering design process are often readily observable (both good ones and bad ones). In turn, the impact of engineering outputs upon the well-being of humans tend to be more obvious. The clarity of the impact of engineering upon human well-being is often, and unfortunately, due to catastrophic failure. Identification of the reasons for failure for many other problem solving processes tends to be more difficult. Failure avoidance, in particular, makes engineering rigorous – with relatively high levels of accountability. As a result, it is additionally assumed that processes used in engineering will reflect a greater appreciation of the potential effect on human well-being than many other types of problem solving.

Chapter 2 ─ Literature Review

The review of literature begins with the definition of a relatively new and active area of research related to engineering design called knowledge management. Four additional sections follow. Design process representations are reviewed next. In the third section, literature about the people and organizations that do engineering, including key communication concepts, is summarized. Technology that is used for information management and capture is overviewed fourth. Lastly, additional key concepts for improving knowledge management are presented. This last section ends with an assessment of what is needed for significant improvement in knowledge management and capture.

2.1 Knowledge Management and Capture

"The technical term for a method of digitizing the design process, including the brainpower involved, is called *knowledge capture*. Making sure the information is formatted and accessible is another can of worms called *knowledge management*," states Thilmany [italics added] (Thilmany, 2003). In the past, knowledge management (KM) was primarily technological management of information in the form of documents. More recently, knowledge management has expanded to include approaches related to organizational management, in an effort to maximize the potential benefits of, "an organization's intellectual assets" (McMahon et al., 2004). The earlier focus of knowledge management coincides with a *commodity* view of knowledge. That is, knowledge is thought of as consisting of discretely quantifiable objects (e.g., a nugget of wisdom) that can be managed accordingly (i.e., unearthed, etc.). In contrast, the more recently introduced knowledge management approaches contribute a *community* view in which knowledge is seen as only being definable relative to individuals and their interactions with others. Managing knowledge more like a commodity is called using a *codification strategy*. This approach is typically used by organizations that provide relatively standard products and services. On the other hand, those organizations that must develop specialized responses to unusual problems tend to employ a *personalization strategy* that emphasizes the interaction of people, with computers facilitating communication. Both views of knowledge management are considered valid, and the functioning of an organization often involves both. One view, however, is typically emphasized over the other, and that emphasis depends on the organizational context (McMahon et al., 2004).

McMahon et al. (2004) further characterize the importance of knowledge management as follows:

> Knowledge management has been identified as one of the key enabling technologies for distributed engineering enterprises in the 21st century.…With [the] transformation from primarily industrially based societies to those more reliant on the exploitation and use of accumulated knowledge, the productivity of the 'knowledge worker' has become a crucial issue (Drucker 1993). Creating and sharing knowledge is essential to fostering innovation, and is the key challenge of the knowledge-based economy (Chan Kim and Mauborgne 2003). Central to this application and exploitation of knowledge in engineering is the engineering design process (McMahon et al., 2004).

2.2 The Engineering Design Process

Numerous reference sources provide descriptions of the engineering design and problem solving process, or the product design process. Many include the process presented in a graphical form that attempts to elaborate on the simple three-step engineering problem solving process model. In addition to identification of the major process phases, these representations typically include more specific steps, and denote potential procedural loops. The possibility that the process might include task overlap, or concurrency, may also be included.

Graphical descriptions of the design process will be reviewed next. A more specific description of concurrency follows.

2.2.1 Graphic Representations of the Design Process

Engineering design and problem solving process graphical representations can be categorized into four main categories: 1) linear flowcharts, 2) circular flowcharts, 3) Gantt charts, and 4) other types (i.e., multi-directional and/or implying extra dimensions). Linear flowchart representations can further be divided into two groups: top-to-bottom and left-to-right (though a few do both). The presence or absence of iterative feedback loops further differentiates linear flowcharts. Circular or cyclical flowcharts may also include feedback connections. Koberg et al. (1976) also identify a 'branching' chart type (see Figure 13, on the next page) (Olsen, 1982). A Gantt chart representation of steps in design is shown in Figure 14 (see page 17).

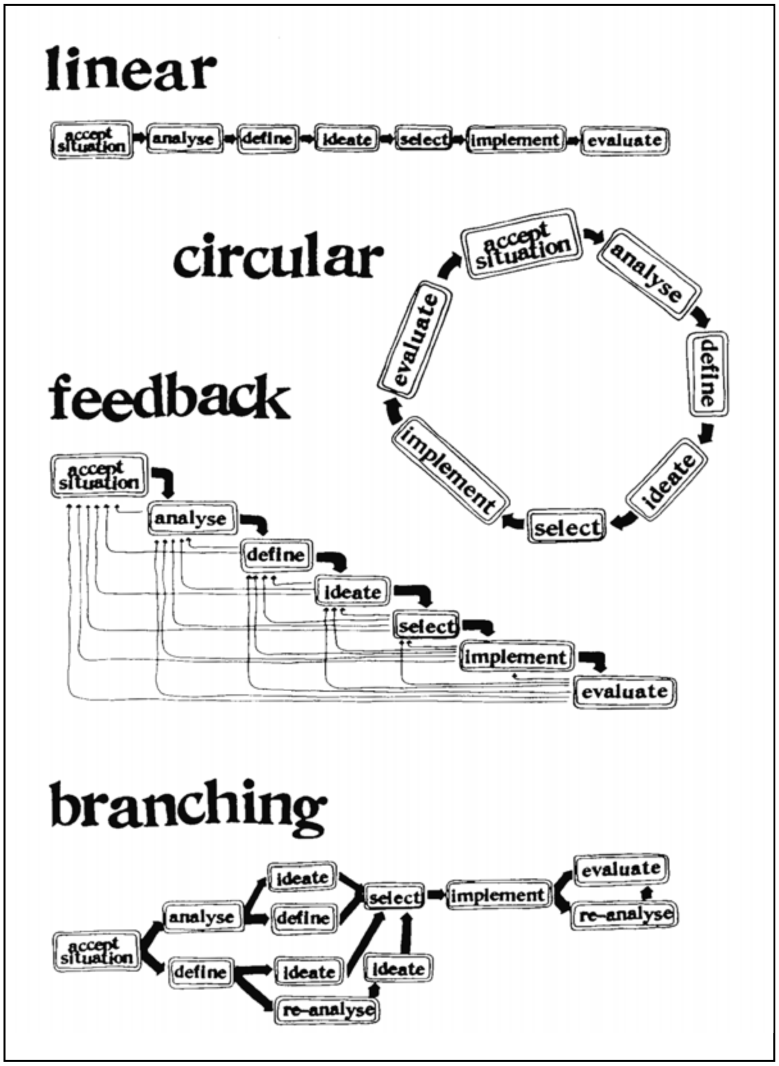


Figure 13: Models of the design process [Koberg et al., 1976] (Olsen, 1982)

Differentiation of flowcharts into vertical and horizontal categories eases initial comparisons of the charts' contents. Once some familiarity with the representations has been established within sub-categories, inter-category comparisons can be made more readily. Additionally, and significantly, flowcharts that flow in different directions inherently have different levels of compatibility with other graphical models that are commonly used. In particular, information that is presented in a left-to-right manner is highly consistent with the graphical representations of time dependent phenomena used in science and engineering. Time is a primary constraint upon the engineering design process, and this graphical compatibility can potentially be used to benefit designers.

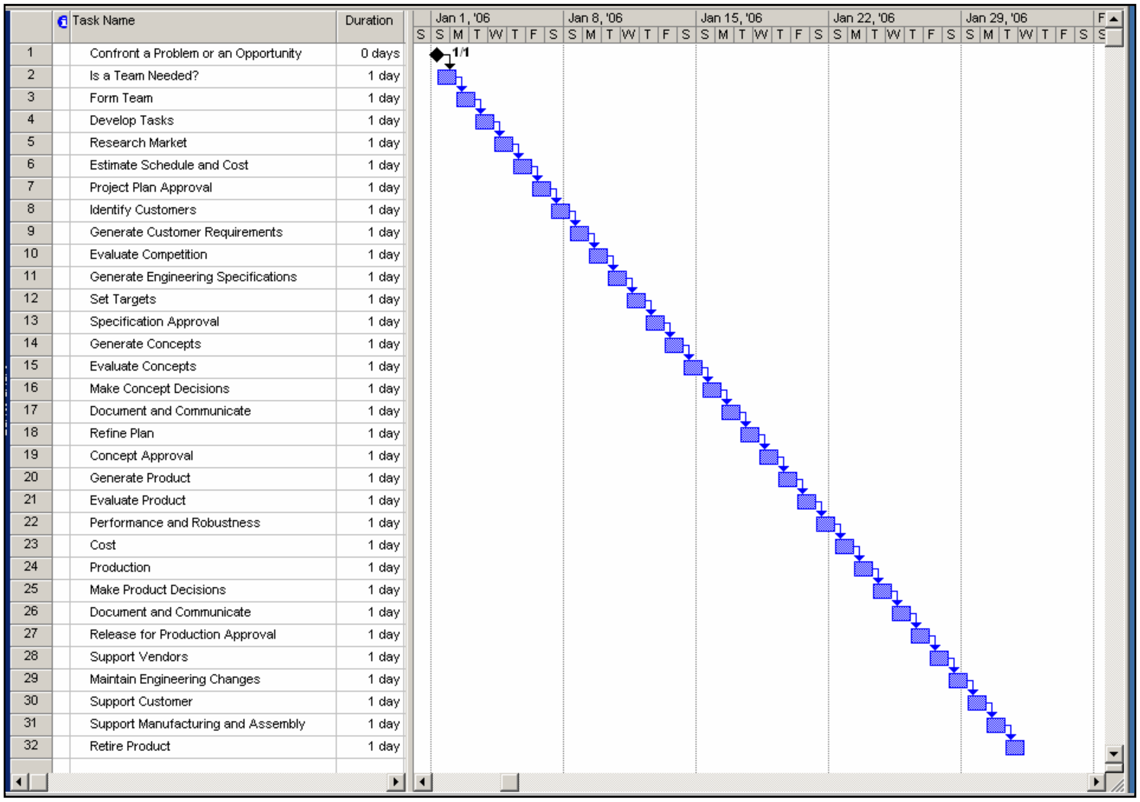


Figure 14: The design process in Gantt chart form

Beginning on page 19, ninety-six process figures are presented over twenty-eight pages. There are two main reasons why this is done. First, such a compilation, which apparently has not been done previously, is a valuable resource. It offers a starting point for further research that reduces repeated effort. Also, some of the representations, when revisited, might lead to changes in the engineering design and process overview document.

The thinking behind the second reason is as follows: If one is in the unique position to put together an extensive (though not exhaustive) collection of process representations, then one should do so, because doing so might lead to insight or a breakthrough in understanding that otherwise would not occur. This, in fact, did occur in this case. The third product of the thesis work, mentioned in the introduction, is another model of the design process whose development was initiated during efforts to assemble the process representations. This model will be described in Chapter 5. It is also worth noting that the process figure collection is consistent with good knowledge management and capture practice, and with the idea that the possibility of subsequent innovation is enhanced. Furthermore, as will be clarified later in the chapter, this explanation of the reasoning for the process compilation is also good knowledge management and capture practice.

The process representations are organized and presented in five groups, which are:

1) Top-to-bottom flowcharts
2) Left-to-right flowcharts
3) Gantt charts
4) Circular charts
5) Other charts

A brief description precedes each section. Also, in addition to general design and problem solving process representations, some company-specific process descriptions are included.

Top-to-bottom, or vertical, flowcharts number forty, and are the greatest in number of the five groups. The presentation begins with those seventeen that do not feature feedback looping (i.e., Figures 15-31). The remaining twenty-three figures do have feedback loops (Figures 32-54). Also, each of the two sub-sections begins with the simpliest diagrams; with subsequent diagrams becoming increasingly more complex.

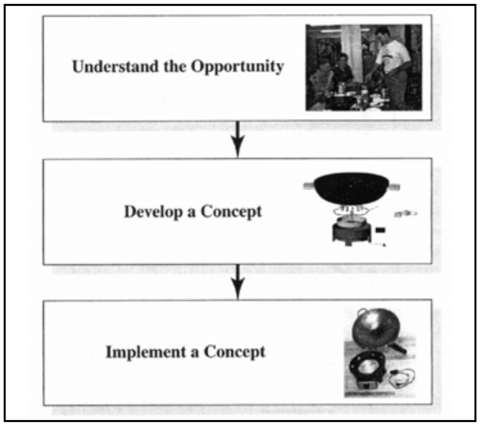


Figure 15: Phases in a product development process (Otto & Wood, 2001)

General Problem-Solving Procedure	Five-Step Design Process
1. Define the problem.	Develop functional specifications.
2. Gather information.	Develop the concept design.
3. Generate and evaluate potential solutions.	Generate design alternatives.
4. Refine and implement a solution.	Select and model the best alternative.
5. Test and verify the solution.	Test and verify the design.

Figure 16: The five-step design process (King, 1996)

The Problem-Solving Cycle
→ Exploring the Problem ←
Establishing Goals
Generating Ideas
Choosing the Solution
Implementing the Solution
Evaluating the Solution

Figure 17: The problem-solving cycle (Harris, 2002)

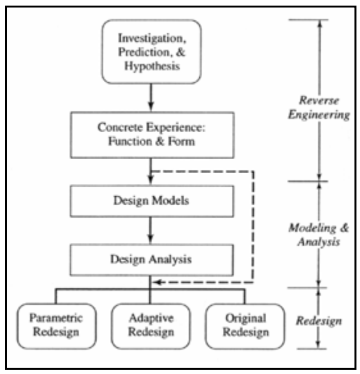


Figure 18: General reverse engineering and redesign methodology (Otto & Wood, 2001)

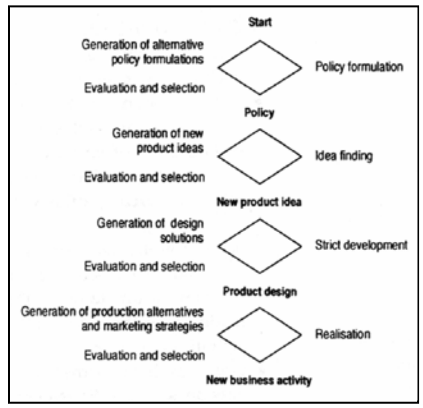


Figure 19: Divergence and convergence in the innovation process (Roozenberg & Eekels, 1995)

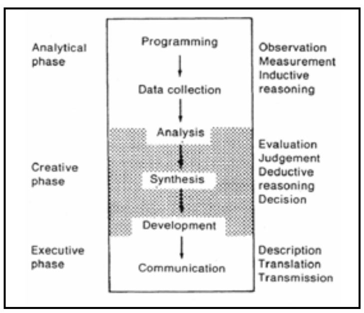


Figure 20: Archer's three-phase summary model of the design process (Cross, 2000)

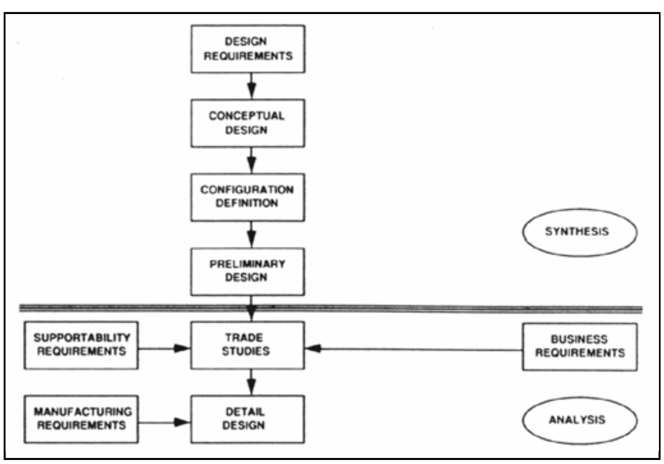


Figure 21: Traditional design process (Schrage, 1993)

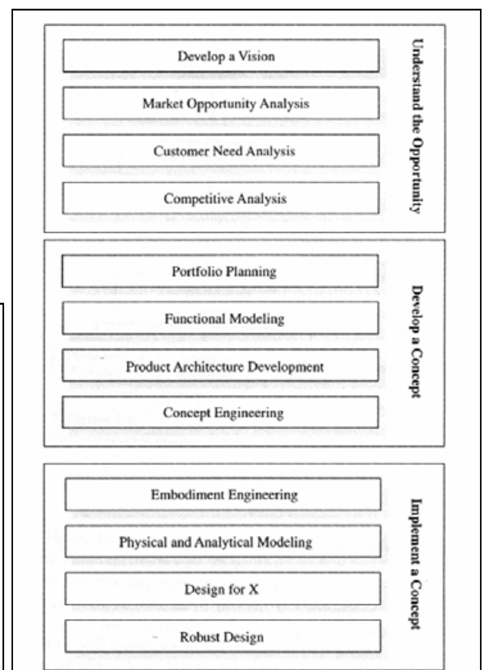


Figure 22: Activities in the typical product development process (Otto & Wood, 2001)

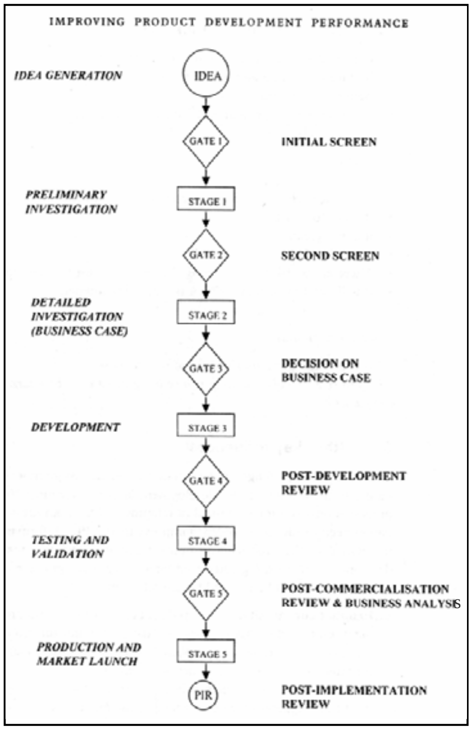


Figure 23: The stage gate process model (Barclay et al., 2000)

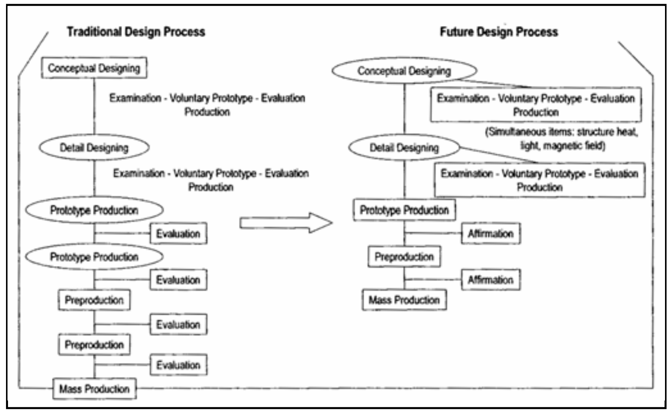


Figure 24: Change of design system by the introduction of CAE (Ikeda, 2000)

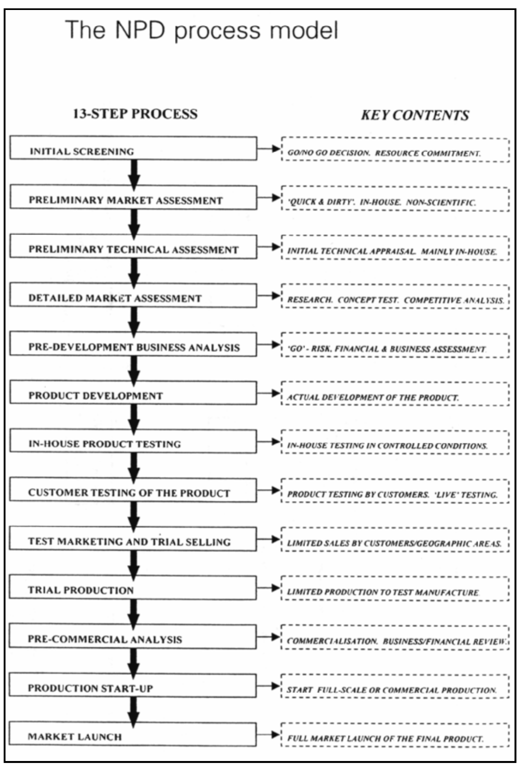


Figure 25: The NPD process model (Barclay et al., 2000)

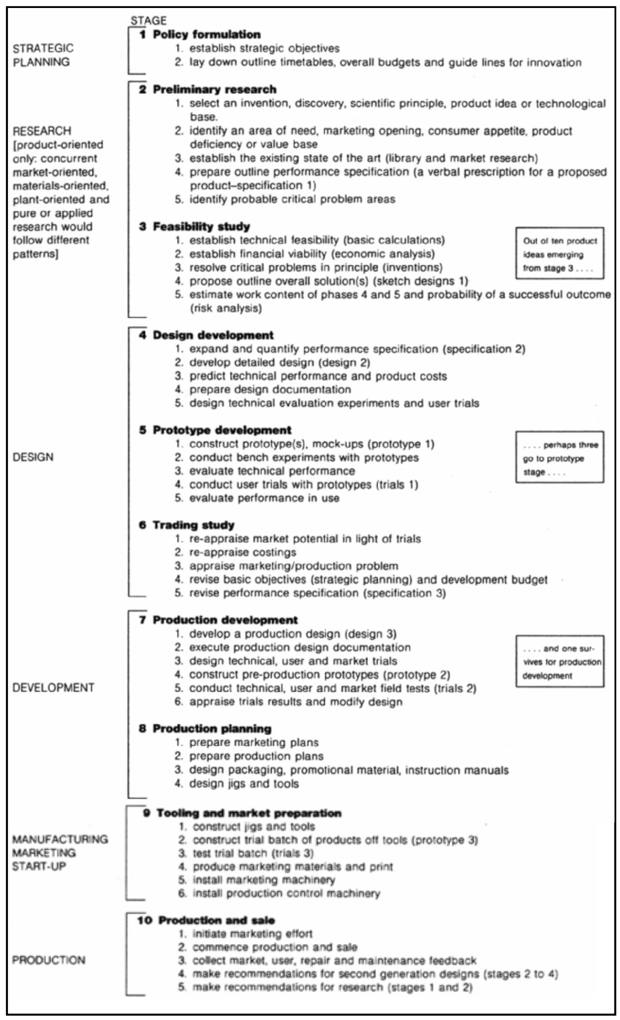


Figure 26: A characteristic program for product development [Archer, 1971] (Roozenberg & Eekels, 1995)

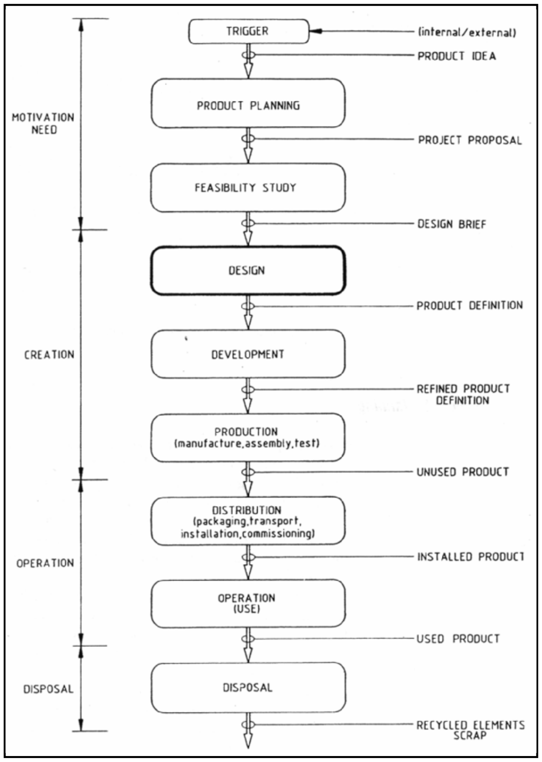


Figure 27: The product development process according to BS 7000 (Cross, 2000)

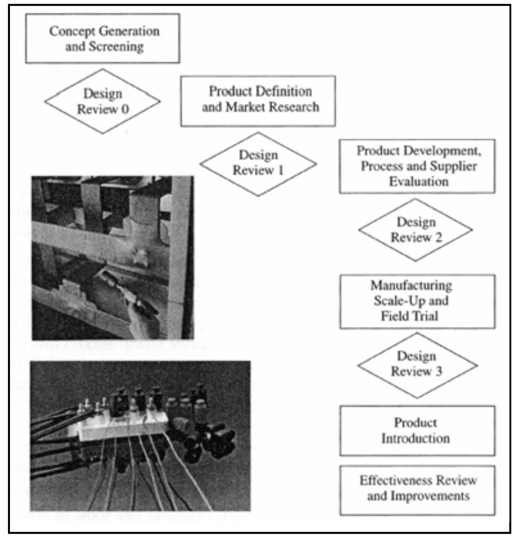


Figure 28: Characterization of Raychem's product development process (Otto & Wood, 2001)

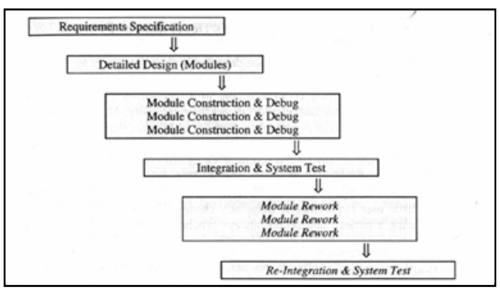


Figure 29: Simplified "waterfall" development process (Cusumano, 2000)

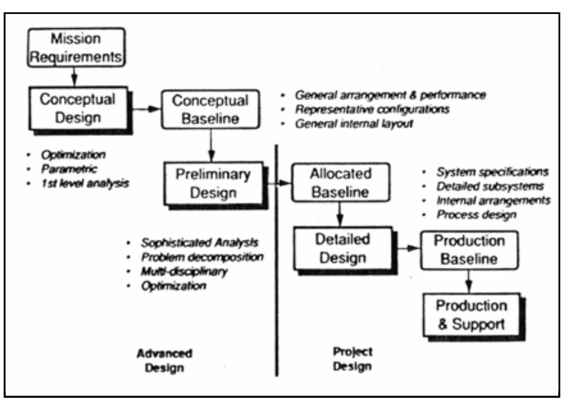


Figure 30: Sequential design process (Schrage, 1993)

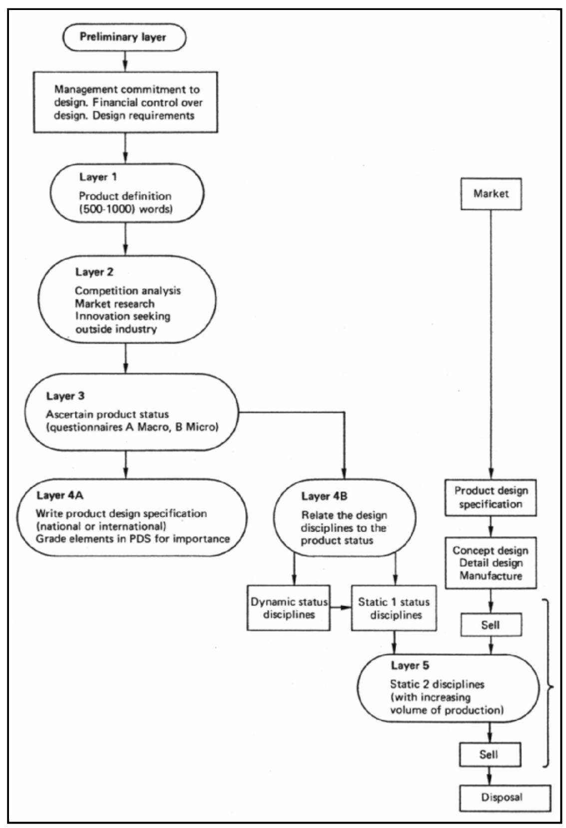


Figure 31: The total design plan's relationship to the design activity model (Hollins & Pugh, 1990)

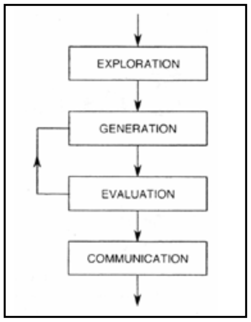


Figure 32: A simple four-stage model of the design process (Cross, 2000)

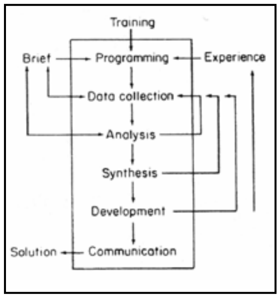


Figure 33: Archer's model of the design process [1984] (Cross, 2000)

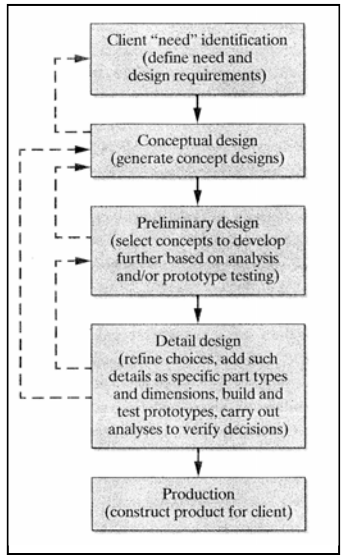


Figure 34: Product realization process flow chart (Sheppard & Tongue, 2007)

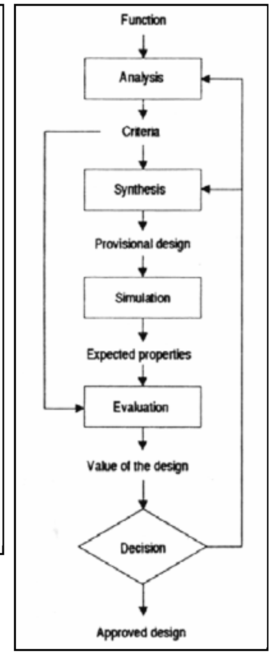


Figure 35: The basic design cycle (Roozenberg & Eekels, 1995)

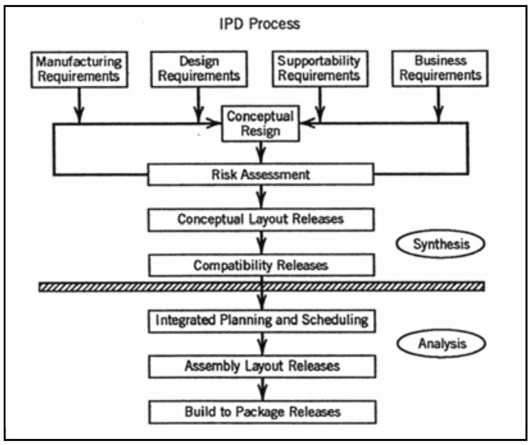


Figure 36: Integrated product definition (IPD) process (Schrage, 1993)

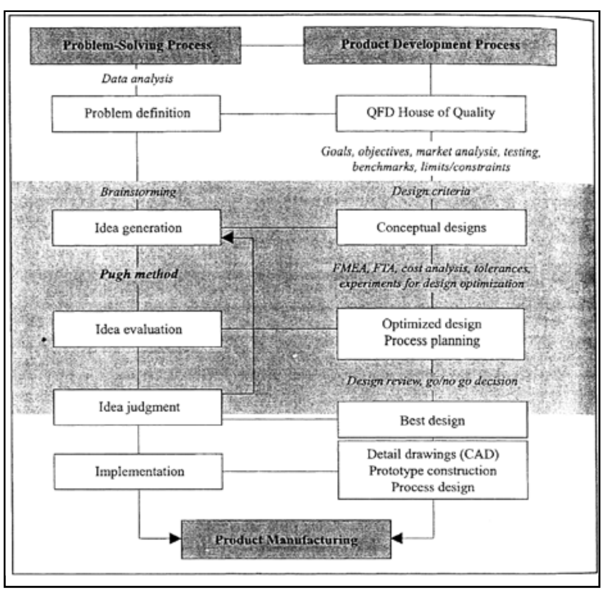


Figure 37: The product development process (Lumsdaine et al., 1999)

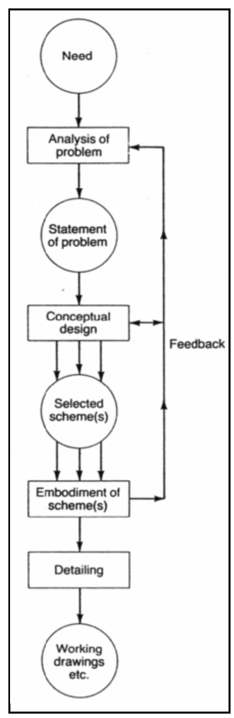


Figure 38: A pictorial view of the design process [after French, 1992] (Dym, 1994)

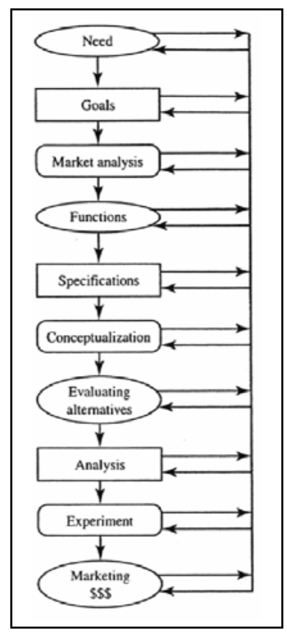


Figure 39: Design process (Haik, 2003)

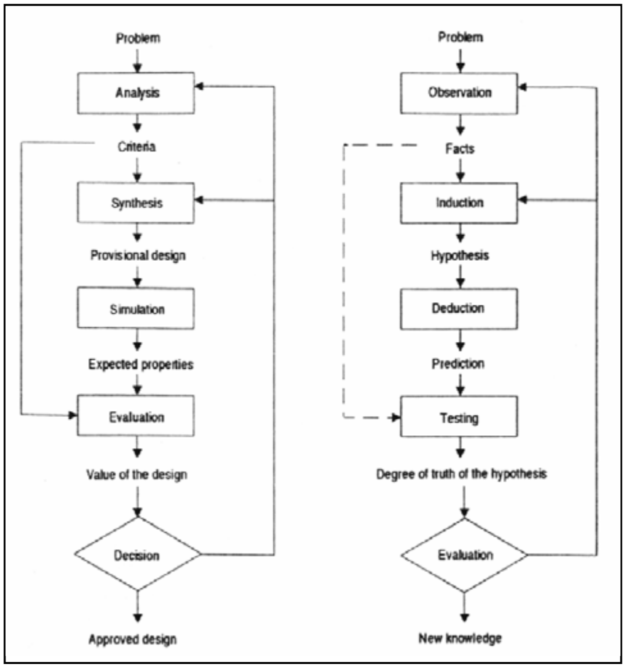


Figure 40: The basic cycles of design and empirical scientific inquiry (Roozenberg & Eekels, 1995)

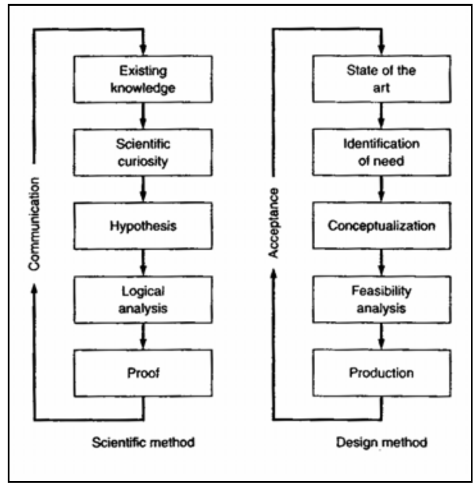


Figure 41: Comparison between the scientific method and the design method [after Hill, 1970] (Dieter, 2000).

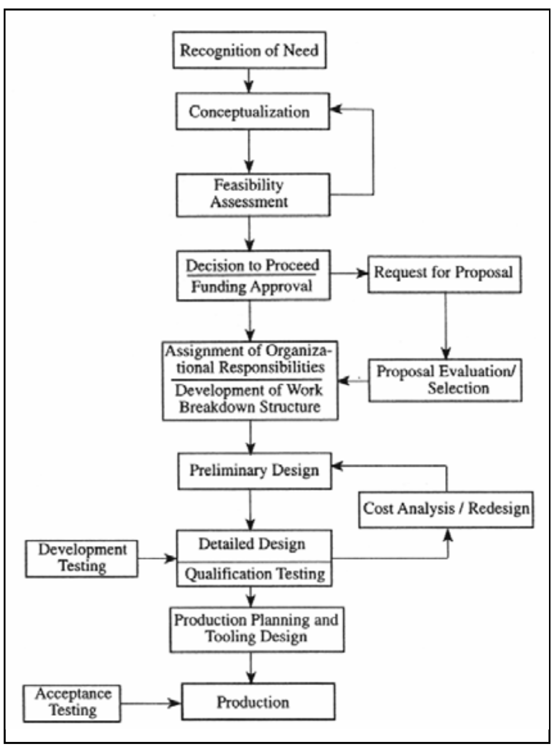


Figure 42: Steps in the engineering design process (Ertas & Jones, 1993)

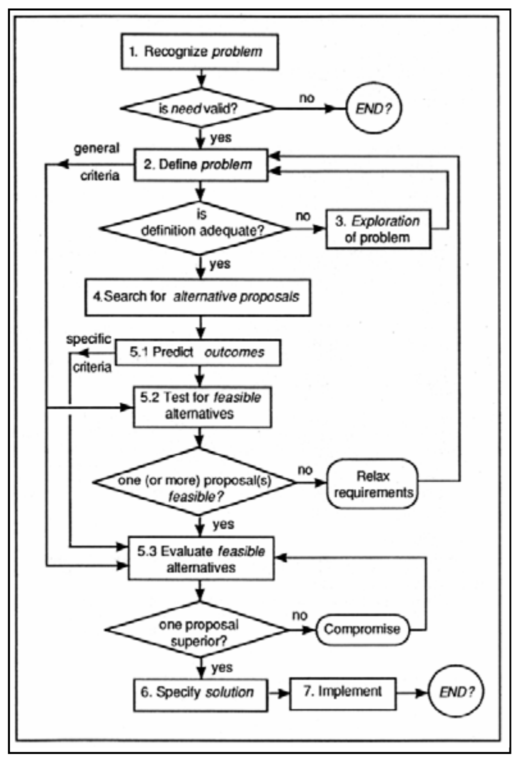


Figure 43: Flow chart of the design process (Lewis & Samuel, 1989)

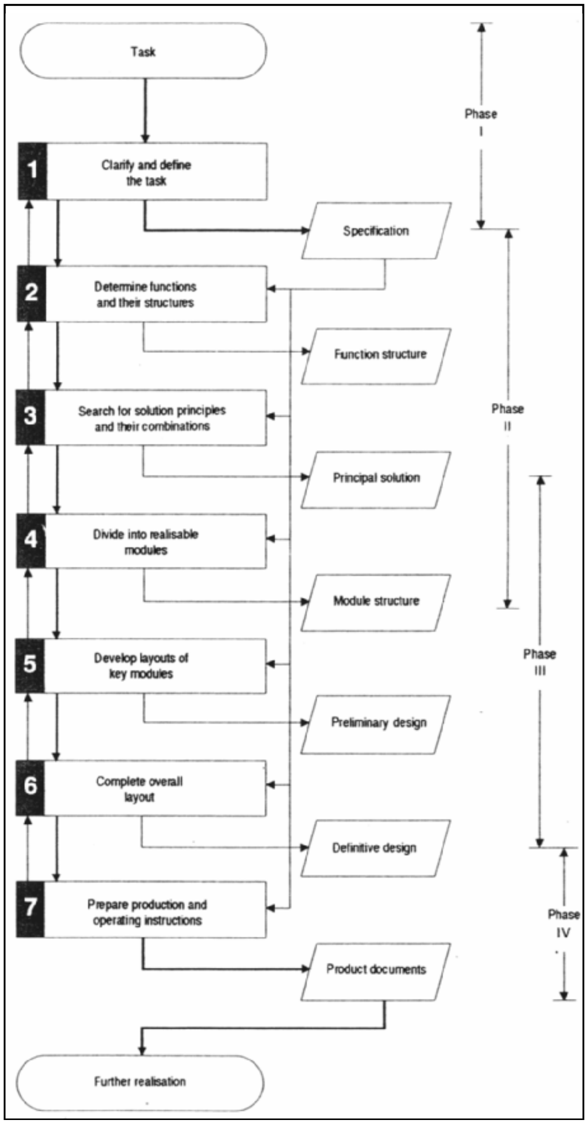


Figure 44: General approach to design according to VDI 2221 [1987] (Roozenberg & Eekels, 1995)

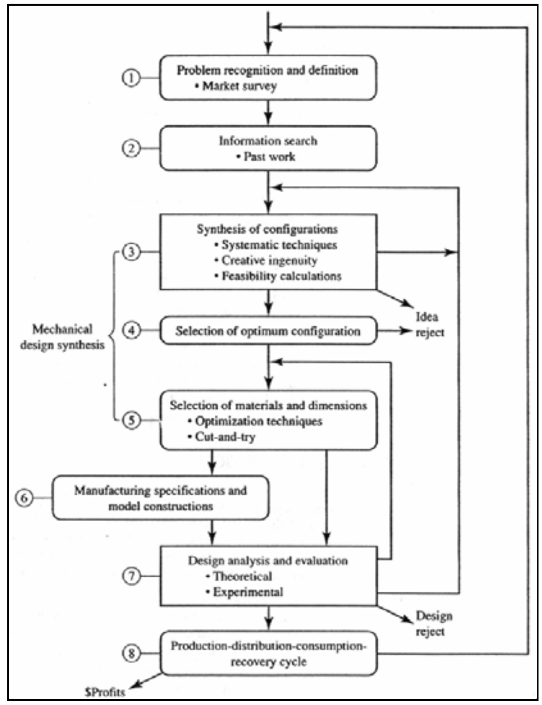


Figure 45: Design process map [from Johnson, 1978] (Haik, 2003)

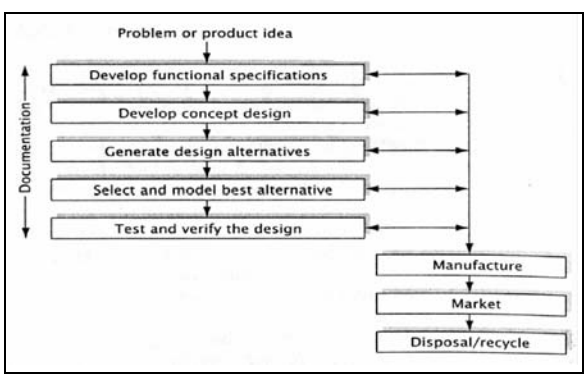


Figure 46: The iterative design process (King, 1996)

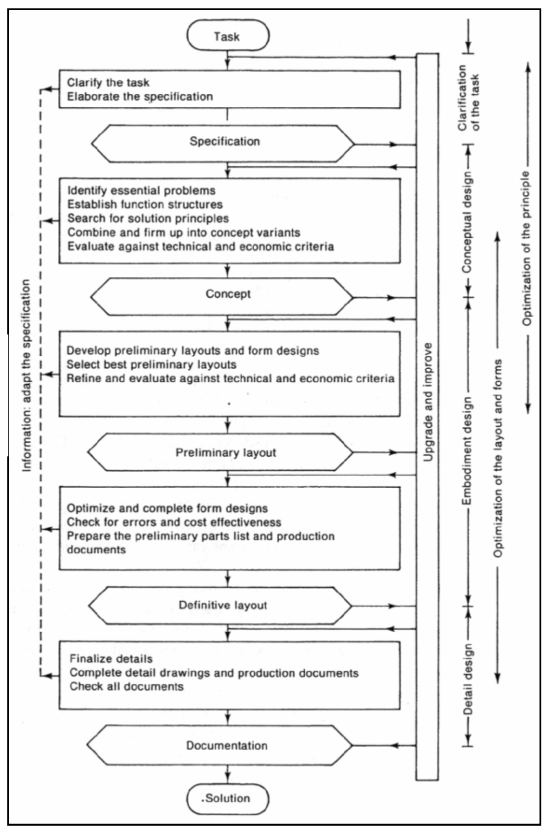


Figure 47: Pahl and Beitz's model of the design process [1996] (Cross, 2000)

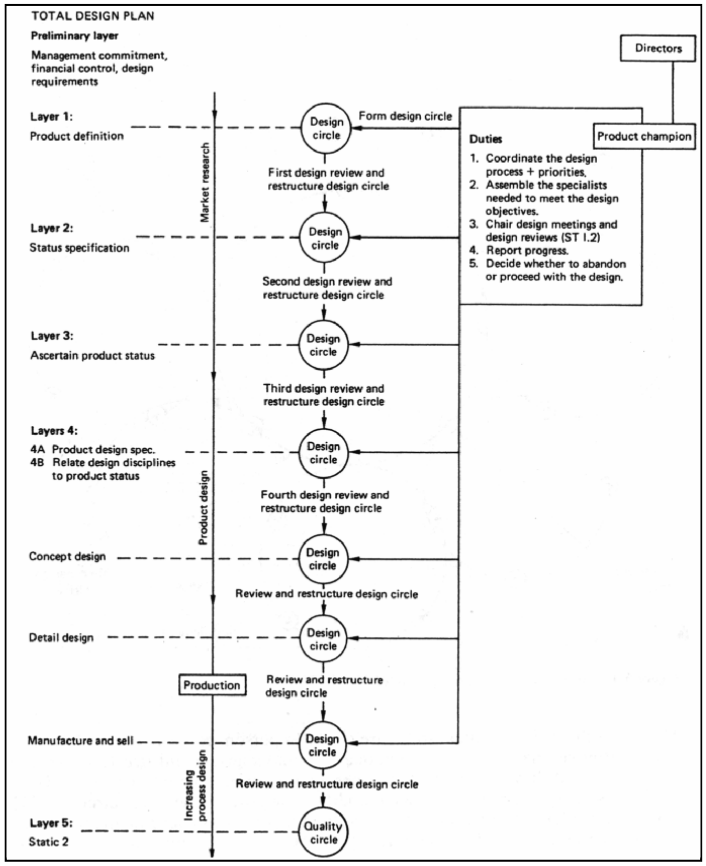


Figure 48: Design circles (Hollins & Pugh, 1990)

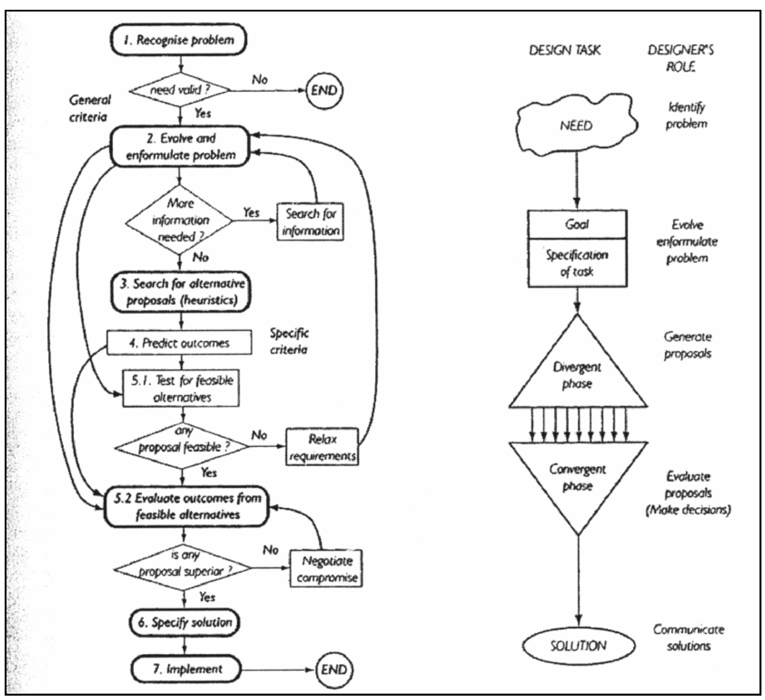


Figure 49: Flow diagram for the generic formal design process (Samuel & Weir, 1999)

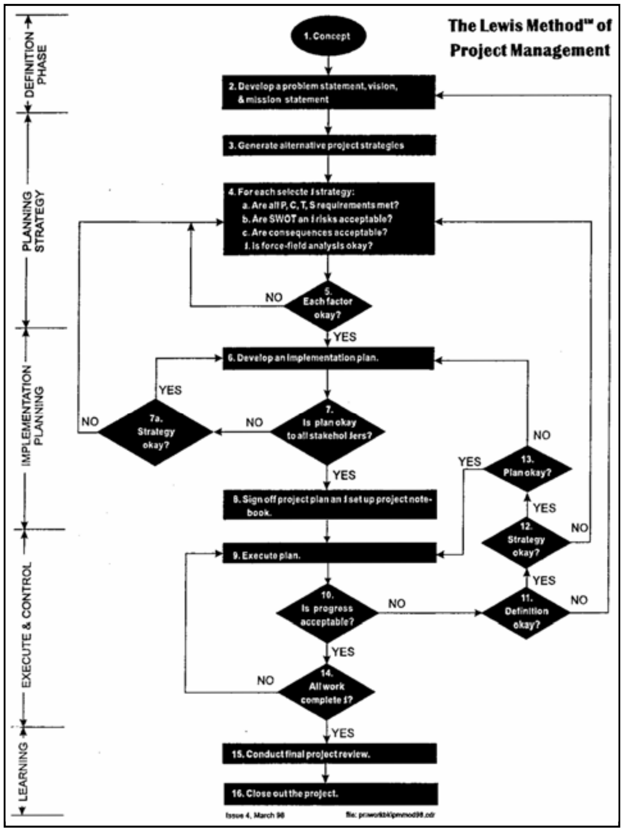


Figure 50: A model for managing projects (Lewis, 2000)

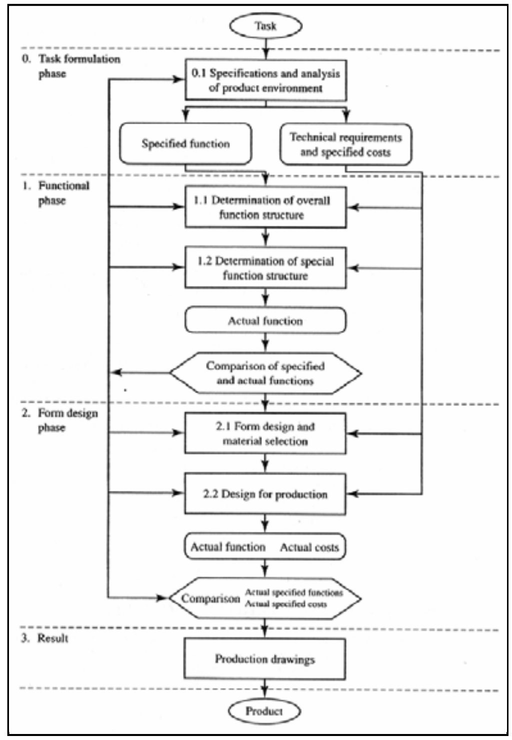


Figure 51: Design process map [from Dym, 1994] (Haik, 2003)

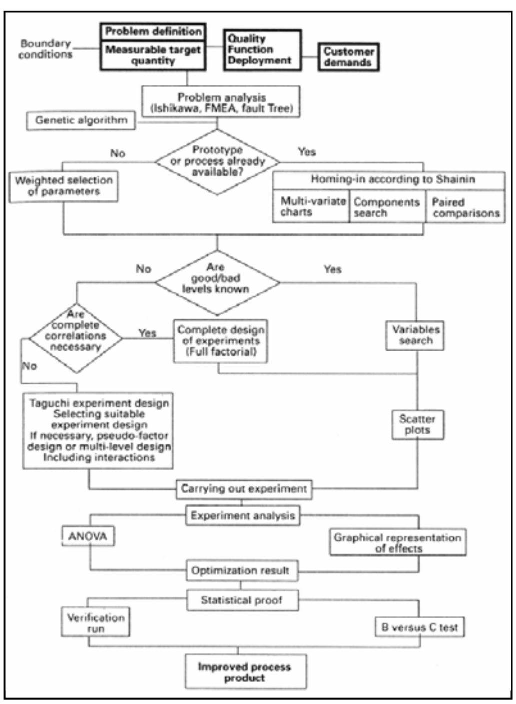


Figure 52: Flowchart for parameter optimization (Krottmaier, 1993)

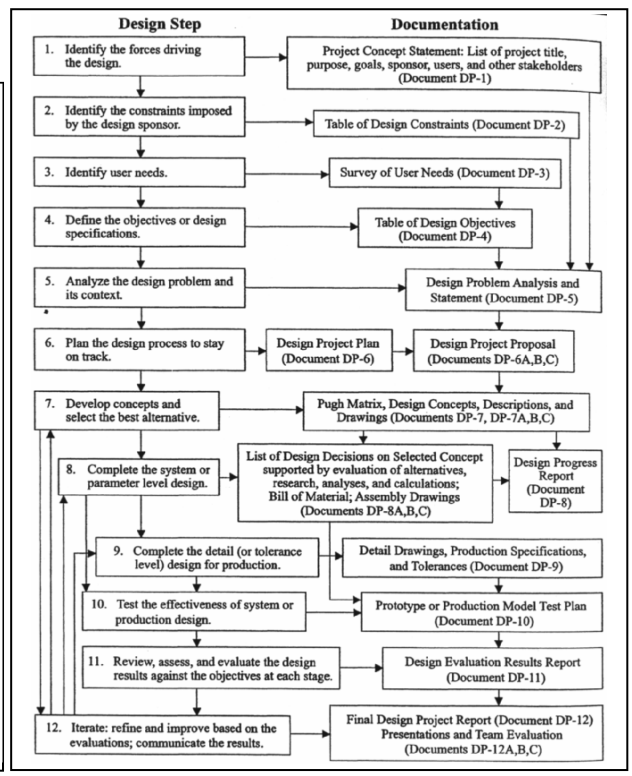


Figure 53: Stages and documentation in the engineering design process (Lumsdaine et al., 1999)

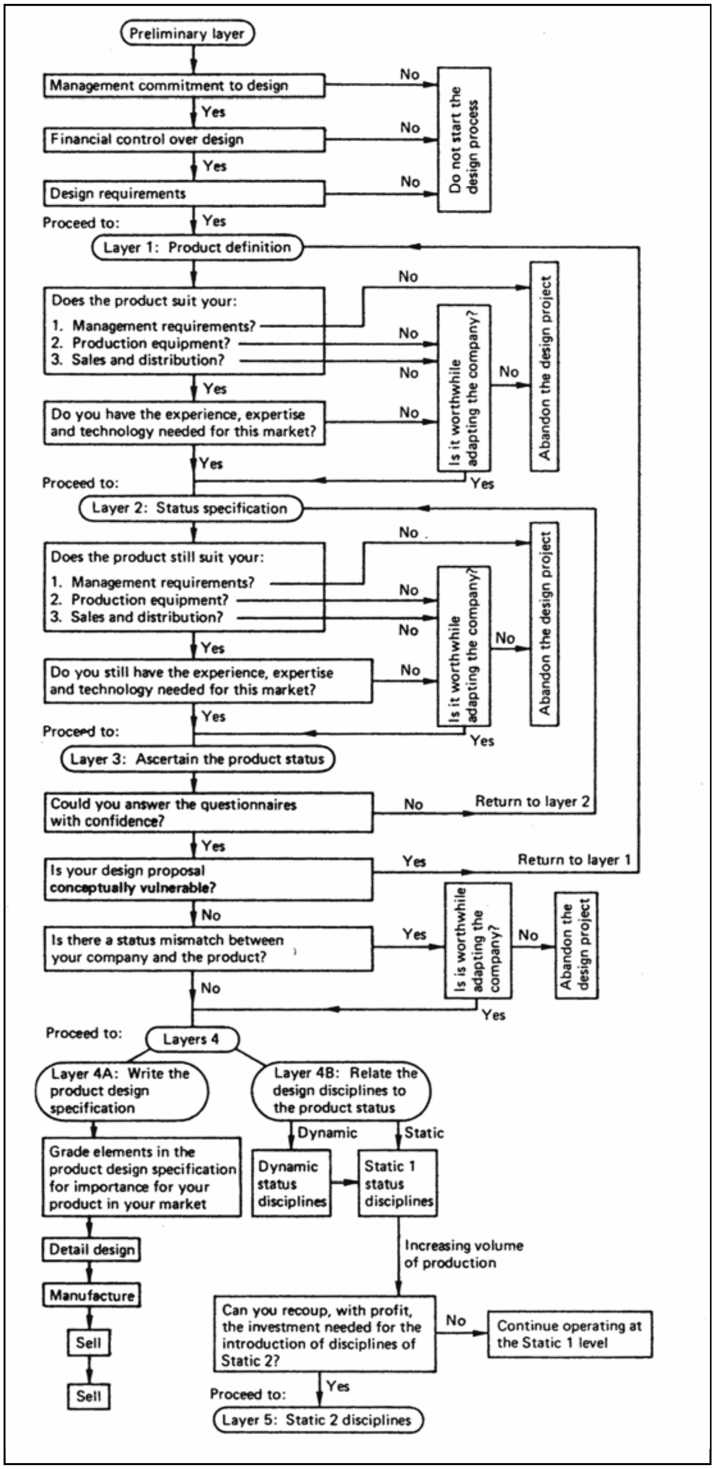


Figure 54: The total design plan [Levitt, 1962] (Hollins & Pugh, 1990)

Twenty-six left-to-right, or horizontal, flowcharts are presented. The fifteen charts without feedback looping begin on the next page (see Figures 55-69). The following eleven other horizontal charts include the possibility of feedback (see Figures 70-80). Ullman (2003) shows the five-phases of the design process from left-to-right, with each phase having numerous steps laid-out vertically beneath it (see Figure 80, on page 35). As before, diagrams go from simple to increasingly complex in each sub-section.

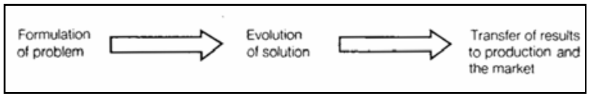


Figure 55: A simple linear model of the design process (Oakley, 1990)

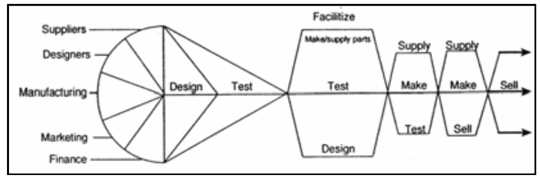


Figure 56: The team process of simultaneous engineering (Payne et al., 1996)

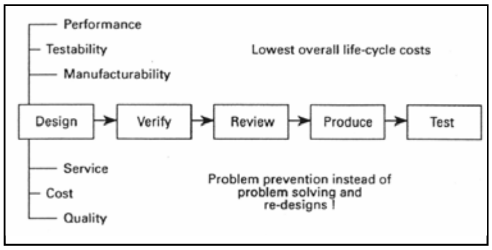


Figure 57: The concurrent engineering process (Syan, 1994)

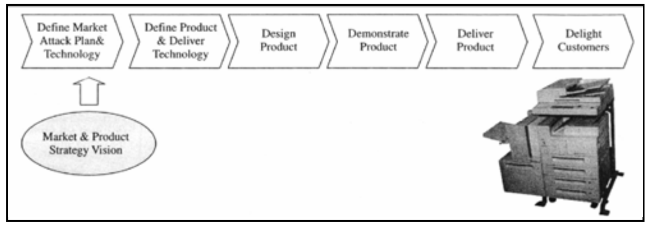


Figure 58: Characterization of Xerox's product development process and an example copier (Otto & Wood, 2001)

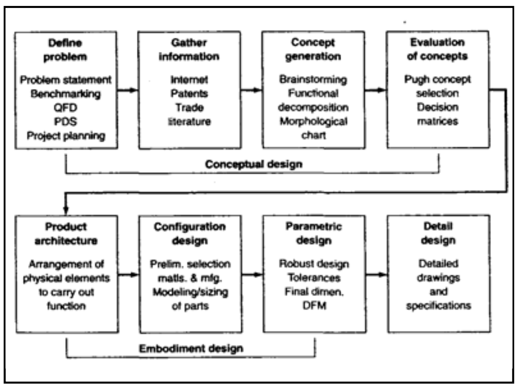


Figure 59: Discrete steps in [the] engineering design process from problem definition to detail design. The chief tools or techniques applicable in each step are given (Dieter, 2000)

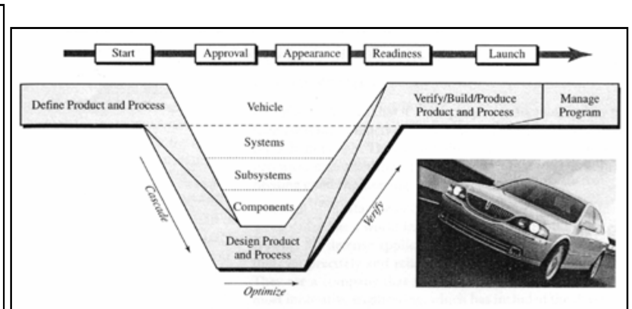


Figure 60: Characterization of Ford's product development process (Otto & Wood, 2001)

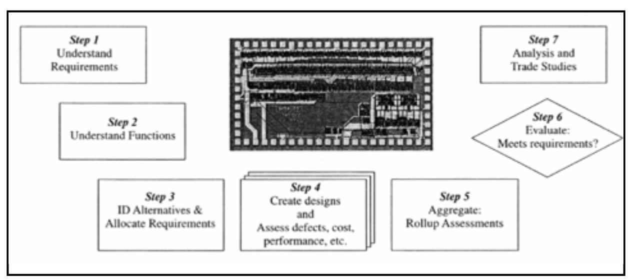


Figure 61: Characterization of Raytheon's product development process (Otto & Wood, 2001)

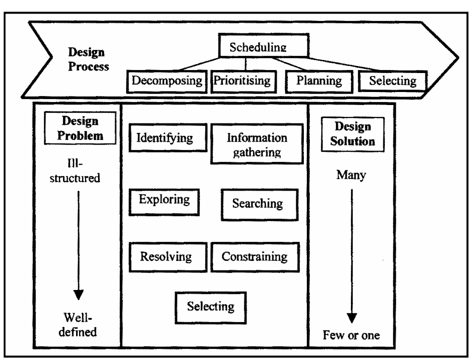


Figure 62: Taxonomy of design management activities (Sim & Duffy, 2003)

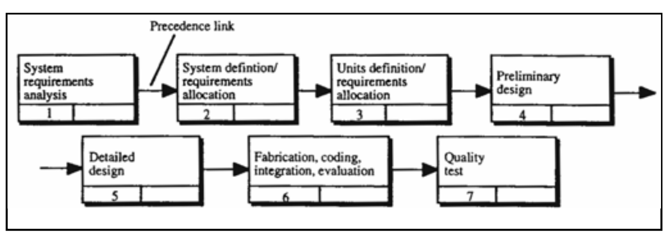


Figure 63: The seven phase engineering development process (Kusiak & Wang, 1993)

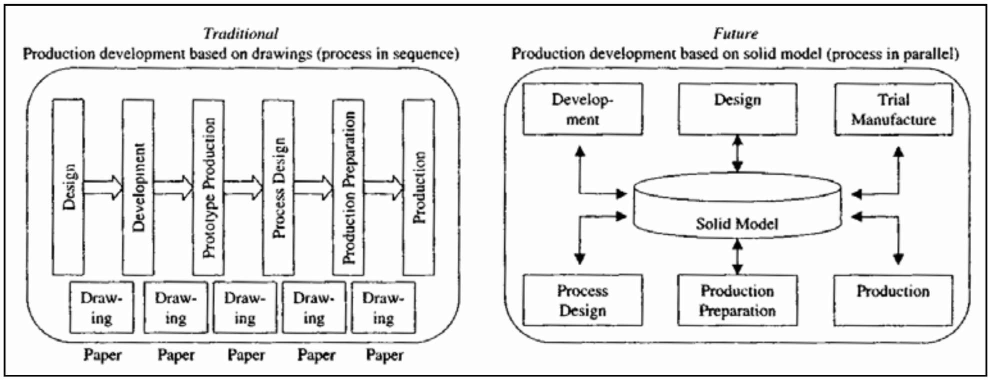


Figure 64: Transition to joint design system (Ikeda, 2000)

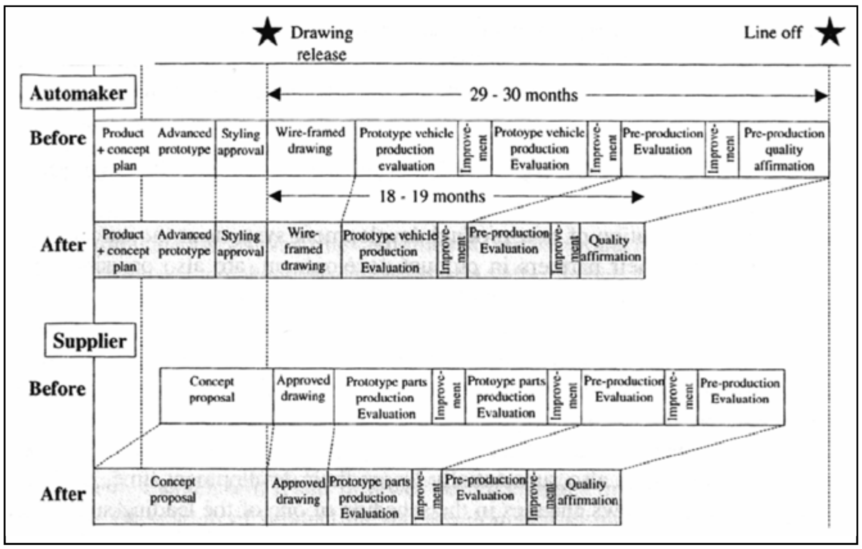


Figure 65: Changes in the interlinking development schedules of auto maker and supplier (Ikeda, 2000)

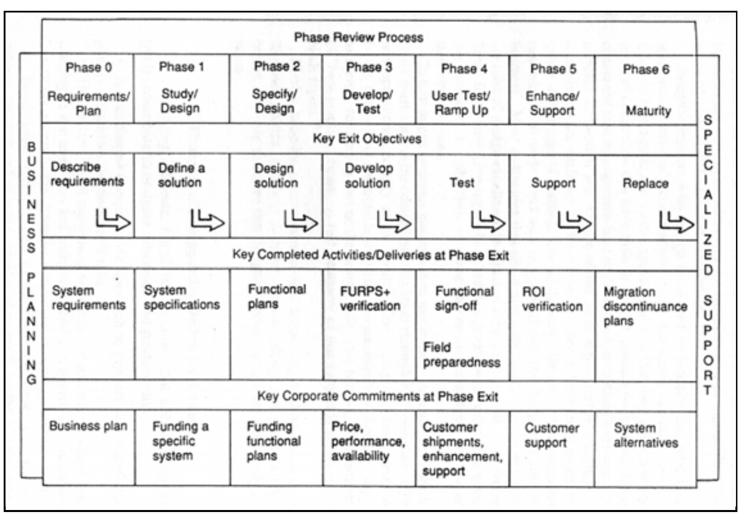


Figure 66: Phase review process themes (Jurgens (ed.), 2000)

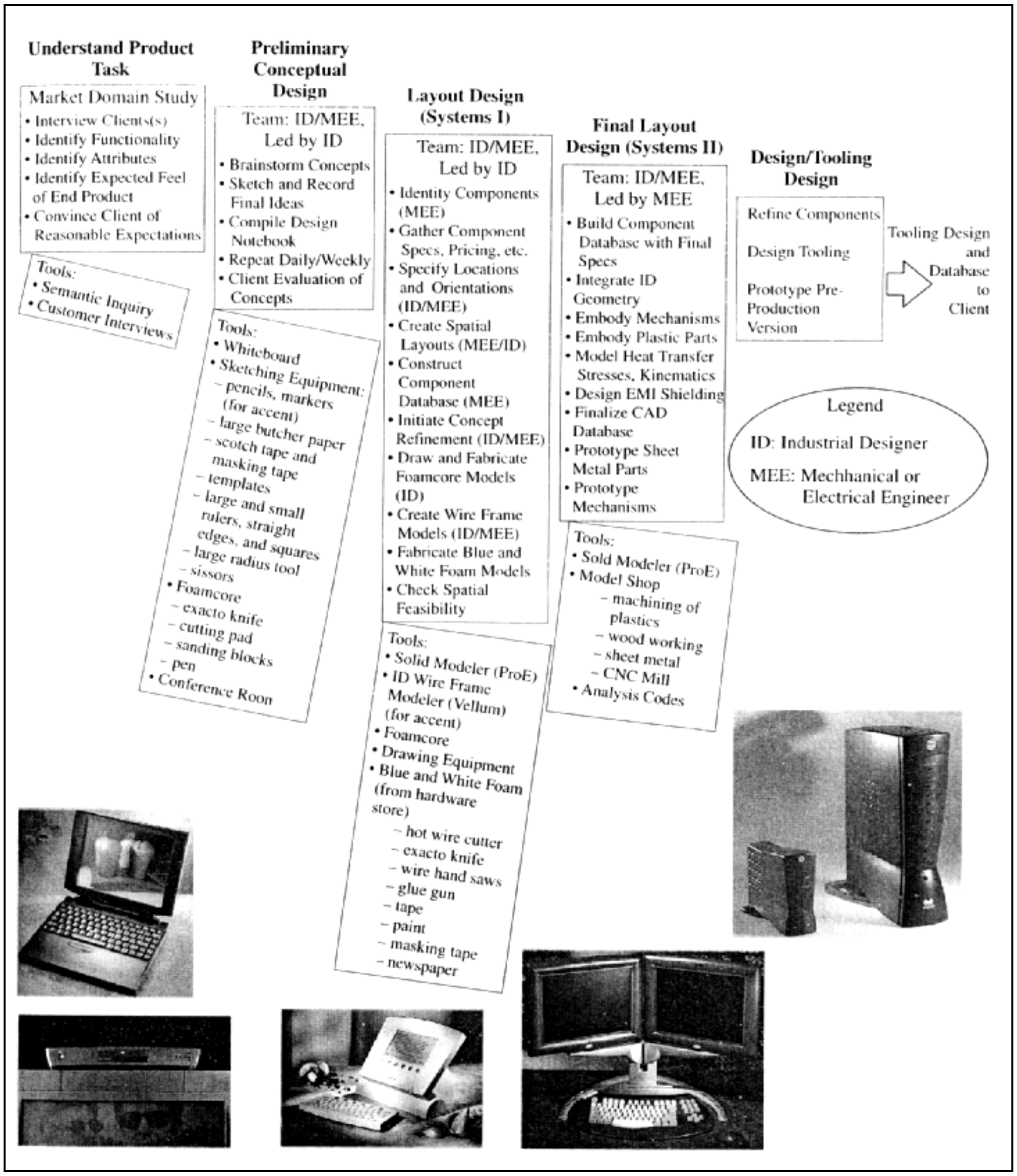
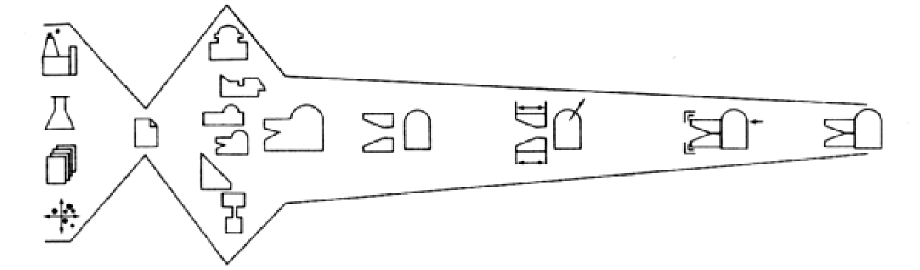


Figure 67: Characterization of the Design EDGE product development process and example products (Otto & Wood, 2001)



Planning	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing					
• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family.	• Develop marketing plan	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design					
• Consider product platform and architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major sub-systems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Reliability testing. • Life testing. • Performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
Manufacturing					
• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance processes.	• Begin operation of entire production system.
Other Functions					
• Research: Demonstrate available technologies. • Finance: Provide planning goals. • General Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	

Figure 68: The generic product development process. Six phases are shown, including the tasks and responsibilities of the key functions of the organization for each phase (Ulrich & Eppinger, 2000)

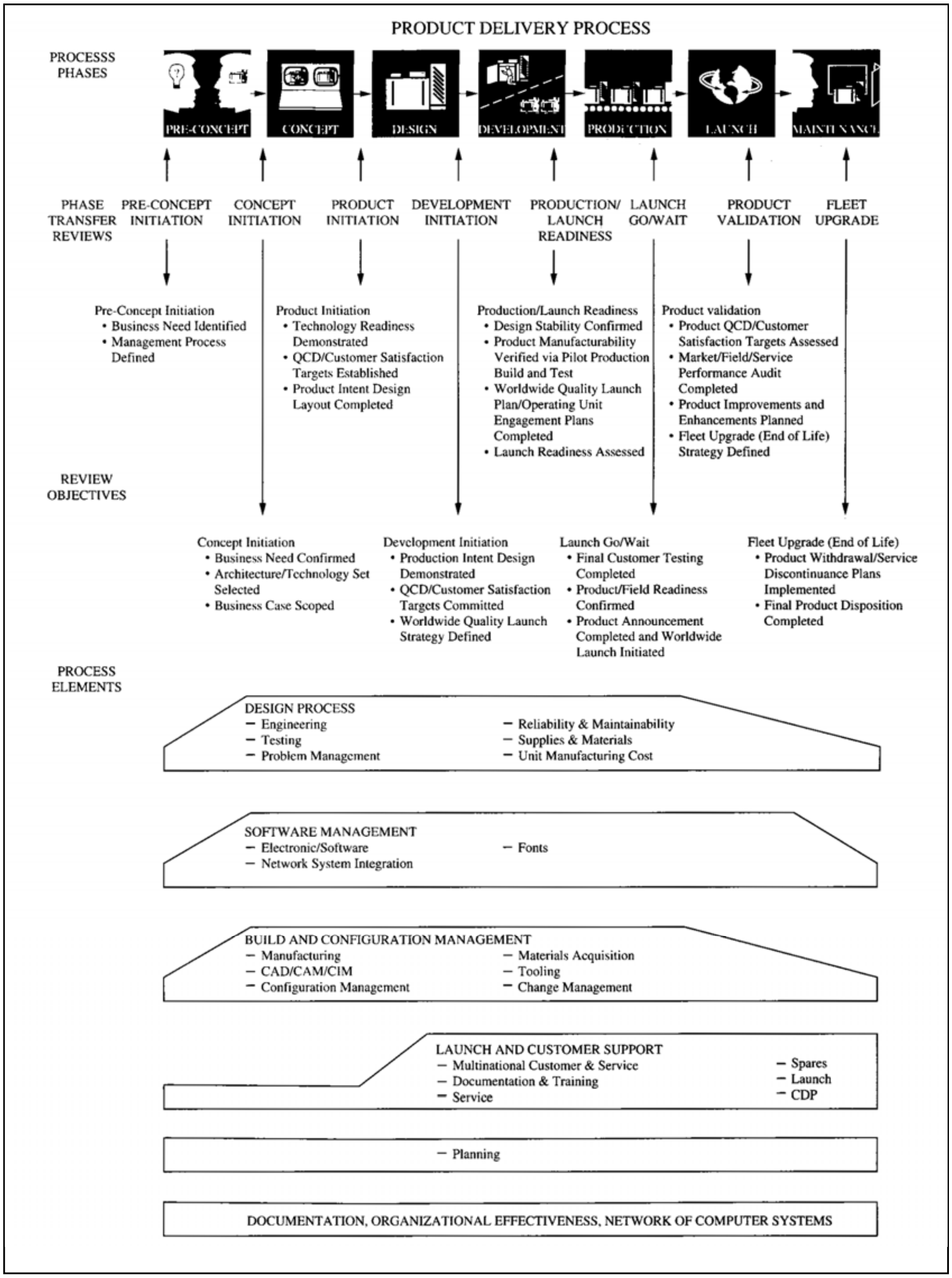


Figure 69: The Xerox product delivery process (Ullman, 2003)

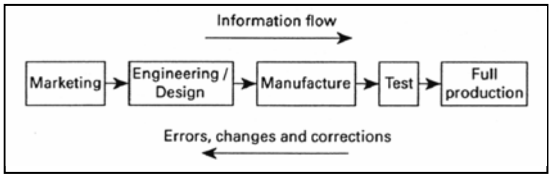


Figure 70: The sequential engineering process (Syan, 1994)

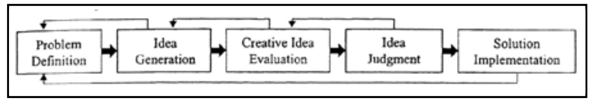


Figure 71: The creative problem-solving process (Lumsdaine et al., 1999)

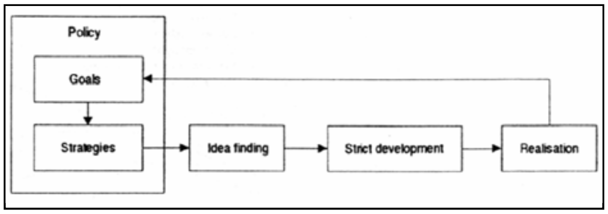


Figure 72: The structure of the innovation process (Roozenberg & Eekels, 1995)

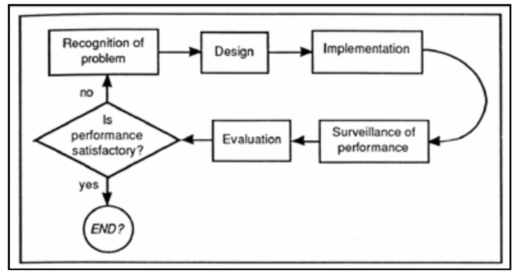


Figure 73: The design cycle (Lewis & Samuel, 1989)

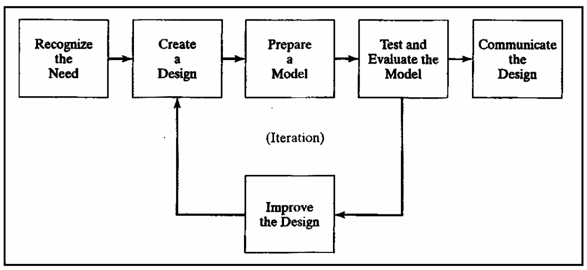


Figure 74: The six-step process of design (Spotts et al., 2004)

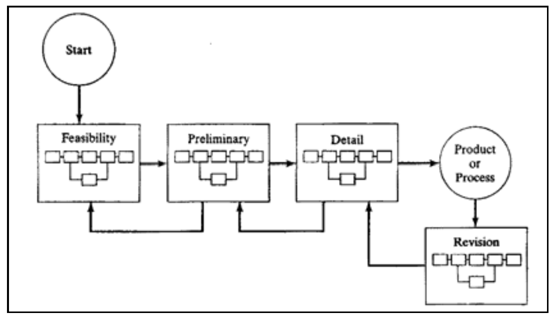


Figure 75: The four stages of design (Spotts et al., 2004)

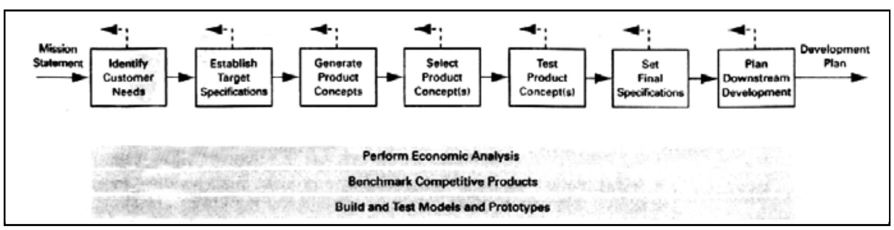


Figure 76: The many front-end activities comprising the concept development phase (Ulrich & Eppinger, 2000)

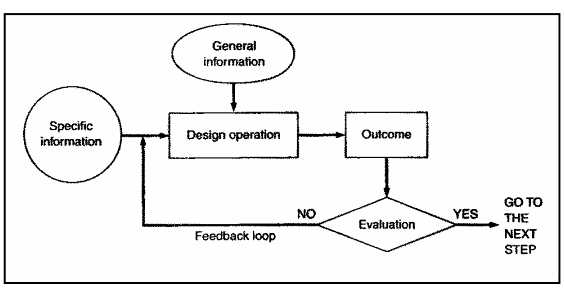


Figure 77: Basic module in the design process [after Asimow, 1962] (Dieter, 2000)

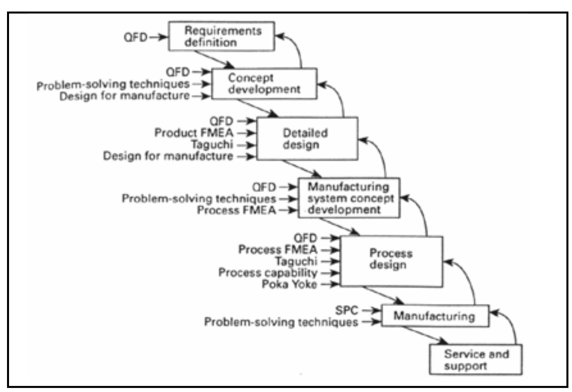


Figure 78: Typical uses of common CE tools in the product development process (Syan, 1994)

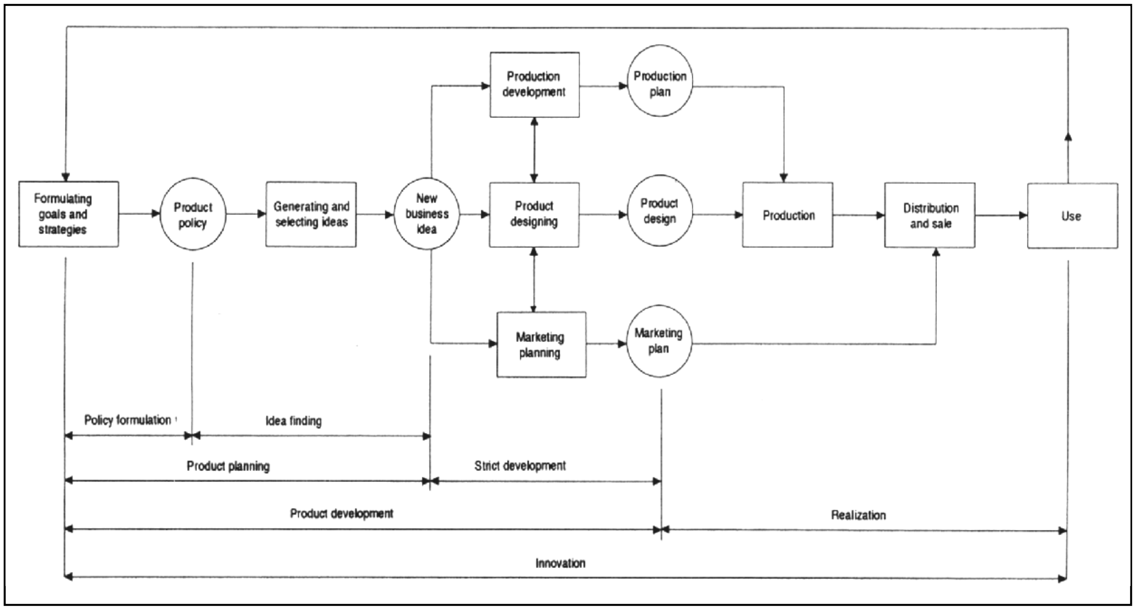


Figure 79: The phases of the innovation process (Roozenberg & Eekels, 1995)

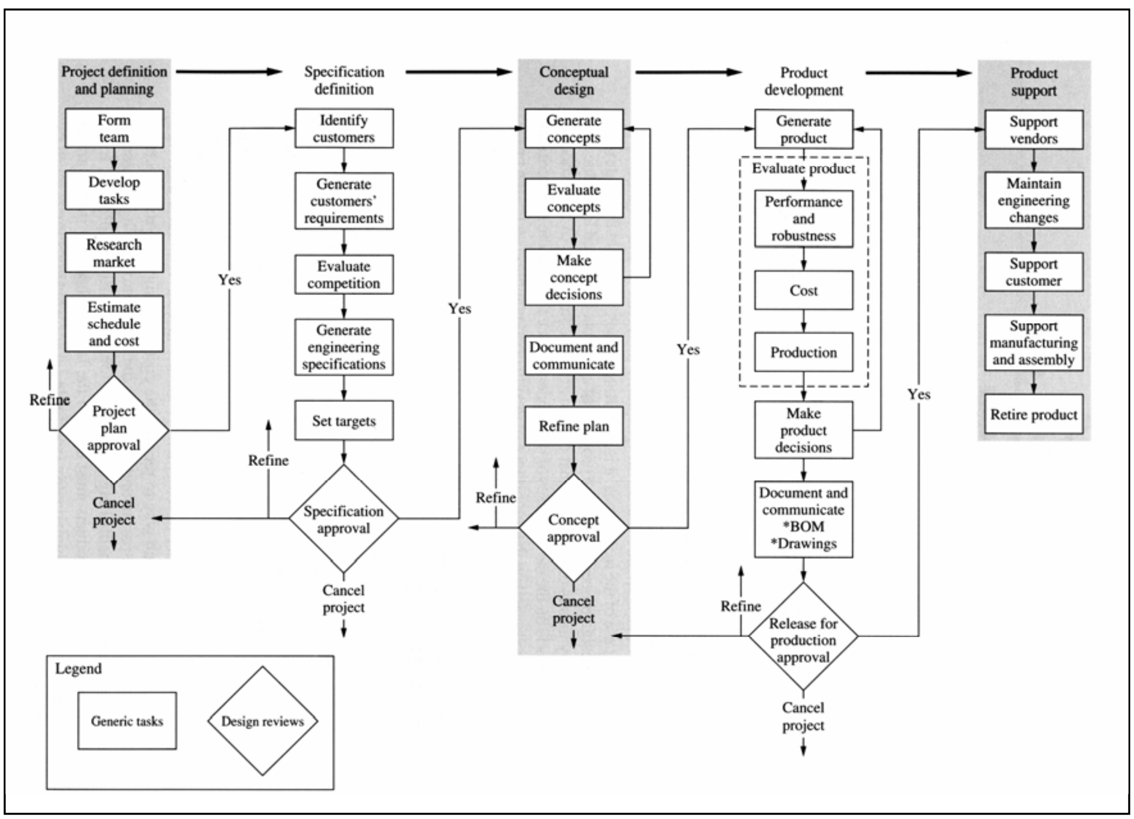


Figure 80: The mechanical design process (Ullman, 2003)

Gantt charts appear in seven representations (Figures 81-87). One of these charts, presented by Ulrich and Eppinger (2000), includes a Gantt chart combined with a loop-free left-to-right flowchart (see Figure 87, on page 38). Also, for clarification, the acronym DMU in Figure 84 (on page 37) stands for digital mock-up and RP is short for rapid prototyping (Tegel, 2000).

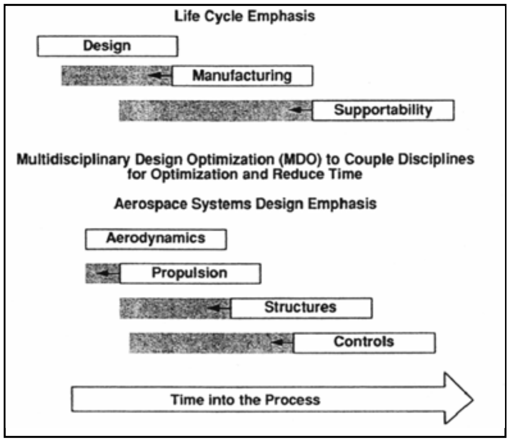


Figure 81: Concurrent engineering to improve quality and reduce time (Schrage, 1993)

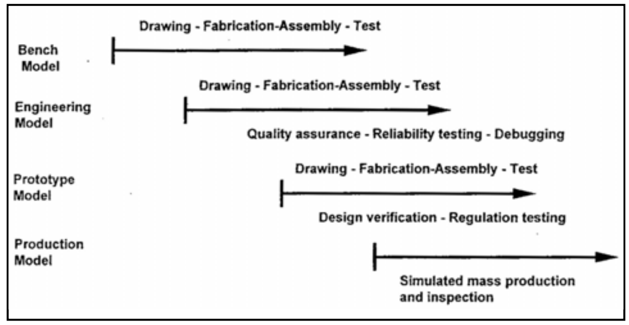


Figure 82: The “Sashimi” concurrent development schedule (Handfield, 2000)

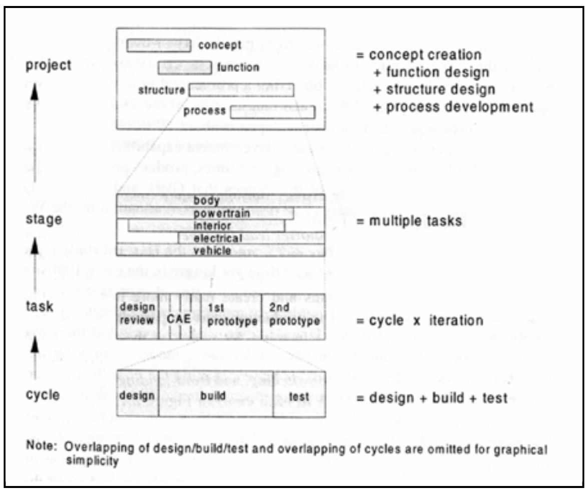


Figure 83: Product development project as problem-solving cycles and stages (Fujimoto, 2000)

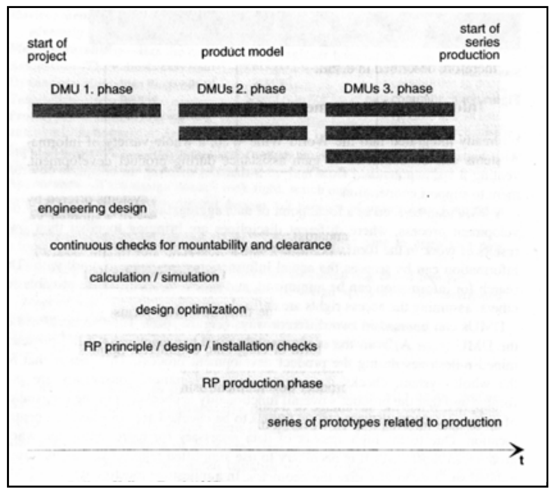


Figure 84: Overall process using DMUs, RP technologies, and more intensive calculation and simulation [Dollner et al., 1997] (Tegel, 2000)

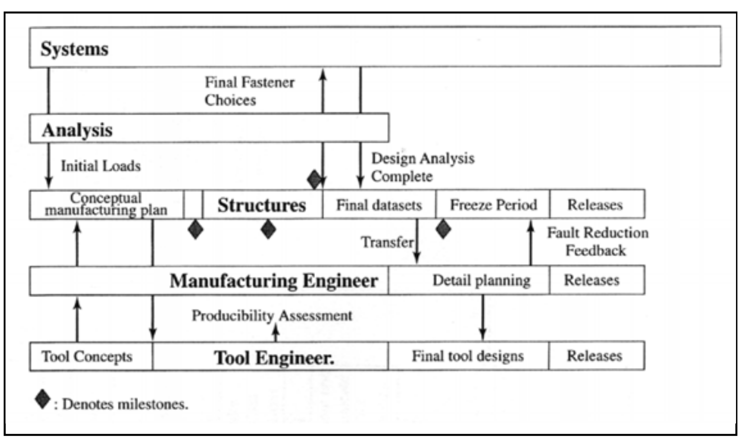


Figure 85: Concurrent engineering process at Boeing (Otto & Wood, 2001)

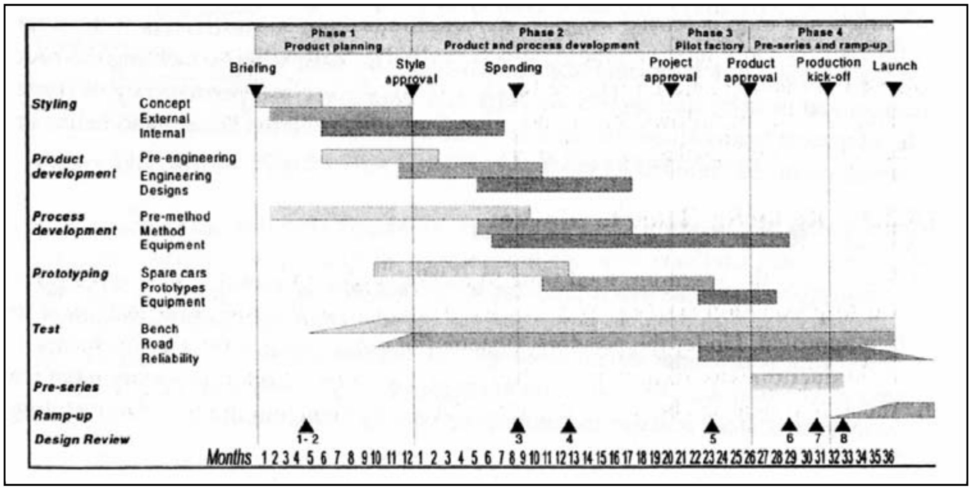


Figure 86: Gantt chart at Itcar (Calabrese, 2000)

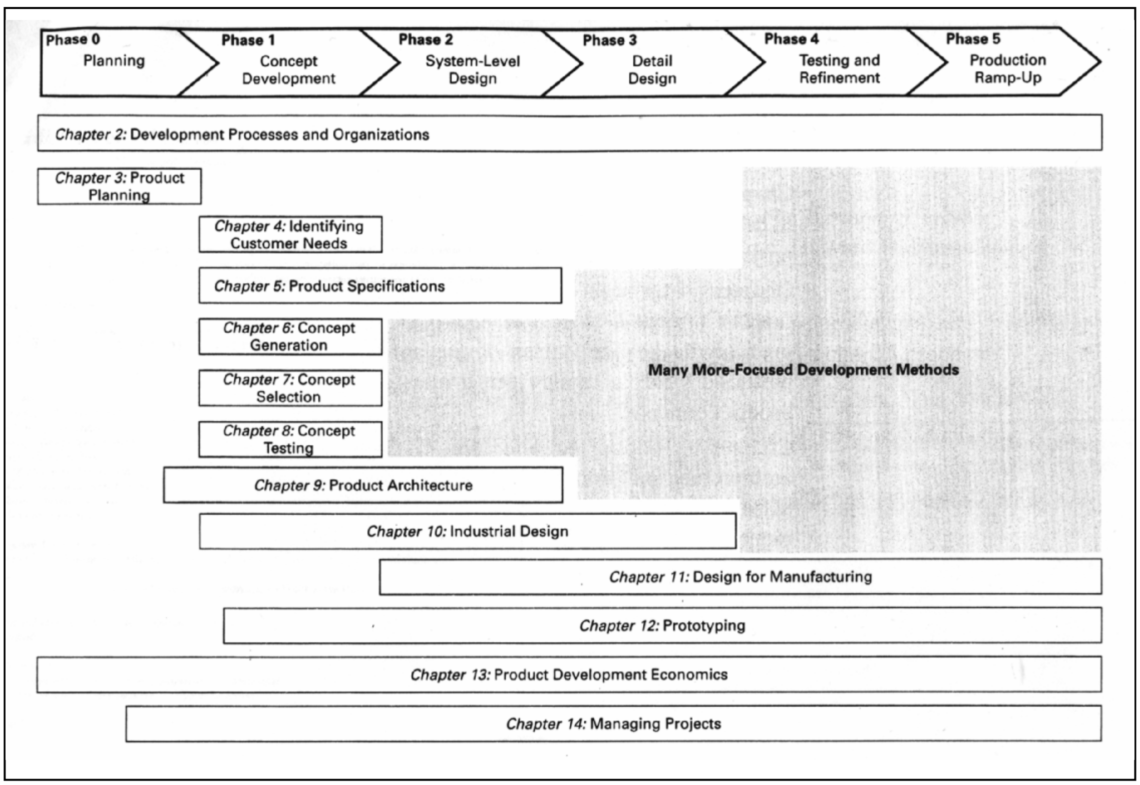


Figure 87: The product development process (Ulrich & Eppinger, 2000)

Nine circular process depictions are presented (see Figures 88-96). Most are clockwise, two have feedback looping that is short of cyclical iteration, and three involve some spiraling. The Wilson and Morren process in Figure 96 (on page 41) has been used to guide system definition efforts in resource conflict situations (Daniels & Walker, 2001).

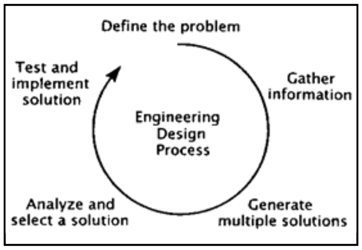


Figure 88: The design process (King, 1996)

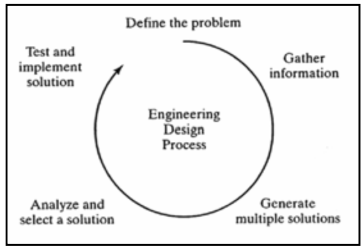


Figure 89: The design process (Howell, 2002)

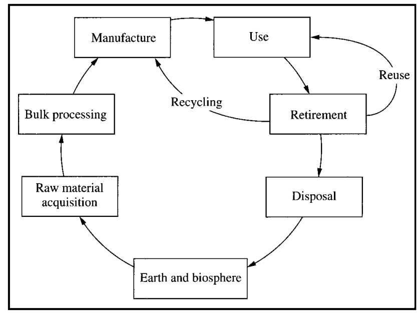


Figure 90: Green design life cycle (Ullman, 2003)

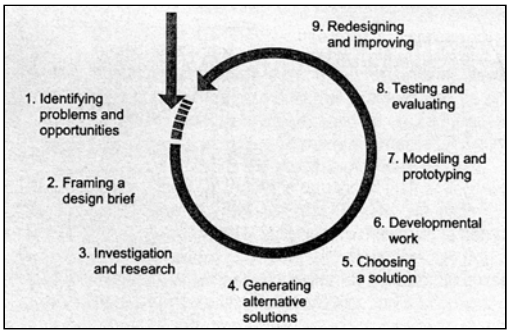


Figure 91: The design loop (Hutchinson & Karsnitz, 1994)

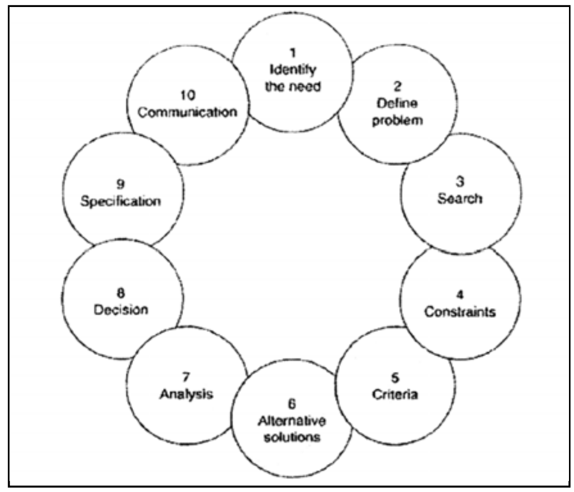


Figure 92: The design process is iterative in nature (Eide et al., 2002)

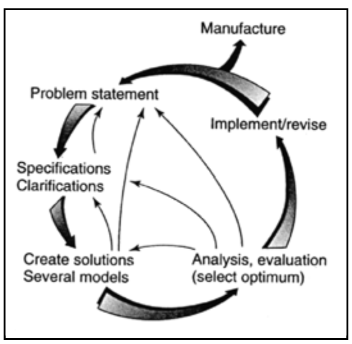


Figure 93: The design process (Burghardt, 1999)

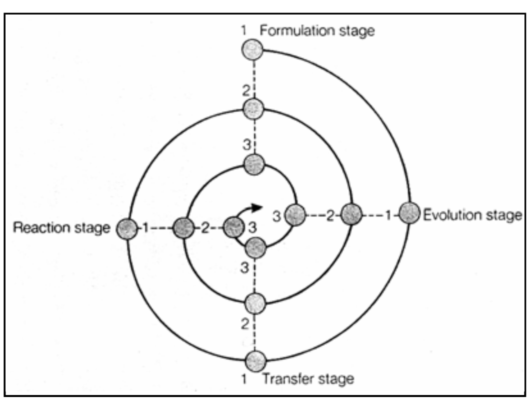


Figure 94: A spiral model of the design process (Oakley, 1990)

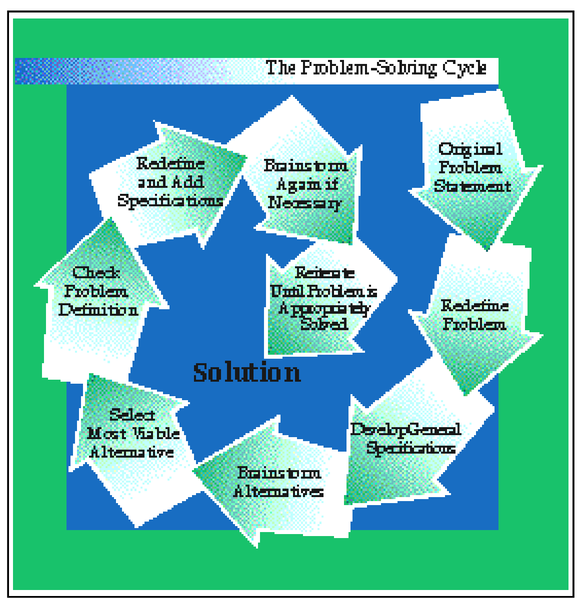


Figure 95: The problem-solving cycle (Dartmouth, 1998)

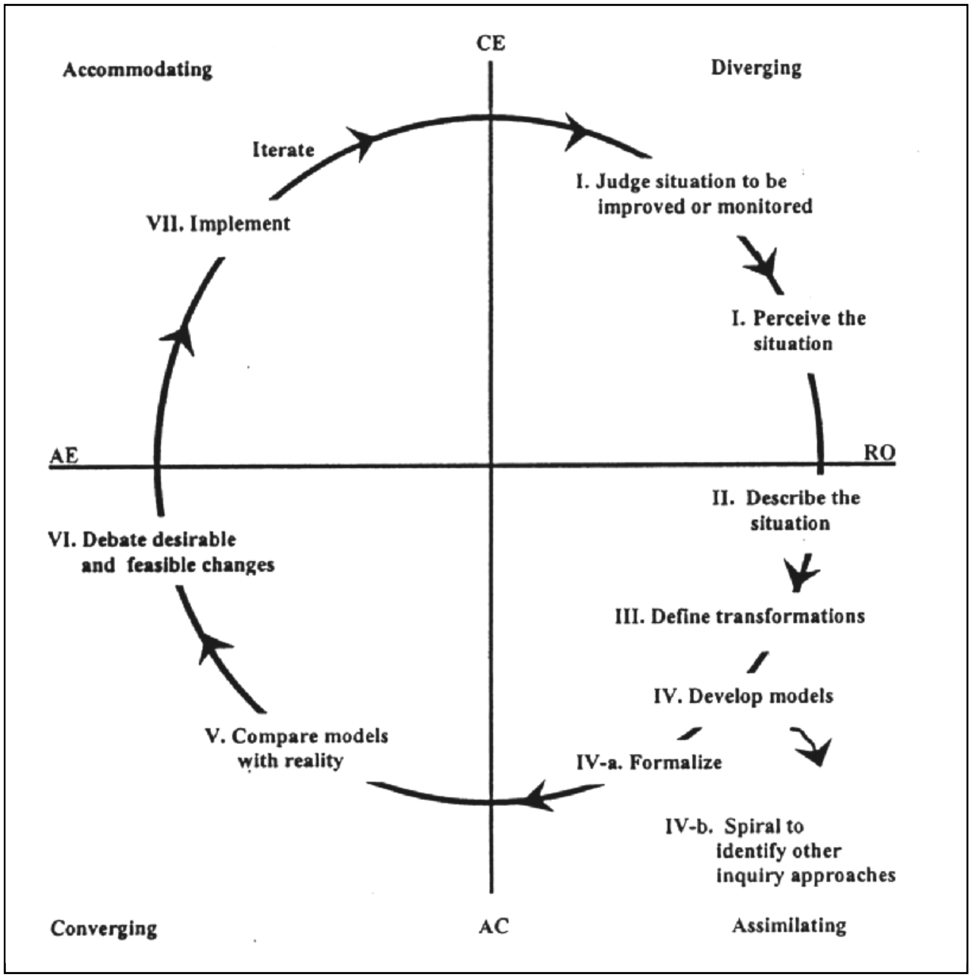


Figure 96: Wilson and Morren's modification of Checkland's [1981] soft system model [Wilson and Morren, 1990] (Daniels and Walker, 2001)

The fifth and final process diagram group has fourteen other charts (see Figures 97-110). Many of these representations include multi-directional process flows. Several of the diagrams include consideration of detail design or sub-problems. Two diagrams imply a three-dimensional model to describe the process. For clarification, in Figure 108 (on page 45), TS stands for technical systems (Hubka & Eder, 2002).

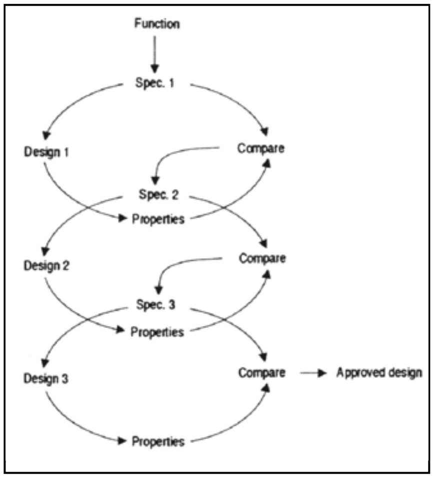


Figure 97: The iterative structure of the design process (Roozenberg & Eekels, 1995)

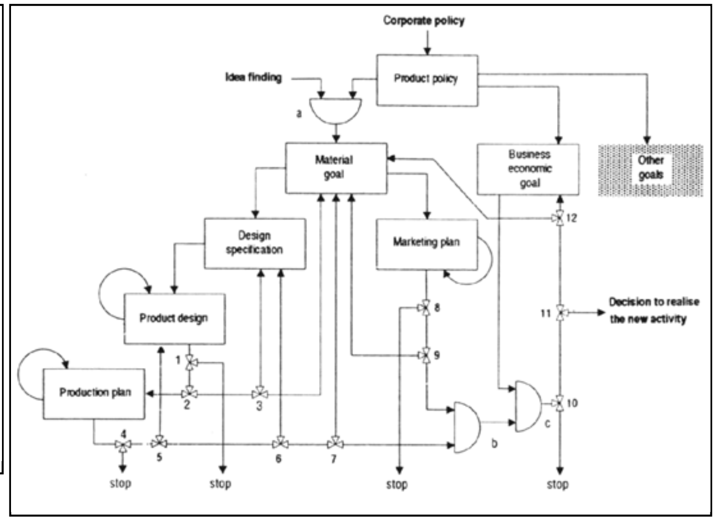


Figure 98: Product development as a whole (Roozenberg & Eekels, 1995)

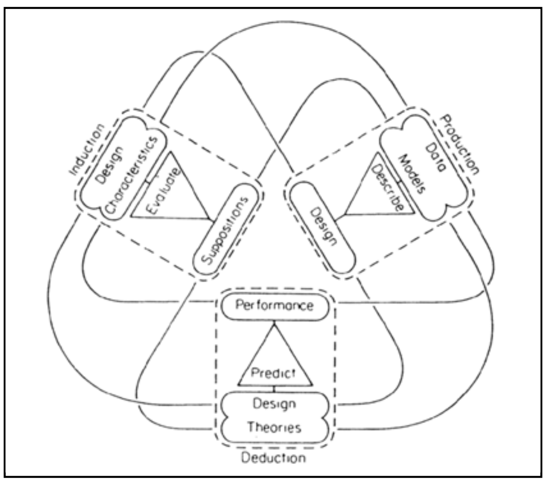


Figure 99: March's model of the design process [1976] (Cross, 2000)

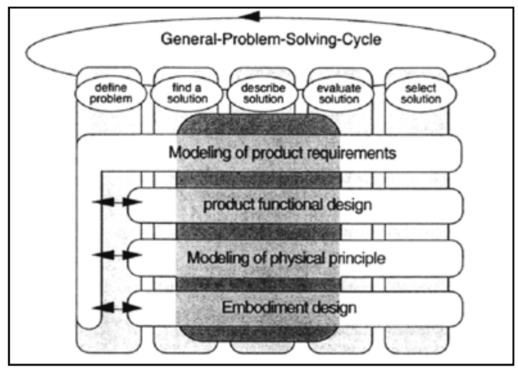


Figure 100: Design process (Lossack, 2002)

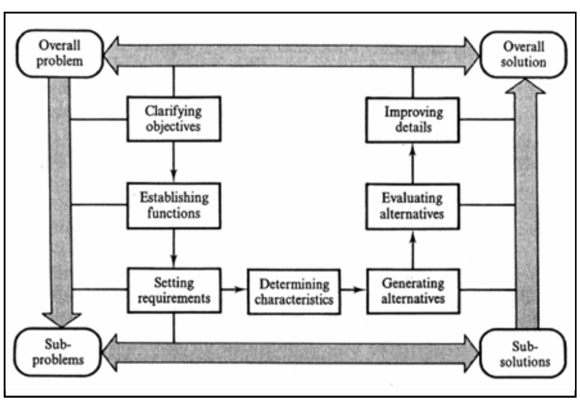


Figure 101: Cross's model of the design process [1989] (Birmingham et al., 1997)

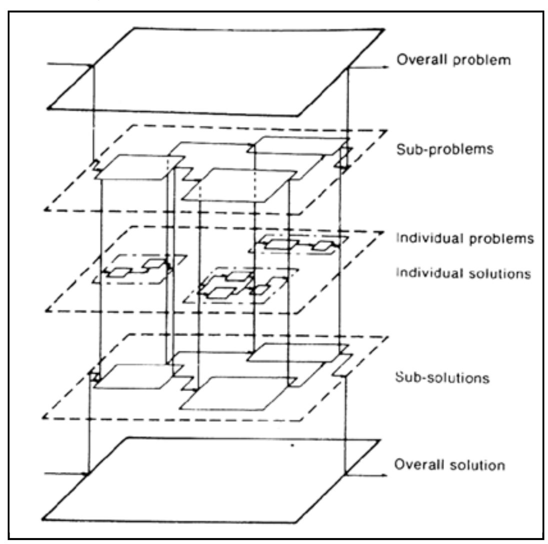


Figure 102: The VDI 2221 model of development from problem to solution [1987] (Cross, 2000)

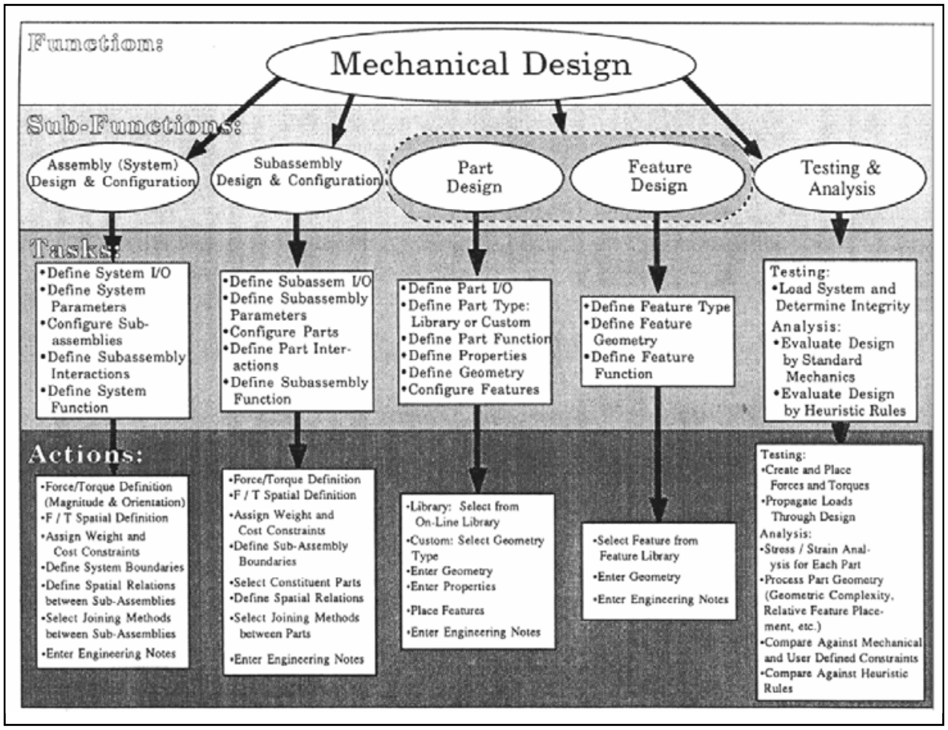


Figure 103: Operator function model (Colton, 1993)

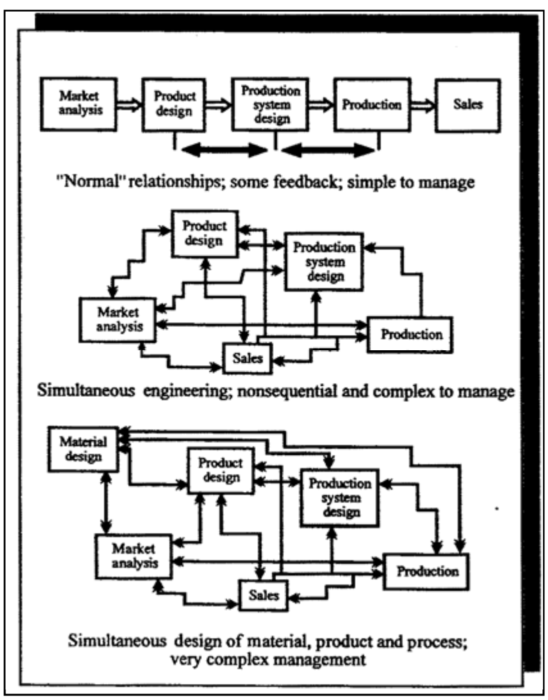


Figure 104: Increasing management complexity (Payne et al., 1996)

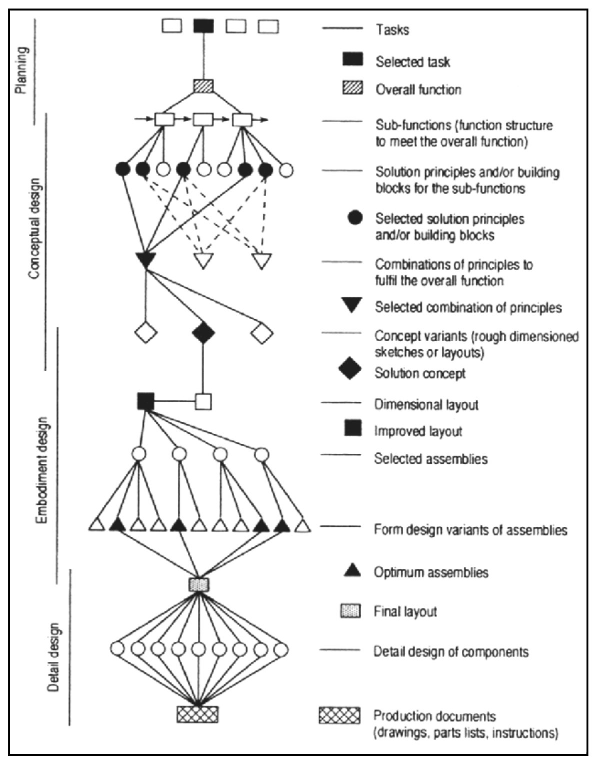


Figure 105: Divergence and convergence in the design process. The shadowed elements indicate the chosen points of departure for the next phase [VDI 2222] (Roozenberg & Eekels, 1995)

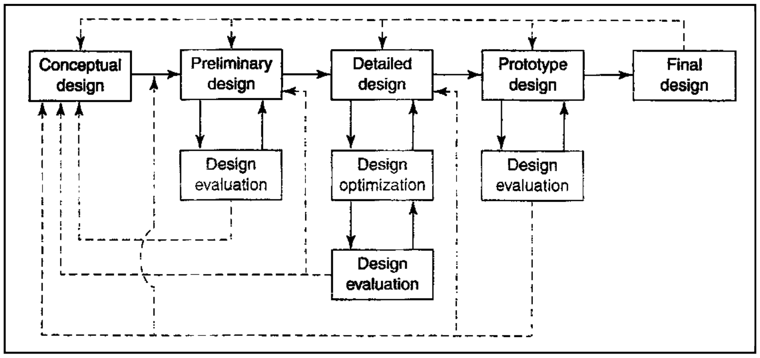


Figure 106: A flow diagram for the categories of engineering design (Eide et al., 2002)

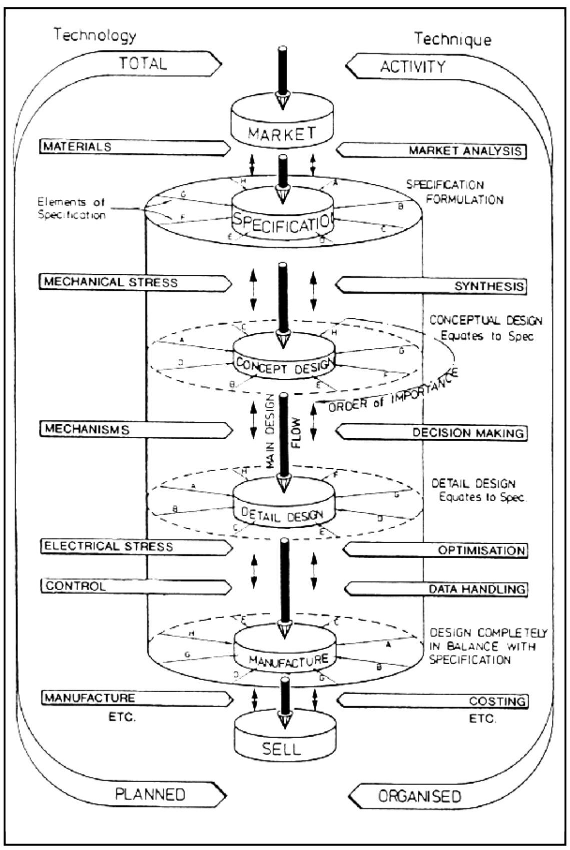


Figure 107: Total design activity model (Pugh, 1991)

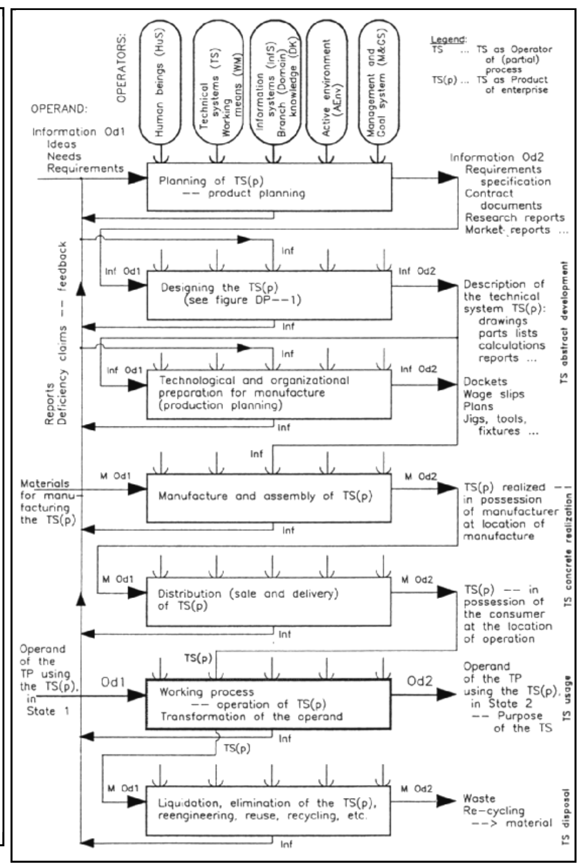


Figure 108: General model of the life cycle of TSs (Hubka & Eder, 2002)

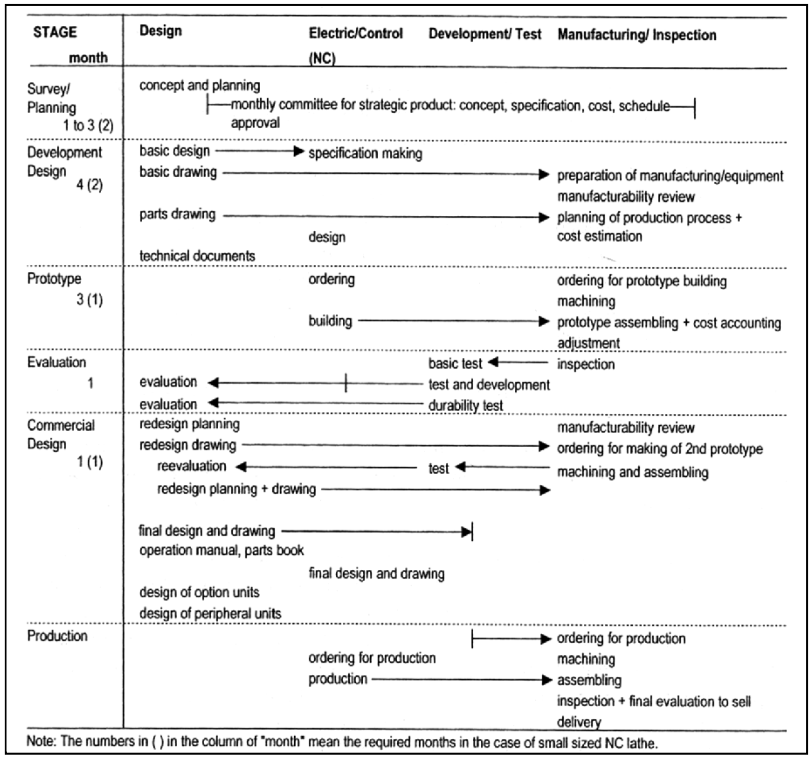


Figure 109: Procedure for the development of a new tool machine at Jama, 1992 (Kobayashi, 2000)

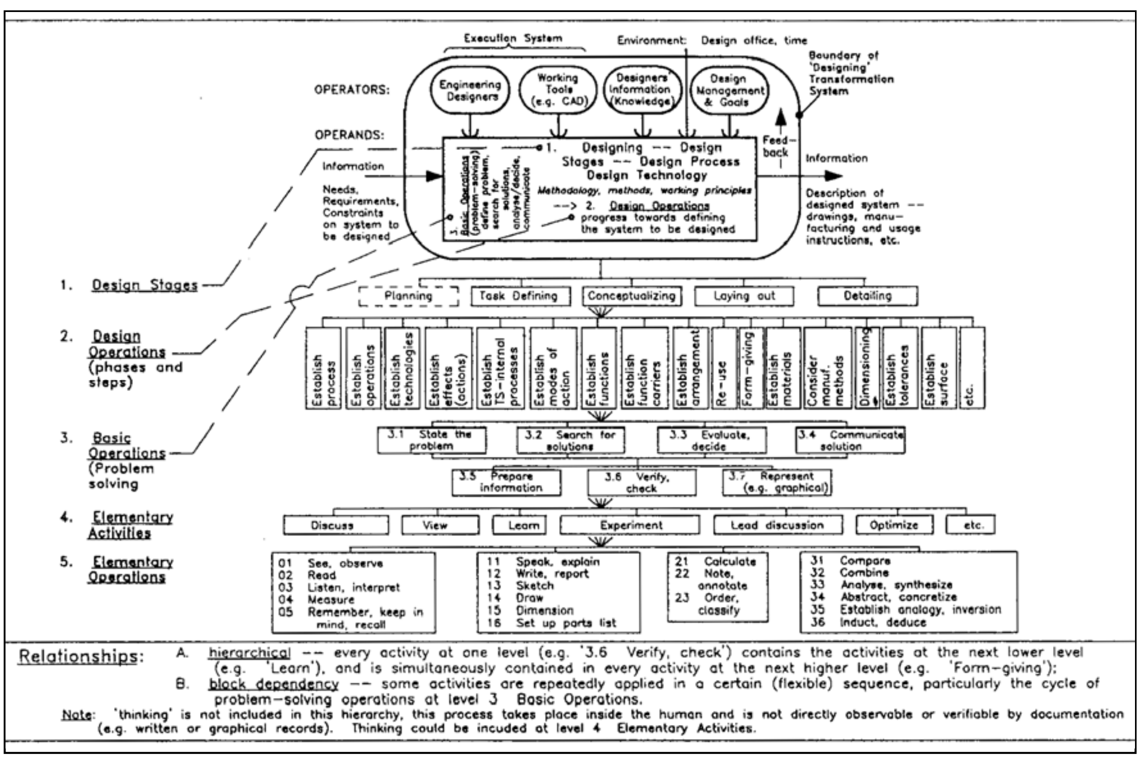


Figure 110: Structure of possible activities in the design process (Hubka & Eder, 2002)

2.2.2 The Possibility of Task Concurrency During Design

Relatively few of the graphical process depictions presented include the possibility of task concurrency during the design process. Gantt charts are useful in planning and scheduling tasks, and allow for the representation of different levels of task concurrency. Further, task interdependencies can be considered, with tasks occurring sequentially or in parallel. Parallel tasks can be coupled or uncoupled. Figure 111, below, shows the difference between sequential development and overlapped development, in which activities or tasks take place in parallel (Swink, 2000). A given task's *predecessors* are other tasks that must be completed prior to the

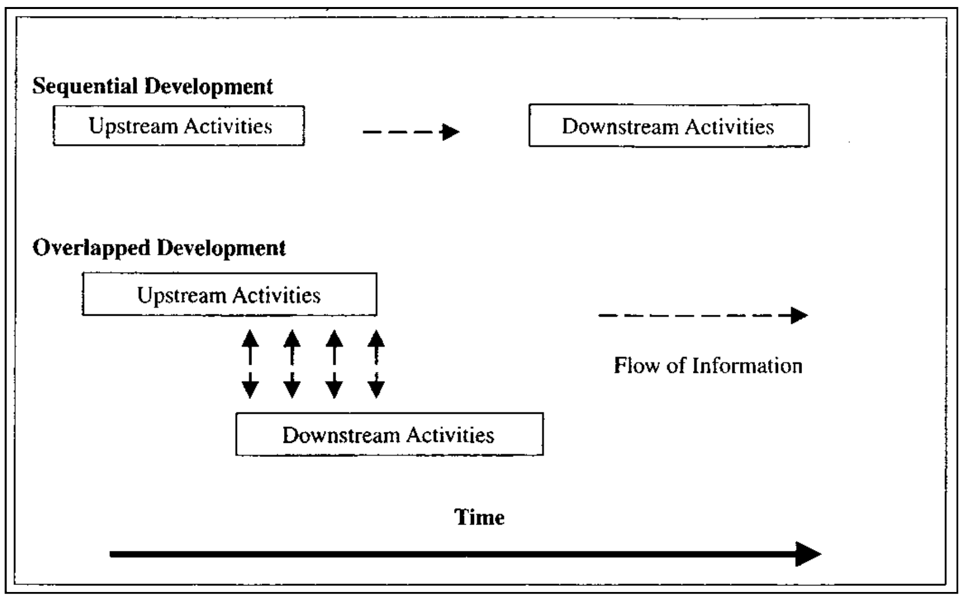


Figure 111: Sequential and overlapped product development activities (Swink, 2000)

given task. *Successors* are tasks that must occur after. The overlap of tasks is characteristic of concurrent engineering (Ullman, 2003).

Driven by competition, and an increased emphasis on the customer, product development firms have increasingly turned to concurrent engineering. Instead of sequential project contributions by the various functional groups (i.e., marketing, engineering, manufacturing, etc.), concurrent engineering pursues, "simultaneous development of different disciplinary subsystems required for a product launch" (Otto & Wood, 2001). Concurrent engineering can reduce the need for engineering changes, and can also reduce cycle times (Otto & Wood, 2001).

The level of task concurrency should be considered when planning a project. Figure 112, below, presents examples of task concurrency levels. Zero task overlap, or completely sequential development, is presented at the top. The second example is of uniform 50-percent concurrency, which is more theoretical and highly unlikely for a real project. Next, variable task

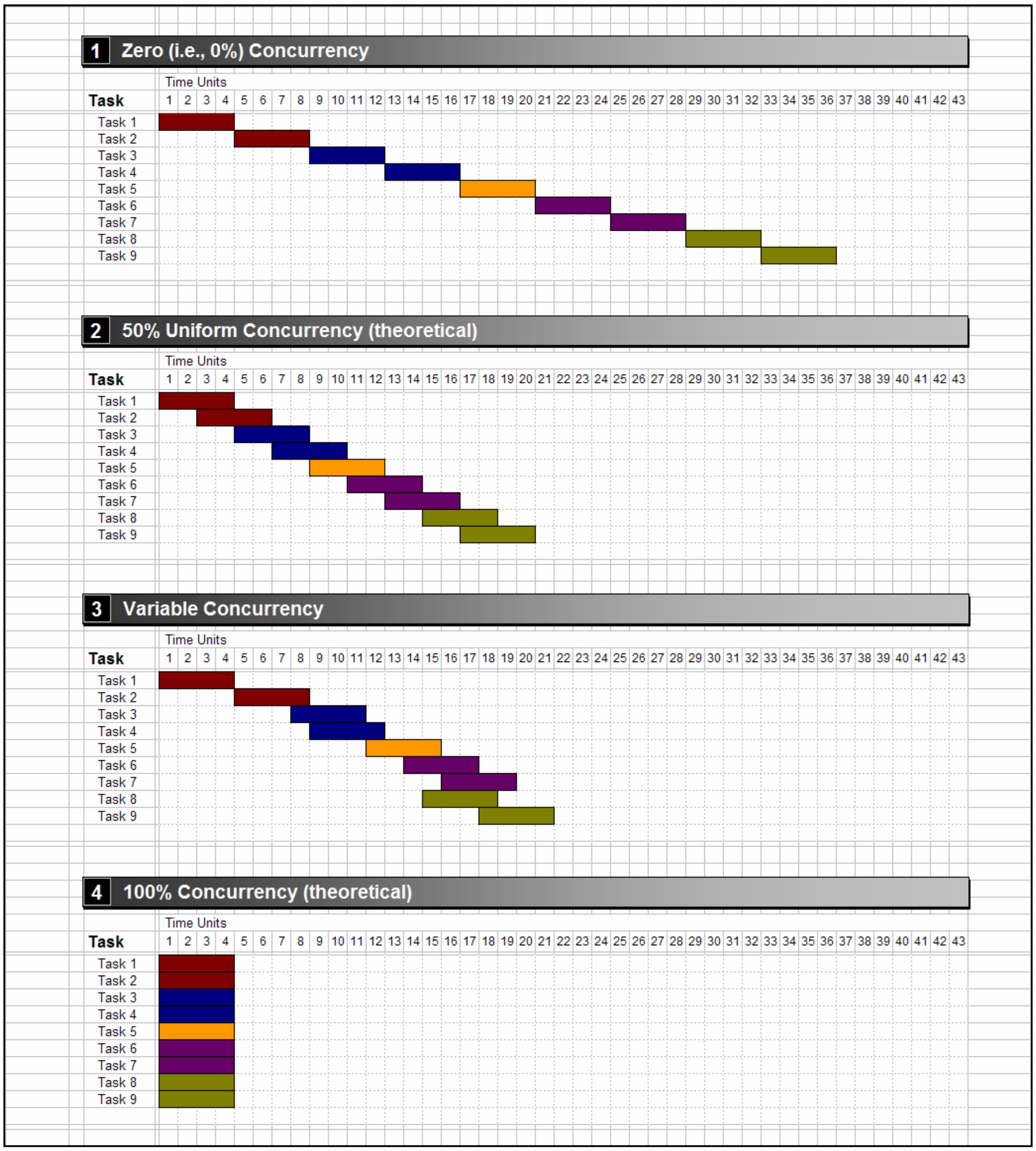


Figure 112: Various levels of task concurrency

concurrency is shown. 100-percent uniform concurrency, which is also theoretical, is shown at the bottom. Notably, it is possible for a task to have greater than 100-percent overlap with a preceding task. This is the case for some of the tasks in the third example. Task 8 has 125-percent overlap with Task 7, and starts before it.

Researchers have found, however, that increasing levels of uncertainty and task dependence make concurrency increasingly *unattractive* (Loch & Terwiesch, 1998). Also, research has found that information changes during concurrent engineering result in significant rework. Further, the concepts of information precision and information stability have been defined, and two time-dependent strategies for the management of interdependent tasks have been developed. Those strategies are termed iterative and set-based coordination. An *iterative coordination* approach emphasizes the sharing of information that is precise, and should be pursued if, "the downstream task faces ambiguity, or if starvation costs are high and iteration (rework) costs are low" (Terwiesch et al., 2002). There must be no ambiguity for *set-based coordination*; in which, instead of precision, the stability of information is important. This second approach should be used, "if either starvation costs or the cost of pursuing multiple design alternatives in parallel are low" (Terwiesch et al., 2002). Notably, information exchange strategies that are exclusively either iterative or set-based are extremes between which combination approaches are possible (Terwiesch et al., 2002).

2.3 The Design Team Environment

Research related to the organizational context of engineering, and the communication that occurs within it, is summarized next. To attempt to improve knowledge management and capture, awareness of the characteristics and norms of engineering organizations is necessary. With such an understanding, key constraints and likely failure modes can be identified. Since communication is essential for knowledge to be shared, and communication is heavily influenced by individual and cultural factors, these factors must be considered for knowledge management and capture approaches to be most successful.

2.3.1 The Organizational Context

Most engineering designs today are realized through the work of a group of people, "with complementary skills who are committed to a common purpose, common performance goals and a common approach for which they hold themselves mutually accountable," or a *design team* (Ullman, 2003). As customer expectations have driven the development of increasingly complex products, the organizations that engineer those products have changed. Multi-functional, multi-national, and multi-locational integrated product teams have become common. Key to team success is communication that creates a sufficiently shared understanding of the problem, potential solution approaches, design ideas, and idea evaluations (McMahon et al., 2004; Ullman, 2003).

Design teams have many positions, roles, and are of numerous types. The complexity of coordinating design teams becomes clearer when these positions, roles, and types are listed. Positions on a product design team can include the following twelve specialist categories: 1) product design engineer, 2) product manager, 3) manufacturing engineer, 4) detailer, 5) drafter, 6) technician, 7) materials specialist, 8) quality control or assurance specialist, 9) analyst, 10) industrial designer, 11) assembly manager, and 12) supplier representative. Each person on a design team, regardless of specialty, fills various team-function roles. Eight roles that individual team members may fill to varying levels and at different times are: 1) organizer, 2) creator, 3) gatherer or resource-contactor, 4) motivator , 5) evaluator, 6) team worker, 7) solver, and 8) completer or pusher. Adding another layer of complexity are five types of design teams, which are: 1) functional organization, 2) functional matrix, 3) balanced matrix, 4) project matrix, and 5) project team (Ullman, 2003).

During product design, according to McMahon et al. (1999), the know-how of those involved in design connects with other information to create "an information model" of a product (McMahon et al., 2004). Grabowski et al. (2001) add that the design-community expertise can be about products (or market-based), systems (i.e., infrastructure-based), people (including suppliers and co-workers), and/or processes (e.g., administration or workflow) (McMahon et al., 2004).

Knowledge is differentiated from information by the presence of commitment and beliefs usually tied to processes and action. Nonoka and Takeuchi (1995) define 'tacit knowledge' as that within people and 'explicit knowledge' as that that has been codified for organizational use. Companies would like to transfer tacit knowledge to explicit knowledge (McMahon et al., 2004).

Keys to knowledge management include the characteristics of design team members, whether 'routine' or 'critical' design work is being done, and the development of what Wenger (1998) calls communities of practice. The voluntary communities of practice develop naturally between those doing the same type of engineering work, and provide lateral support as a learning community. The use of concurrent design teams, however, can isolate an individual from the support provided by communities of practice (McMahon et al., 2004).

Healthy communities of practice must also be supported with other sources of knowledge. McMahon et al. (2004) state it as follows:

> As Langley (1995) notes, unaided human judgement is frequently flawed, in that people tend to be unduly influenced by recent or vivid events, consistently underestimate the role of chance and are often guilty of wishful thinking. From an engineering standpoint, Busby (1998) also found that engineers often fail to learn from their experiences because the feedback provided to engineers from previous projects was often unreliable, delayed and negative, and sometimes missing altogether (McMahon et al., 2004).

2.3.2 Communication Factors During the Design Process

Review of literature about relevant communication concepts begins at the start of the design process and problem definition communication. Next, a new type of organizational structure that is increasingly being used by engineering organizations, called virtual teams, is described. The interaction styles of problem solving groups, and how those styles relate to the resulting process outcomes, is clarified. Uncertainty receives additional attention, and equivocality is defined. Lastly, key intercultural communication concepts are summarized.

The topic of problem definition communication in engineering problem solving organizations can be viewed as the intersection of three areas of knowledge: 1) problem definition during organizational problem solving, 2) engineering, and 3) communication. No articles were found that examined the intersection of all three areas of knowledge. Instead, the literature reviewed is a collection of articles that cover some the topics of interest, but not all (i.e., problem definition communication in problem solving organizations, but not problem definition communication in *engineering* problem solving organizations).

Problem definition communication in engineering organizations that have greater success in solving problems likely differs from communication in less successful organizations in six ways. Research reveals those six differences to involve higher levels of problem solving communication. More specifically, the first difference is that information related to problem definition is processed in more significant amounts. Also, that information is from appropriate sources. Third, individuals display higher levels of communication that relate to group problem solving processes, and critical requirements. Fourth, individuals also display greater levels of competence in oral communication and written communication (i.e., emails and documentation). Work teams within organizations are also more constructive. Sixth, tools and techniques that facilitate communication and collaboration are used to a greater extent (Darling & Dannels, 2003; Fulk & DeSanctis, 1995; Grandgenett & Grandgenett, 2001; Griffin & Hauser, 1992; Hoffman & Kleinman, 1994; Martins & Aspinwall, 2001; Oh, 1998; Potter & Balthazard, 2002; Propp & Nelson, 1996; Ullman, 2003; Wiley, 1993; Winsor, 1999).

The increasing use of virtual teams is changing how engineering design happens. Virtual teams are a relatively new and increasingly relevant organizational form. That relevance extends to organizations that do engineering. While both conventional teams and virtual teams consist of real people, with complimentary areas of expertise, who work together on projects; in virtual teams, they do so despite geographic and time-zone differences. Conventional teams rely on frequent face-to-face interaction. Virtual teams depend heavily on mediated communication, and the extensive use of tools such as computer networks, email, telephones, faxes, and video; in addition to occasional face-to-face interaction. Advantages of virtual teams include responsiveness and flexibility, and these qualities have made them increasingly attractive to organizations. The potential for social isolation, however, is a drawback (Potter and Balthazard, 2002).

Research results provide strong evidence that supports the conclusion that nearly all of the relationships that have been described previously between a group's interaction style and group outcome for face-to-face groups, or conventional teams, are true for computer-mediated-communication groups, or virtual teams, as well. More specifically, members of conventional face-to-face problem-solving work teams confront three primary pressures. First, there is pressure to achieve a solution that takes advantage of all the group members' expertise. Additionally, the team is typically pressed to reach a solution efficiently, and to do so by consensus (Potter and Balthazard, 2002).

Two outcomes of the functioning of a problem solving group are the *task result*, or performance, and the *maintenance result*, or the group satisfaction with the process used in generating performance. How good the two outcomes are for a given group depends significantly upon how the group handles the various pressures it confronts, or the group's *interaction style*. This style is defined by a combination of stable behavioral traits of individual group members; traits which are based in the individuals' personalities. Three types of group behaviors contribute positively to group performance: 1) expectations of performance and integration, 2) leadership, and 3) cohesiveness. One group of behaviors that negatively affected performance was identified, and includes the withholding of information and non-involvement (Potter and Balthazard, 2002).

Interaction styles of groups can be reliably determined, and are predictive of performance on collaborative decision-making tasks. Styles can be categorized as constructive, passive, or aggressive. The first style, *constructive*, involves relatively high levels of cooperation, creativity, information exchange, and respect for others' input; with concern for group and personal outcomes being balanced. *Passive* groups emphasize group harmony and affiliation goals, and have low levels of information sharing, impartiality, or questioning. The third style, *aggressive*, is defined by competition, impatience, interruptions, and criticism; with personal achievement goals taking priority over group goals (Potter and Balthazard, 2002).

Constructive groups consistently produce better solutions than passive groups. Put differently, their performance is rated higher. Aggressive group solutions are usually not as good as constructively generated ones, but are typically better than passive group outputs. Also, group performance, in general, has been found to be better than the average performance of the individual members of the group, but not as good as the best individual in the group. For process outcomes, constructive group solutions have a higher degree of group member acceptance than either passive or aggressive group solutions (Potter and Balthazard, 2002).

Increasingly diverse engineering design teams, with respect to culture, are becoming more likely; and are adding to the complexity of design team function. As a result, another type of uncertainty is introduced. Further, cultural norms impact individual expectations during interpersonal and group interactions, including negotiation and problem solving situations.

New product and process design has repeatedly been described as, essentially, an information-processing exercise incorporating problem-solving and decision-making. When engineers do not have an obvious way to meet a design objective, they confront a problem and initiate a problem solving process. Two barriers must be overcome by engineers engaged in new product development problem solving. First, *equivocality* is the presence of various and often incompatible perceptions of the organizational setting in which the problem is being addressed. *Uncertainty* is a second obstacle that is defined as the difference between the information known and the information necessary for task accomplishment. Successful problem solving, thus, requires that design teams resolve equivocality and eliminate uncertainty (Susman and Dean, 1992).

Intercultural communication is defined as, "a transactional, symbolic process involving the attribution of meaning between people from different cultures" [italics removed] (Gudykunst and Kim, 2003). Minimum misunderstanding defines *effective* intercultural communication. Further, people who are relatively unknown to us – often, such as those from other cultures – fall under the category of *strangers*. Gudykunst and Kim's Anxiety and Uncertainty Management model (AUM) presents a general framework for understanding communication between strangers. "When we interact with strangers, our ability to communicate effectively is based, at least in part, on our ability to manage our anxiety and uncertainty," state Gudykunst and Kim (2003).

With repeated interaction with a stranger, uncertainty usually declines. The unexpected, however, will increase uncertainty. High anxiety, an emotional state, tends to accompany the cognitive state of high uncertainty. The two states are positively related, and the "greater the anxiety we experience, the more intrusive thoughts we experience.…[, which] decrease our cognitive capacity" (Gudykunst and Kim, 2003). Members of intercultural engineering design teams, then, must deal with three types of uncertainty: 1) procedural, 2) the problem solution information disparity, 3) and the lack of knowledge regarding those with whom they must interact to achieve the solution, including design team members, clients, and superiors.

A design team, also, usually experiences conflict when trying to solve a problem or take advantage of an opportunity. *Conflict* is defined as a struggle between at least two interdependent parties who encounter and recognize, do not recognize, or merely perceive incompatible goals, scarce resources, and/or interference from others in achieving their goals (including resource acquisition). The definition of a negotiable conflict situation sounds a lot like an engineering design team. In particular, a *negotiable conflict situation* involves two or more interdependent parties that have incompatible interests and flexible preferences that are in a voluntary relationship and engaged in joint decision-making amongst alternatives that involve the exchange of resources or the resolution of issues (Gudykunst and Kim, 2003; Walker, 2005; Wilmot and Hocker, 2001).

Ten cultural factors have been identified that influence international negotiation. These factors are worth remembering in intercultural design team contexts, as well. The ten factors are definable as continuums with two poles (see Figure 113, on the next page). The first relevant cultural factor is the desire to build either a contract or a long-term relationship. Second, negotiating attitude may be more win-win or win-lose. The first approach is also termed

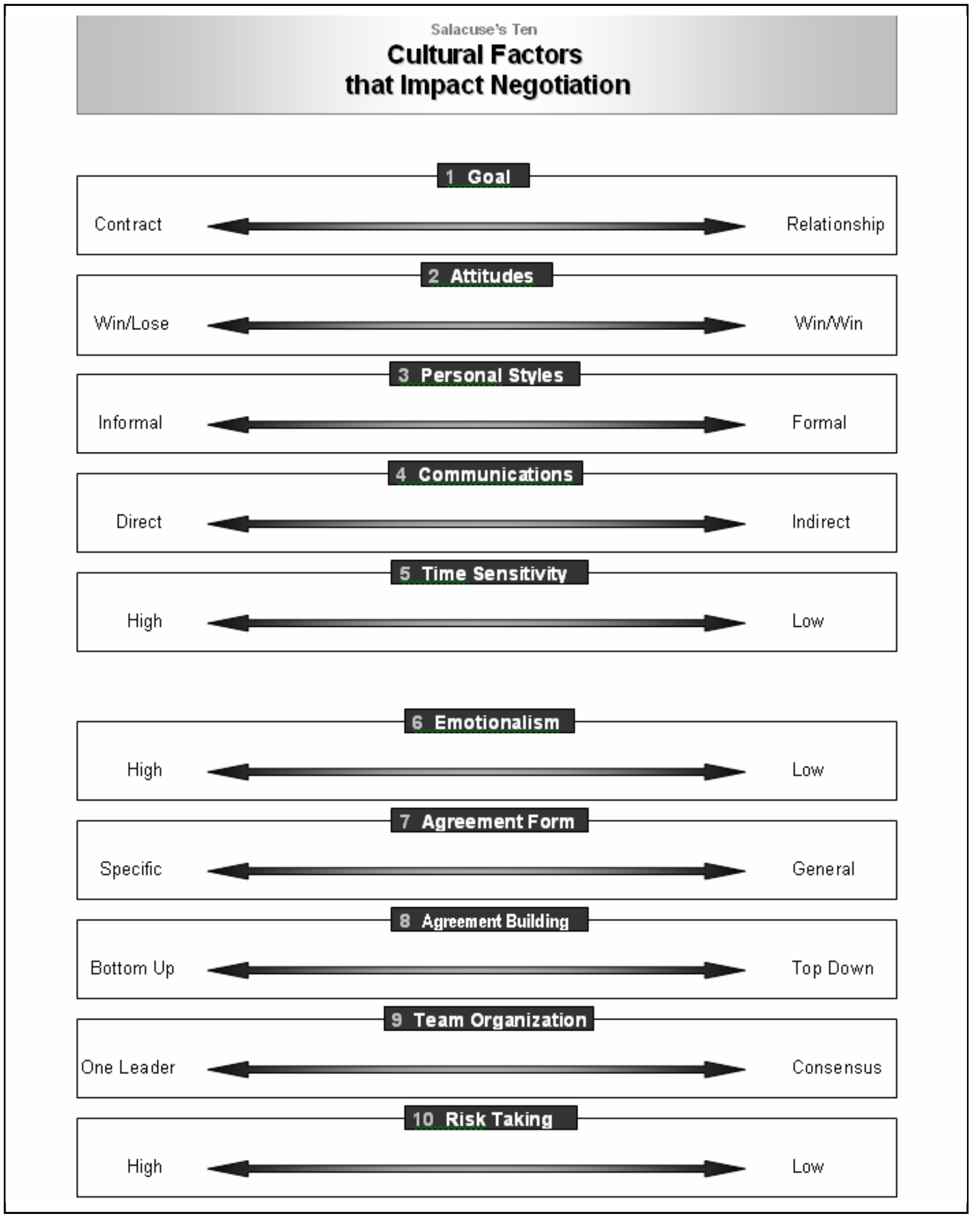


Figure 113: Ten cultural factors that impact negotiation (after Salacuse, 2004)

integrative negotiating and win-lose is also referred to as *distributive* negotiation. Next, personal style may be more formal with the use of formal attire and titles, or informal and characterized by more casual clothing and possibly the use of first names. Fourth, communication may be direct and explicit or it might be indirect and implicit. A fifth factor, one that may be linked to the relationship-versus-contract continuum, is time sensitivity. Cultures may value punctuality and quick negotiations (i.e., have a more contract orientation and high sensitivity to time) or, conversely, cultures may expect the process to develop more slowly (i.e., low time sensitivity). The level of emotion displayed during negotiation may also be high or low. Seventh, agreements may be highly specific and detailed, or they may be more general and rely on the relationship to resolve ambiguities. Agreements may also be built from the bottom up or the top down. The former focuses on specifics first, while the latter begins with general principles and ends with specifics. Ninth, some cultures value a consensus team organization while others prefer a one leader or chief negotiator approach. Finally, cultures may also differ in risk taking behavior, with some more likely to take risks and others being risk avoiders (Brett, 2001; Salacuse, 2004).

Four dimensions of cultural variability identified by Hofstede (1984) that affect intercultural communication are: 1) individualism-collectivism, 2) uncertainty avoidance, 3) power distance, and 4) masculinity-femininity. Additionally, Hall (1976) adds the cultural variable of contextual communication (i.e., either high- or low-context) (Gudykunst and Kim, 2003). The cultural dimension of individualism-collectivism merits additional clarification.

Individualistic cultures value a person's initiative and the achievement of self-centered goals. Association with many groups influences individual behavior. Examples of countries that are primarily individualistic are Great Britain, Australia, France, Germany, the Netherlands, and the United States of America (Gudykunst and Kim, 2003).

Collectivistic cultures, conversely, emphasize the goals of in-groups, and expect in-group members to fit in. Also, a person's behavior is influenced significantly by the few in-groups to which the person belongs. China, India, Japan, Brazil, and Saudi Arabia are examples of collectivistic cultures (Gudykunst and Kim, 2003). In both individualistic and collectivist cultures, various individual level influences, including personality characteristics, can change the relative impact of the cultural-level emphasis in specific communication situations (Gudykunst and Kim, 2003).

Thinking in individualistic cultures is linear, logical, analytical, and action oriented. The growth of natural sciences and technological advancement driven by these cultures are the result of gathering information through the senses, and organizing it through principled rationality or scientific induction. Further, individualistic cultures tend to have a *field-independent* cognitive style; that is, components of systems are more readily identified and utilized in other contexts (Gudykunst and Kim, 2003).

Notably, there are differences between the thinking of individualistic cultures of the United States and Europe. First, Americans often rely on dichotomies, such as hot and cold, and conservative and liberal, that provide a means by which comparisons can be made. Thinking in the U.S., also, places primacy upon induction, or first physically gathering empirical data and then applying abstract thought to it. Pragmatism and functionalism are characteristic American social values that stem from an emphasis on consequences, or *operationalism* (Gudykunst and Kim, 2003).

In contrast, European thinking places a greater significance on deduction. Deduction starts with abstract ideas, including theories, and then makes connections between them and the physical world. This approach reflects an emphasis on the conceptual realm. Europeans rely more on logic and less on fact-finding than Americans do (Gudykunst and Kim, 2003).

Collectivistic cultures differ from individualistic cultures in that logical analysis is of lesser importance relative to intuitive knowledge. Intuition is, "quick and ready insight," or "immediate apprehension or cognition…without evident rational thought and inference" (Merriam-Webster, 2005). Also, collectivist cultures tend to have a *field-dependent* cognitive approach in which the context is not broken down into components. Other terms used to describe collectivist thinking include holistic, integrative, and relational (Gudykunst and Kim, 2003).

2.4 The Tools of Knowledge Management and Capture: Information and Communication Technologies

Information and communication technologies (ICT) have numerous applications in knowledge management. Enabling mediated communication, capturing, encoding and organizing knowledge, and making the automation of processes related to design possible, all involve information and communication technologies. Six particular areas of information technology application are: 1) computer-supported collaborative work (CSCW), 2) information systems, 3) knowledge organization, 4) presentation of knowledge, 5) knowledge acquisition and structuring, and 6) knowledge-based engineering (KBE) (McMahon et al., 2004).

Also referred to as *groupware*, computer-supported collaborative work includes the technologies (emails, video, CAD, etc.) that facilitate the functioning of distributed communities or virtual teams. The reliance on email, even by colleagues working at the same location, has become the norm. Use of teleconferencing or video has become more routine. However, face-to-face interaction is advised for important situations and/or highly intercultural contexts (McMahon et al., 2004).

Information systems typically involve codifying information such as standards, best practices, directories, and other information into company *intra*nets or other electronic repositories. Search engines for these sources have typically relied either on free-text entry and automation or manual navigation around pre-defined hierarchical structures of information. Users of the first search approach must be adept at word or phrase selection that does not yield results that are too narrow (i.e., missing useful information) or too broad (i.e., causing information overload). Efforts to improve searching include the development of search algorithms that are based on semantics (i.e., language), keywords, and/or statistical concepts, and attempts to do semi-automated classification of documents that reduces manual effort. Also, search systems are beginning to allow users not only to query, browse, and retrieve information, or *pull* documents; but also to have documents sent to them electronically, or be *pushed*, based on information profiles (McMahon et al., 2004).

The remaining four information technology application areas are also confronting limitations. *Knowledge organization* efforts include information architecture experts that are attempting to define a common system with respect to a vocabulary to use, and trying to find ways machines can more readily comprehend documents. Approaches for *presentation of knowledge* pursue explicit incremental narrowing of potentially overwhelmingly complex hierarchical structures, adaptive hypermedia using domain knowledge, and search results in either page or hyperlink form. *Knowledge acquisition and structuring* have typically required much effort, and improving it has involved company-specific projects, data processing development, and machine learning innovation. A specific design methodology, *knowledge-based engineering* uses CAD-geometry and other information to generate models of potential products; which are, usually, variations of known designs (McMahon et al., 2004)

Several of the knowledge management techniques are shown in Figure 114 (on the next page), and are defined as areas indicating the relative emphasis on personalization and codification (McMahon et al., 2004).

Digital textbooks are another innovation that makes knowledge more accessible to engineers. For example, over 450 digital engineering and science books are accessible and searchable from a software service offered by Knovel. Interaction with the data is even possible. “[Engineers] can enter pertinent numbers into equations that would otherwise be static on a page and calculate answers,” Thilmany (2003) writes.

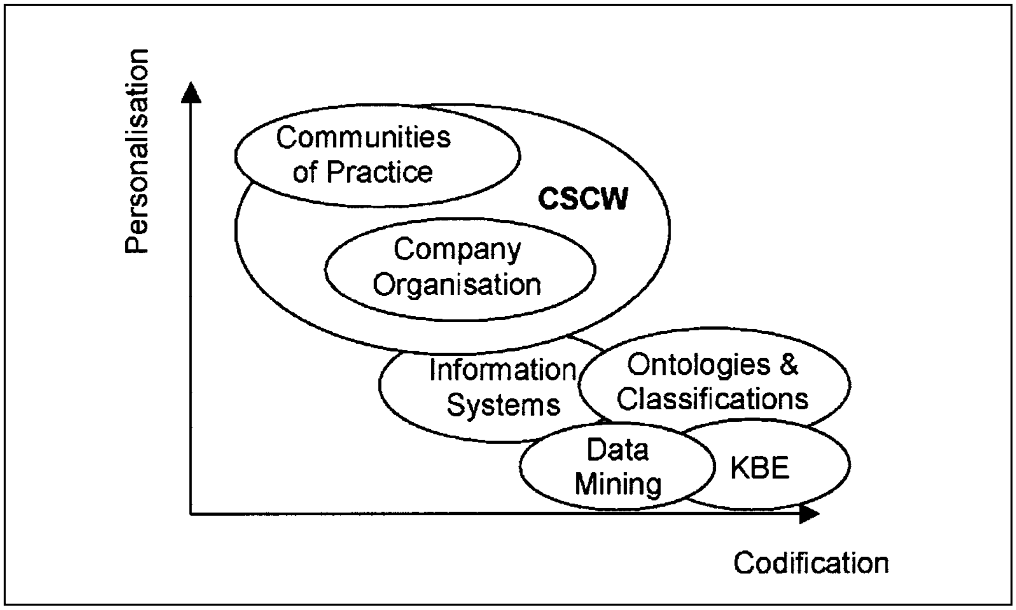


Figure 114: Perspectives on knowledge management [i.e., techniques mapped relative to the importance of codification and personalization] (McMahon et al., 2004)

Primary efforts to improve knowledge management and capture, and the tools used, must address the appropriate balancing of the two approaches, existing collections of data, and the current limits of knowledge capture. Organizations tend to emphasize either the commodity codification (i.e., object) view or the community personalization (i.e., process) view of knowledge management. While, both are deemed relevant in all engineering design organizations, a challenge is to find the appropriate balance given the organization and particular situations. The management of massive amounts of previously created design documents or "legacy data" that is usually in paper form, also presents a challenge for organizations (McMahon et al., 2004). Knowledge capture is another area that needs attention. McMahon et al. (2004) explain it as follows:

> Engineering representations say *how* a design should be, and record (some of) the information and constraints that are used in the design process, but they more rarely indicate *why* a design should be as it is. Very often the rationale behind an existing design will be lost in history. Sharing of design rationale is a major issue in the sharing of design activities among distributed teams. It needs concentration on methods of recording process, process inputs and intermediate process outcomes, as well as the final outcome (McMahon, et al., 2004).

2.5 Additional Concepts Relevant to Improving Knowledge Management and Capture

Ideas related to the analysis of efficiency and productivity, the diffusion of innovations, document design, and experimental design are all highly relevant to any attempt to introduce a new knowledge management and capture tool intended to increase the productivity of engineering design teams.

2.5.1 Efficiency and Productivity

Two concepts that are often central to efforts to improve processes are productivity and efficiency. *Productivity* relates the level of output produced by a process to the level of input used, and is defined as the ratio of a process's output divided by the process's input. Another measure of process performance is efficiency. An *efficiency* measurement occurs when a productivity measurement is compared to an ideal maximum productivity that is possible given a particular technology used for turning inputs into outputs. Further, while theoretical levels of maximum productivity can be estimated using models and mathematical calculations, efficiency is often a relative measurement that requires comparison of two or more processes. A more efficient process is characterized as such from one of two related and equivalently correct perspectives. First, of two processes that produce the same level of output, the process that uses the least input is relatively more efficient. Second, of the two processes that use the same level of input, the process that produces the greatest output is relatively more efficient (Grosskopf, 2003).

2.5.2 Innovation Diffusion

The author has previously provided an overview of innovation diffusion for a course paper on the subject. An excerpt of that overview is as follows:

> "An *innovation* is an idea, practice, or object that is perceived as new by an individual or other unit of adoption," [or , possibly, a transmittable disease] (Rogers, 2003). Notably, since it is based [often] on perception, 'newness' is a relative measure, not an absolute measure. The diffusions of technological innovations have been studied more than other types of new ideas. *Technology* is defined as, "a design for instrumental action that reduces uncertainty in the cause effect relationships involved in achieving a desired outcome" (Rogers,

2003). The two typical components of a given technology are *hardware* and *software*. Hardware is a technology's physical embodiment, or tool. Knowledge of how to use the tool is contained in its software. A technological innovation may also be part of a *technology cluster*, or "one or more distinguishable elements of technology that are perceived as being closely interrelated" (Rogers, 2003). An example of a technology cluster is a computer work station consisting of a display monitor, keyboard, mouse, "the tower" (containing the hard drive, mother board, etc.), and printer. Most of the pieces, by themselves, are not nearly as useful as a combination.

Rogers identifies five perceived characteristics of innovations that effect innovation adoption rates. Further, these attributes account for about half or more of the variance in adoption rates. The five characteristics are: relative advantage, compatibility, complexity, trialability, and observability. *Relative advantage*, "is the degree to which an innovation is perceived [by a potential adoption unit] as better than the idea it supersedes" (Rogers, 2003). Often, relative advantage is measured in social or economic terms. Also, it has been concluded that, typically, the greater the perceived relative advantage, the higher the corresponding rate of adoption. It is beneficial to reiterate that relative advantage is not an objective measure (Rogers, 2003).

The second of the remaining four attributes is how consistent the innovation is with the needs, values, and experiences of a potential adopter or the greater social system. This level of consistency is termed *compatibility*. *Complexity*, the third characteristic, is the perceived difficulty of using or comprehending an innovation. How much experimentation without long-term commitment that an innovation is viewed as permitting is termed *trialability*. Lastly, *observability* is an assessment of how readily an innovation's adoption results can be viewed by others (Rogers, 2003).

Innovations are not necessarily adopted in their original form. Researchers in innovation diffusion eventually began recognizing *reinvention*, and began examining "the degree to which an innovation is changed or modified by the user in the process of adoption or implementation" (Rogers, 2003). Reinvention tends to contribute to both higher rates of innovation adoption, and its *sustainability* or continuation (Rogers, 2003).

Rogers defines *diffusion* as, "the process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2003). Communication is defined [as] a participatory information creation and sharing procedure with mutual understanding between participants as its objective. Message exchange occurs via communication channels of two types: mass media (e.g., television, radio, print), and interpersonal. The first is more effective at generating awareness of an innovation. More persuasive communication regarding innovation diffusion occurs via interpersonal channels. Key to this persuasion is the degree to which individuals involved in the communication are similar or dissimilar in characteristics such as educational level, socioeconomic variables, belief systems, and interests. Higher similarity is referred to as *homophily*, and greater difference is term *heterophily*. Highly homophilous communication — except with respect to knowledge of an innovation — is more effective at diffusing that innovation than more heterophilous communication (Rogers, 2003).

…[T]he *rate of adoption* indicates the relative speed of innovation diffusion in a social system. A plot of a cumulative count of adoption of an innovation as a function of time typically appears as an S-shaped curve (see Figure [115]). The curve's primary inflection point corresponds to 50-percent diffusion (Rogers, 2003).

A *social system* is defined by collaborative problem solving, towards a mutual goal, by interrelated parties (i.e., individuals, organizations, etc.).

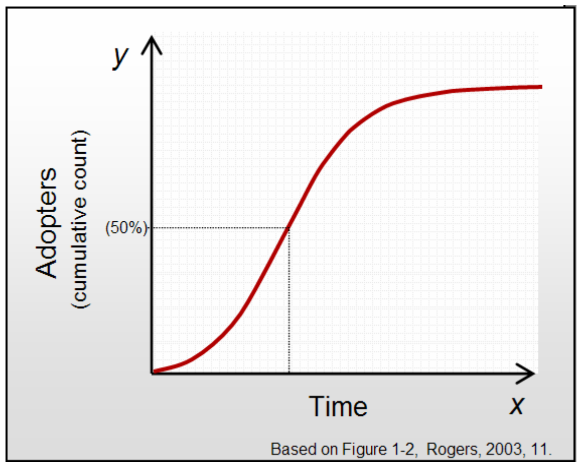


Figure 115: A typical s-shaped diffusion curve

Regulating and stabilizing human interaction in a social system are "patterned arrangements of the units in the system," or *structure* (Roger, 2003). Two types of structure are relational social structure and communication structure. Social systems have *norms*, or a set of usual behavior patterns. A *system effect* is the impact that a particular social structure has upon the behavior of individual system members (when other variables are controlled for). The information flow pattern between social units is defined as society's *communication network* (Rogers, 2003).

…Innovations have *consequences*, or "changes that occur to an individual or social system as a result of … adoption or rejection…" (Rogers, 2003). Three bi-polar categories of consequences are: 1) *desirable* versus *undesirable*, 2) *direct* versus *indirect*, and 3) *anticipated* versus *unanticipated*. While change agencies may correctly anticipate the form and function of an innovation in a given social system, they may not foresee the *meaning*, or subjective evaluation, of an innovation. Unintended consequences may occur as a result (Rogers, 2003).

It must be noted that while some change agents work to promote the diffusion of innovations, other change agents attempt to prevent the diffusion of innovations that have clear undesirable consequences. That is, innovations may also be harmful, such as transmittable diseases. Some of the preceding description of innovation diffusion makes sense only for beneficial innovations (e.g., relative advantage). This shortcoming of the field of diffusion research is identified as the *pro-innovation bias*. Faster adoption by everyone without

> reinvention (let alone rejection) is better, is an implicit assumption in much of [the] diffusion research. Such an assumption may limit efforts to understanding how to prevent the spread of detrimental innovations ([e.g.], diseases). Overcoming this bias may require research of unsuccessful diffusions or the gathering of data earlier in the diffusion process than the typical after-diffusion adopter surveys…(Rogers, 2003).

2.5.3 Document Design

In the process of defining the experimental model, seven communication-enhancing characteristics of documents were identified. These characteristics could help clarify how an overview document, as previously described, could possibly contribute to communication that increases problem solution utility. Notably, this literature was reviewed *after* the creation of the overview document's initial draft. The seven document characteristics are as follows:

1. Involves knowledge management, including the management of commodities (i.e., codification of documents, etc.), and communication (i.e., personalization) (McMahon et al., 2004).

2. Involves knowledge capture (McMahon et al., 2004).

3. The format facilitates navigation and/or the ability to by-pass irrelevant information (note: flowcharts do) (Mirel, 1991).

4. The layout of the flowchart maximizes accuracy and efficiency (i.e., it is laid out either left-to-right, or top-to-bottom) (Mirel, 1991).

5. There are multiple levels to the document (i.e., manual). "Multileveled manuals are superior to solely global or detailed manuals for the amount of information learned and tasks completed. Multileveled results in more accurate and complete mental representations" (Mirel, 1991).

6. The document minimizes the load on working memory. In particular, actions are on the same page as instructions, segmented text (i.e., lists) are used, as are prominent and clear headings (Ganier, 2004).

7. The document uses color. Color is used to: 1) direct attention, 2) delimit shapes and areas, 3) clarify complex ideas, 4) facilitate identification, and 5) create affect (Winn, 1991).

2.5.4 Empirical Study Designs

Various approaches have been used in attempts to identify the processes by which humans do design. Seven ways design has been studied include: 1) verbal protocol analysis (VPA), 2) observation, 3) questionnaires, 4) ethnographic studies, 5) experimental studies, 6) using electroencephalograph (EEG) records, and 7) analyzing sketching (Cardella et al., 2006). Verbal protocol analysis has been widely used and involves the video recording of a designer working to solve a problem while 'thinking out loud' (Blessing, 1994; Cardella et al., 2006). Data from previous VPA studies can be further analyzed later (Atman et al., 2004; Cardella et al., 2006, Chakrabarti et al, 2004).

Examples of the use of a questionnaire include an exploratory study of virtual teams done by Lurey and Raisinghani (2001). Team members were asked to complete an eighty-four item survey. Predictor variables for team effectiveness were included in the questionnaire (Lurey & Raisinghani, 2001).

A paper about a then unpublished study by Jain and Sobek (2003) describes a different approach. Fourteen senior mechanical engineering design project teams were studied over fifteen weeks. For data collection, individual students kept design journals. The technique permitted real-time data collection without a given collection site, or the intervention of a specially trained professional, while still gathering codable and manageable data. For these reasons, the design journal approach was deemed preferable to previous approaches (Jain & Sobek, 2003). Notably, the study has since been published (Jain & Sobek, 2006)

2.5.5 One Assessment of What Is Needed for Significant Improvement

Complexity is seen as a major obstacle to further advances in knowledge management in engineering. In particular, McMahon et al. (2004) conclude the following:

> Engineering processes may be described at a high level, and the detail of low-level processes can also often be described, but a complete description of processes is elusive, owing to the complexity of interactions in large distributed communities, and the highly dynamic nature of product development.
>
> The same is true for our ability to represent information structures. We have a good capability in modelling product structures, and an emerging capability in representing organizational structures for engineering information, but we are a long way from general agreement in this respect. We are also…beginning to address the issue of tying together product and process

representations – but at the present achieved almost solely in variant or highly adaptive design domains (for example, Clarkson and Hamilton 2000). It is probable that radical developments in process and product representation will be needed to effect a significant improvement in capability (McMahon et al., 2004).

Chapter 3 ─ The Materials and Methods of the Experiment

Six features of the experiment are presented in the following order: 1) the hypotheses, research questions, and variables; 2) the experimental treatment (i.e., the created process overview document); 3) the design problem; 4) the subjects; 5) the setting; and 6) the procedure.

3.1 Hypotheses, Research Questions, and Variables

Two hypotheses were tested:

> H_1: Groups that use the process overview document to manage and capture knowledge will generate higher numbers of communicative acts to orient the group and establish procedures than those groups that do not use the process overview document.

> H_2: Groups that use the process overview document to manage and capture knowledge will generate higher numbers of communicative acts to analyze the problem or task than those groups that do not use the process overview document.

In addition, five research questions were asked that related to the diffusion of innovations:

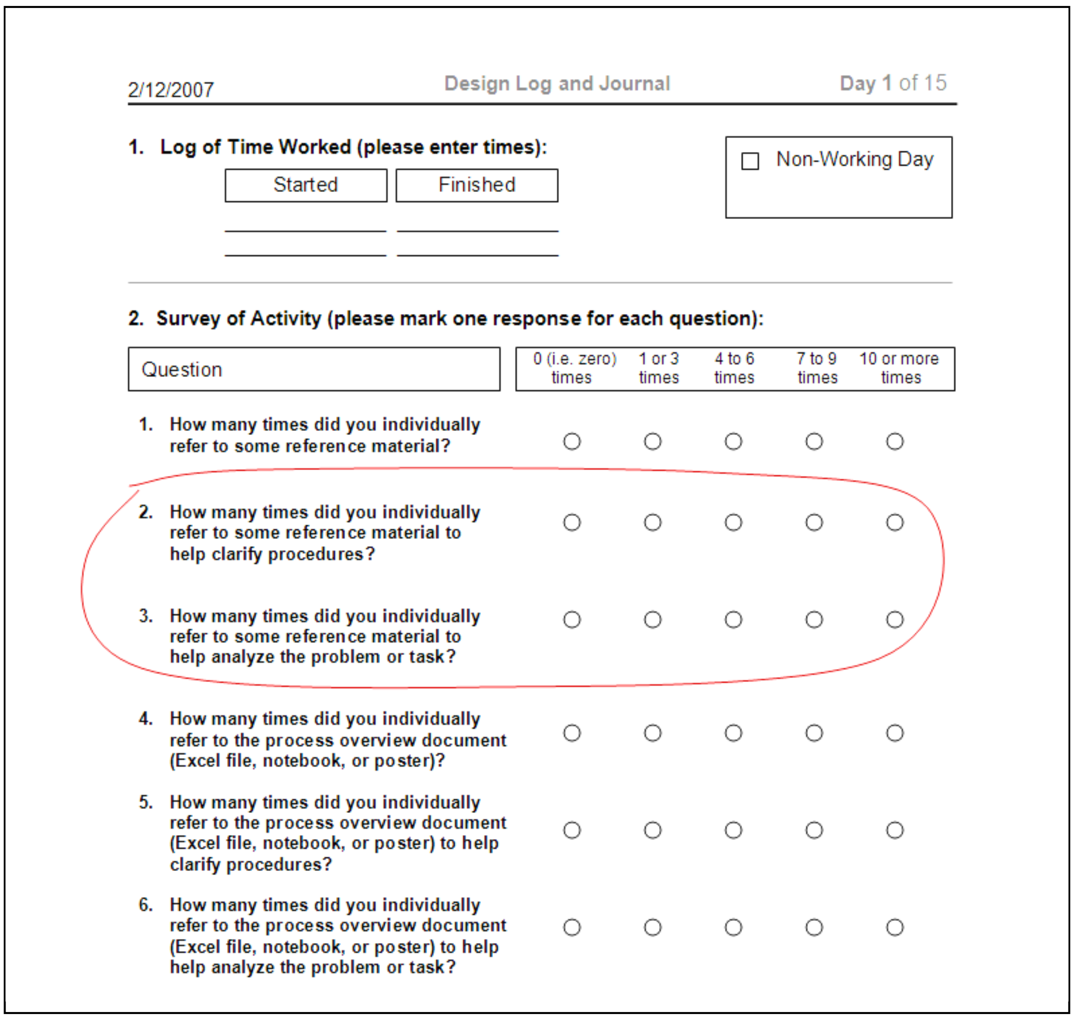
> RQ_1: Is the created overview document perceived to have *relative advantage*?
> RQ_2: Is the created overview document perceived to be *compatible*?
> RQ_3: Is the created overview document perceived as *complex*?
> RQ_4: Is the created overview document perceived as *trialable*?
> RQ_5: Is the created overview document perceived as *observable*?

The operating variables were defined in part based on work done by Shah, Kulkarni, and Vargas-Hernendez (2000). Two primary categories of operating variables are experiment variables and nuisance variables. Experiment variables include both method variables and design problem variables. Method variables are further divided into independent and dependent variables. The independent variable, x, was defined as use of an overview document. This is a categorical variable with two categories:

1. The status quo, operationalized as currently available engineering design and problem solving references

2. Use of an overview document, operationalized as the status quo plus a three version set of an overview document: 1) an Excel computer file, 2) a three-ring notebook hardcopy, and 3) a poster

The dependent variable, *y*, was defined as the total number of communicative acts to both: 1) orient the group and establish procedures, and 2) analyze the problem or task. Operationalization of the communicative act number was done by the subjects maintaining survey-like design journals, and providing answers about the number times they referenced a source; that is, performed a mediated communication act (see Figure 116, below).


2/12/2007 Design Log and Journal Day 1 of 15

1. Log of Time Worked (please enter times):

Started | Finished

☐ Non-Working Day

2. Survey of Activity (please mark one response for each question):

Question	0 (i.e. zero) times	1 or 3 times	4 to 6 times	7 to 9 times	10 or more times
1. How many times did you individually refer to some reference material?	○	○	○	○	○
2. How many times did you individually refer to some reference material to help clarify procedures?	○	○	○	○	○
3. How many times did you individually refer to some reference material to help analyze the problem or task?	○	○	○	○	○
4. How many times did you individually refer to the process overview document (Excel file, notebook, or poster)?	○	○	○	○	○
5. How many times did you individually refer to the process overview document (Excel file, notebook, or poster) to help clarify procedures?	○	○	○	○	○
6. How many times did you individually refer to the process overview document (Excel file, notebook, or poster) to help help analyze the problem or task?	○	○	○	○	○

Figure 116: The two design journal questions that yielded data for the hypotheses tests

The basic assumption is that an increasingly greater number of communicative acts lead to increasingly greater utility – up to a point.

Design problem variables were to be controlled for, and include complexity, decomposability, and the degree of innovation needed. Nuisance variables needed to be controlled for, and include human factors and environment variables. Amongst such human factors are personality, motivation, and level of creativity. Time constraints, location, and temperature are some of the environmental variables. It was decided that the experiment would attempt to create a model upon which future, more extensive, realistic and generalizable studies can be developed and completed. Since most engineering design efforts involve multiple people, it was concluded that a small group unit was preferable to the study of individuals. Figure 117, below, presents the approximate shape for the curve of the frequency of real design projects with a given number of individuals involved, for a given time period. Further, the

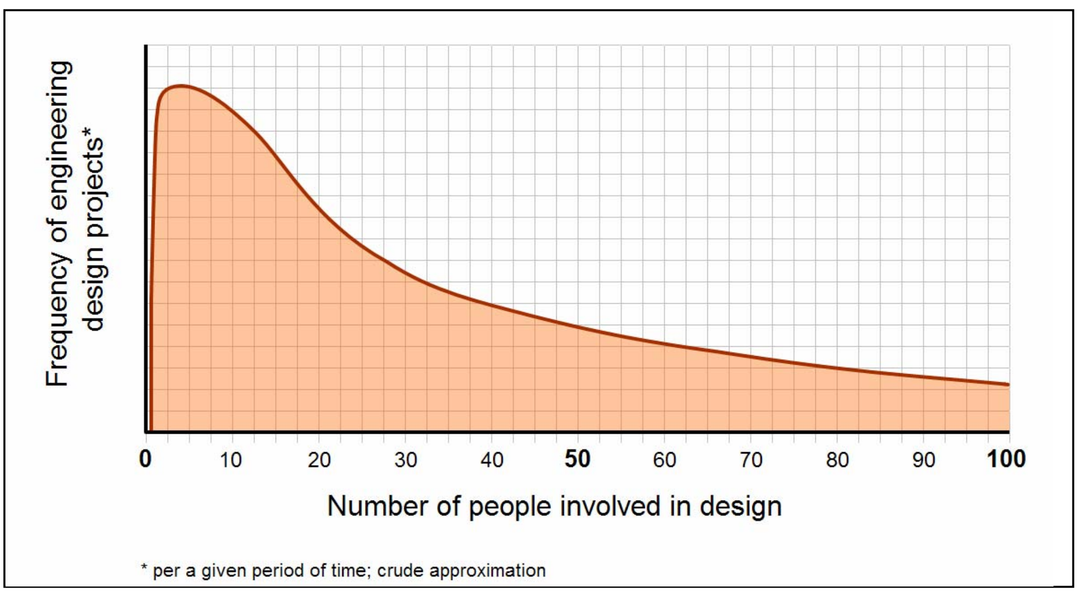


Figure 117: Frequency curve of engineering design projects with a given design team size (approximation)

representation of more than one discipline on the team was also seen a necessary. Finally, design teams typically work on projects for many weeks, if not months or years. Figure 118, below, shows an approximation of the curve of the frequency of real design projects that take a given number of weeks to complete, for a given time period. In turn, a study that reduced design to hours was deemed as too unrepresentative.

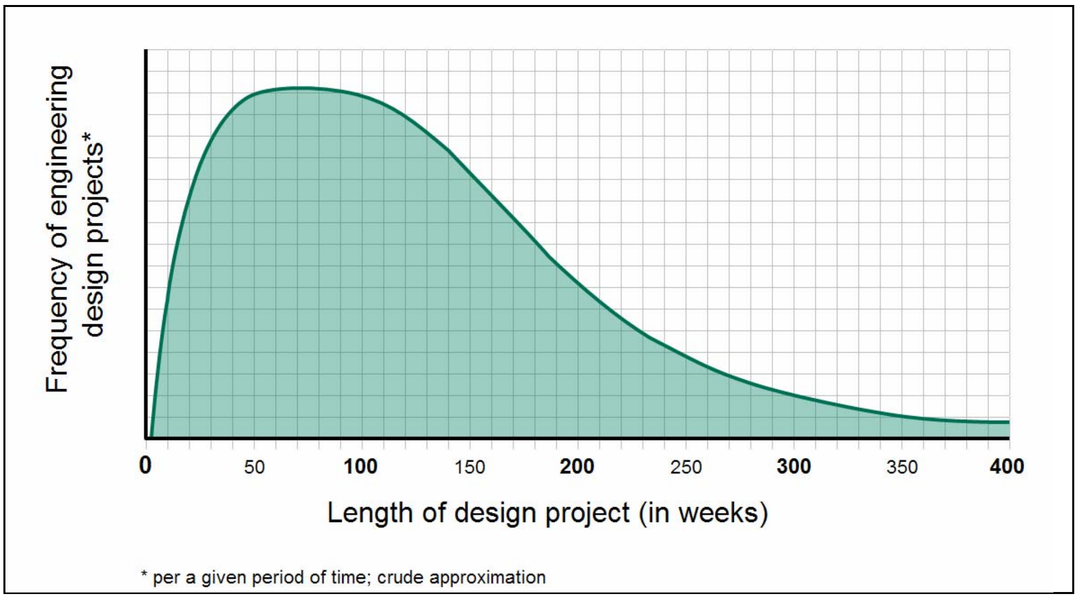


Figure 118: Frequency curve of engineering design projects with a given project length (approximation)

3.2 The Experimental Treatment: The Created Process Overview Document

The flowchart portion of the engineering design and problem solving process overview document is heavily based on the mechanical design process flowchart by Ullman (2003), which was presented previously, and is presented again in Figure 119, below. Figure 120, on the next page, shows an image of the user interface when the overview document is first opened. A fold-out page 72 follows, and presents Figure 121. That figure shows a much scaled-down version of the entire Main Page of the overview document (scale: about 1/6th). In keeping with the features defined in Chapter 1, the task and decision point shapes in the flowchart are hyperlinked and can be clicked on to go to a clarification information page. Further, the Gantt chart below the flowchart can be altered to schedule tasks and define concurrency levels. Figure 122, on page 73, shows the first of the hyperlinked process clarification pages. Again, in keeping with its definition, these pages have clarifying text, data-tracking and contact information capability, and have a list of reference sources. Clarifying information includes a

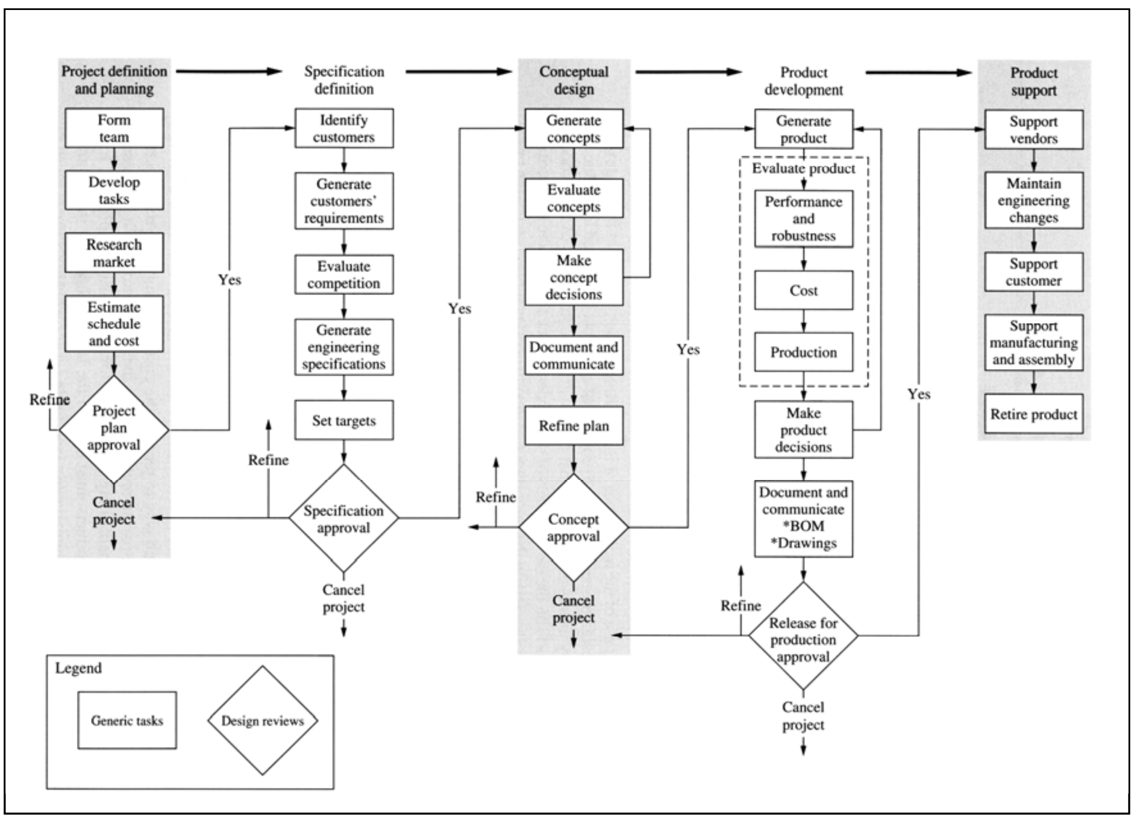


Figure 119: The mechanical design process (Ullman, 2003)

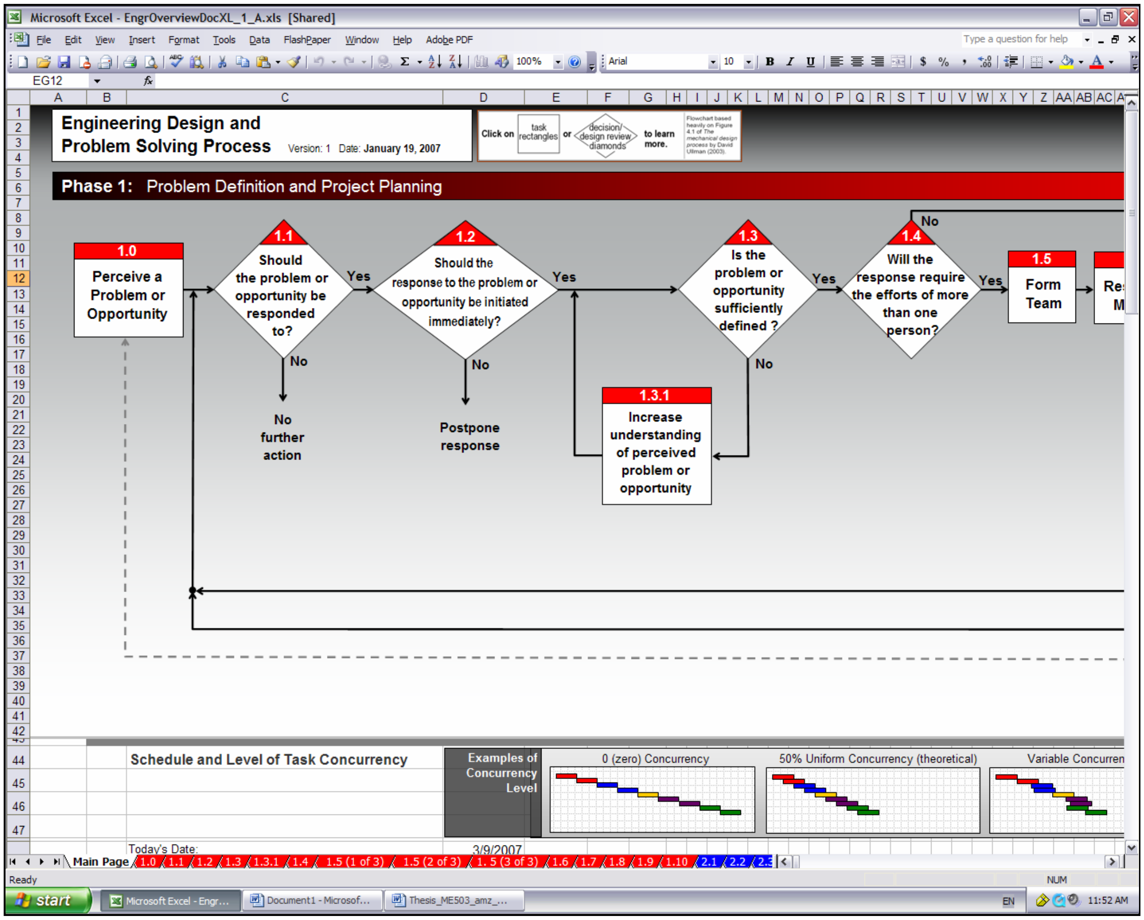


Figure 120: The overview document Excel file when first opened

description of group interaction variables. More specifically, for the team formation step, an overview of group interaction style and its impact on group performance, as well as other communication factors, are summarized. From the clarification pages, a hyperlinked return to the Main Page is possible. Hyperlinks also enable access to worksheets. One of the worksheets – a QFD House of Quality – is shown in Figure 123 (see page 74). Additionally, users can also navigate the spreadsheet pages by simply scrolling the sheet tabs at the bottom, and selecting the desired color-coded sheet.

After some exploratory prototyping, the overview document was ultimately created on a PC using Microsoft Excel spreadsheet software. Prototypes had been built in other types of software, including Word, Visio, and Project. Ease of organization, and the ability to have worksheets in which data could be entered and calculations done, made the spreadsheet preferable. Further, the software is quite prevalent, which makes diffusion easier. Many

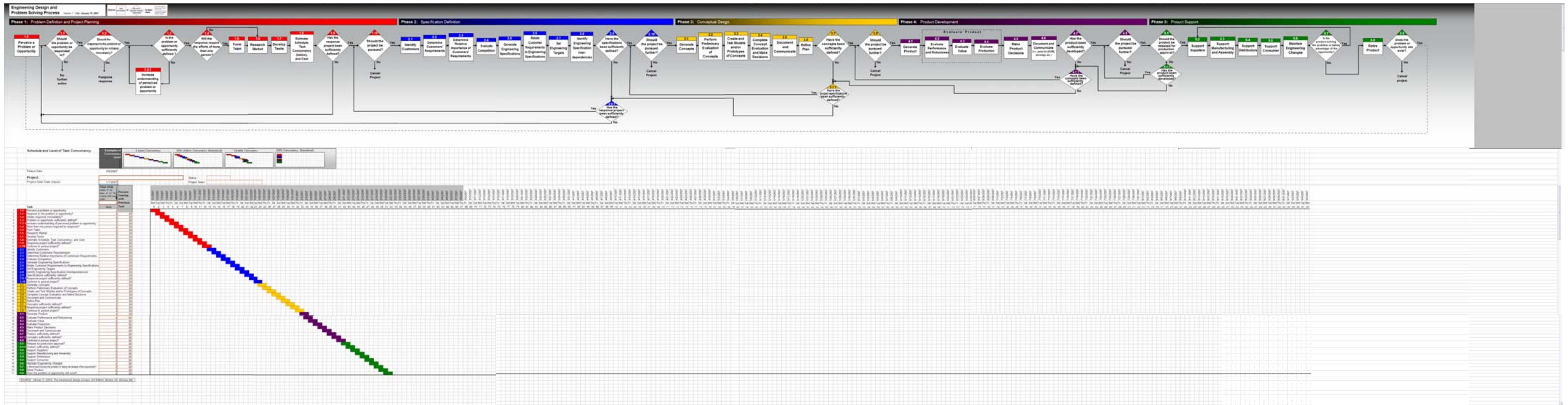


Figure 121: The Main Page of the process overview document Excel file

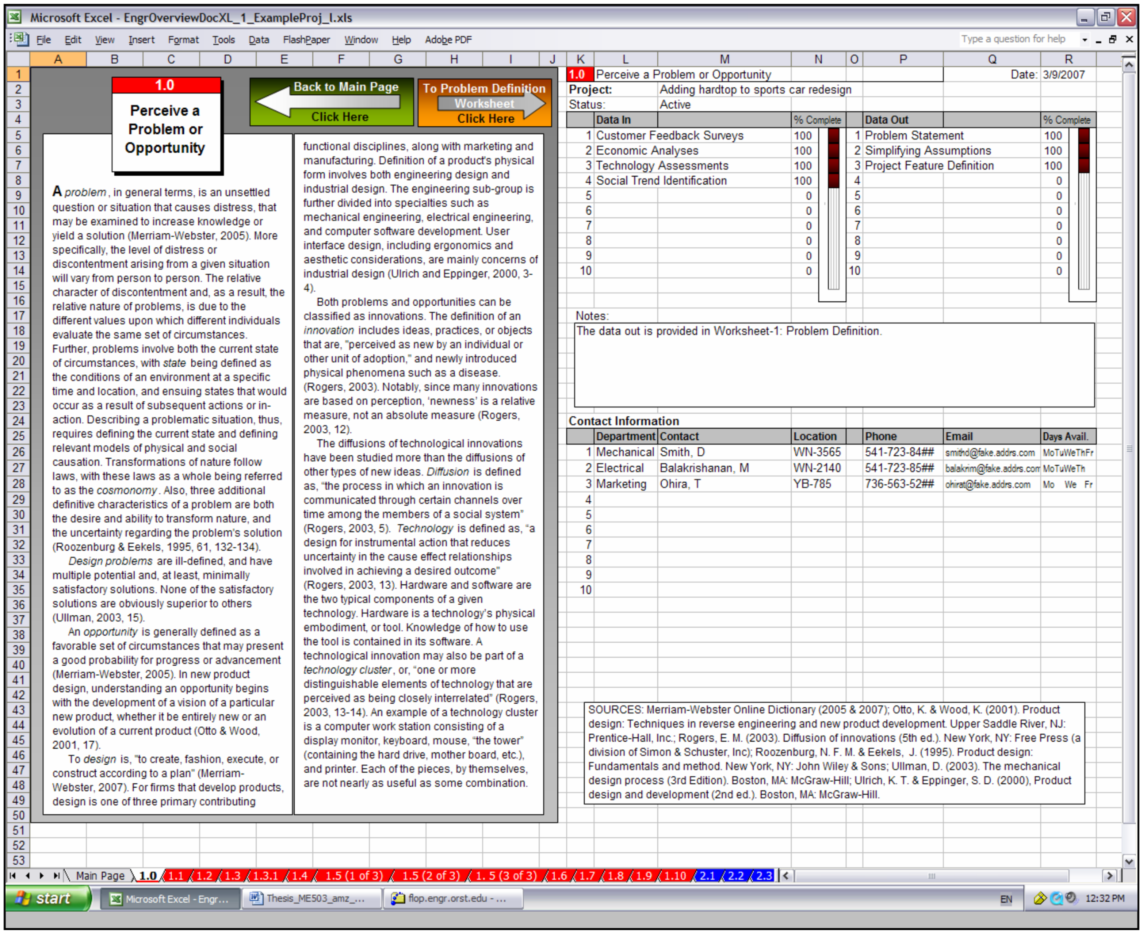


Figure 122: A hyperlinked clarification page (with data tracking and contact examples)

computer users do not have Visio or Project. In contrast, even a large number of Apple users have a version of Microsoft Office on their computers. The overview document has been examined and manipulated on an Apple, and seemed to perform quite similarly to PC use. Figure 124, on page 75, shows the file as opened on an Apple. Further, the concept of the overview document could quite easily be transferred to some other type of spreadsheet software, if need be. Adaptability contributes to robustness.

Four other notable features are intended to contribute to the overview document's utility during actual projects. First, while color is extensively used in the overview document, the need to provide a viable document when printed out in less costly black and white had to also be considered. Figure 125, also on page 75, presents the overview document as viewed prior to a black and white print job. Second, the Gantt chart portion of the Main Page permits entire phases to be repeated through copying and insertion. Those involved in a project get clear evidence of the scheduling impact that re-doing phases can have on the project. Figure 126, on

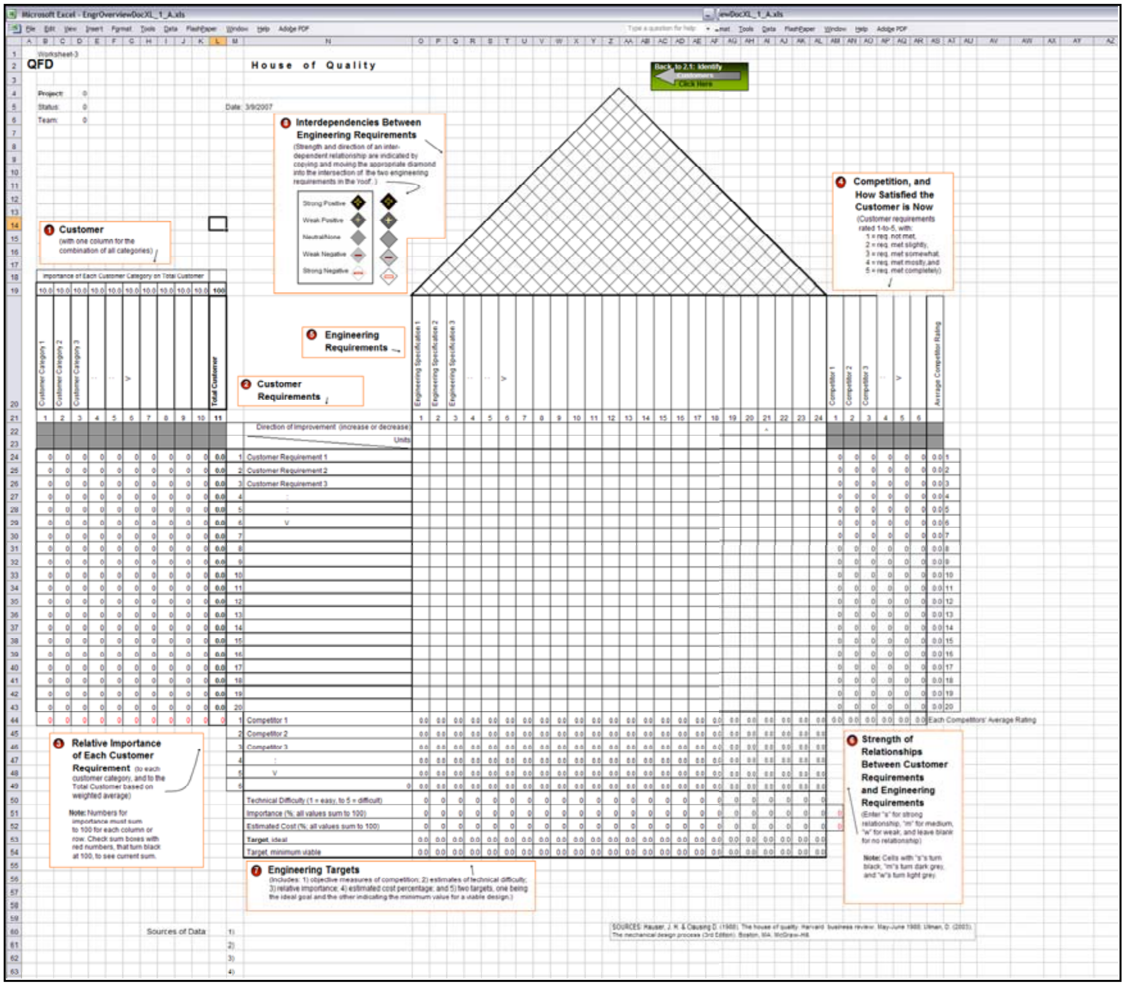


Figure 123: A hyperlinked worksheet

page 76, shows the major effect that repeating the Specification Generation (blue) and Concept Generation (yellow) phases has on a hypothetical project’s completion date. In this case, the to-market date is postponed nearly a year. Third, the dates listed vertically along the top of the Gantt chart are defined by the user input start date of the project, and their cells turn grey after the current date has passed. Lastly, shared versions of the Excel file can track changes to the document, and show those changes either listed separately or highlighted where they took place.

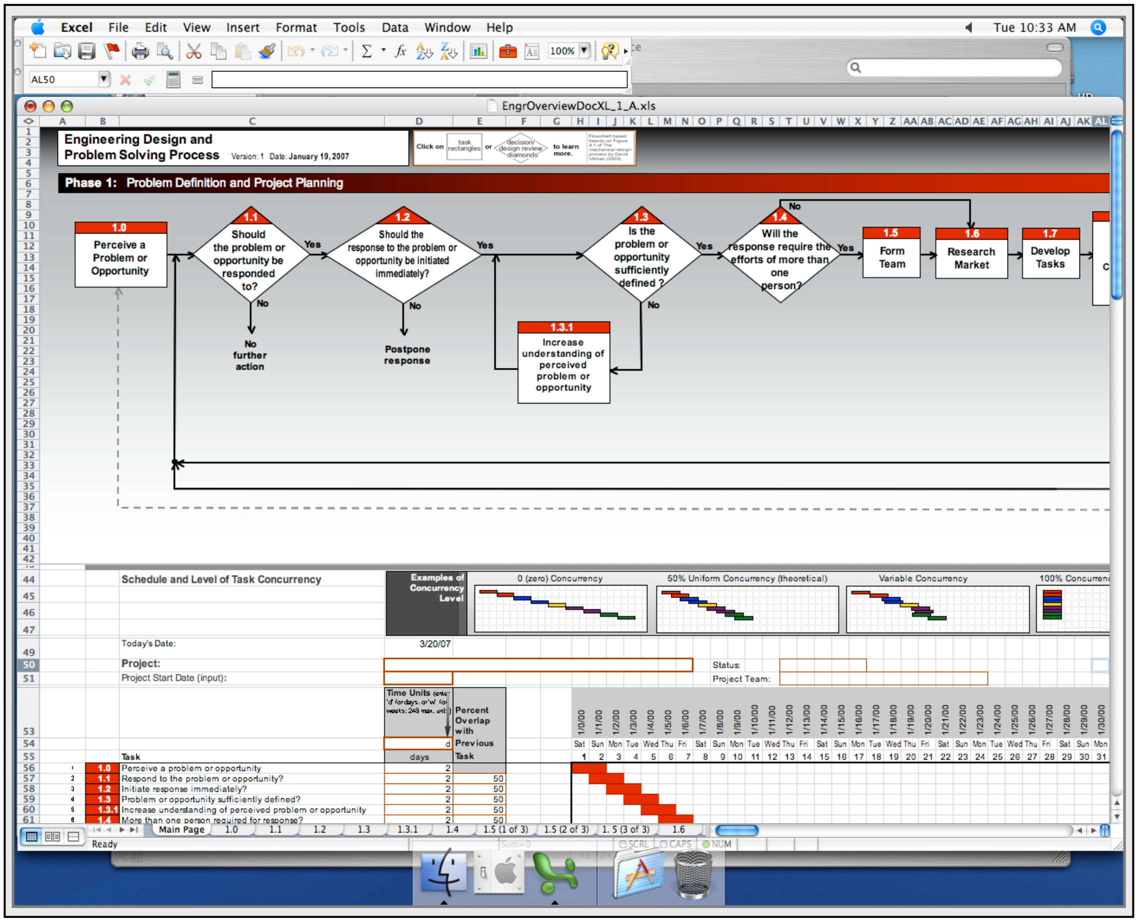


Figure 124: The overview document Excel file as opened on an Apple computer

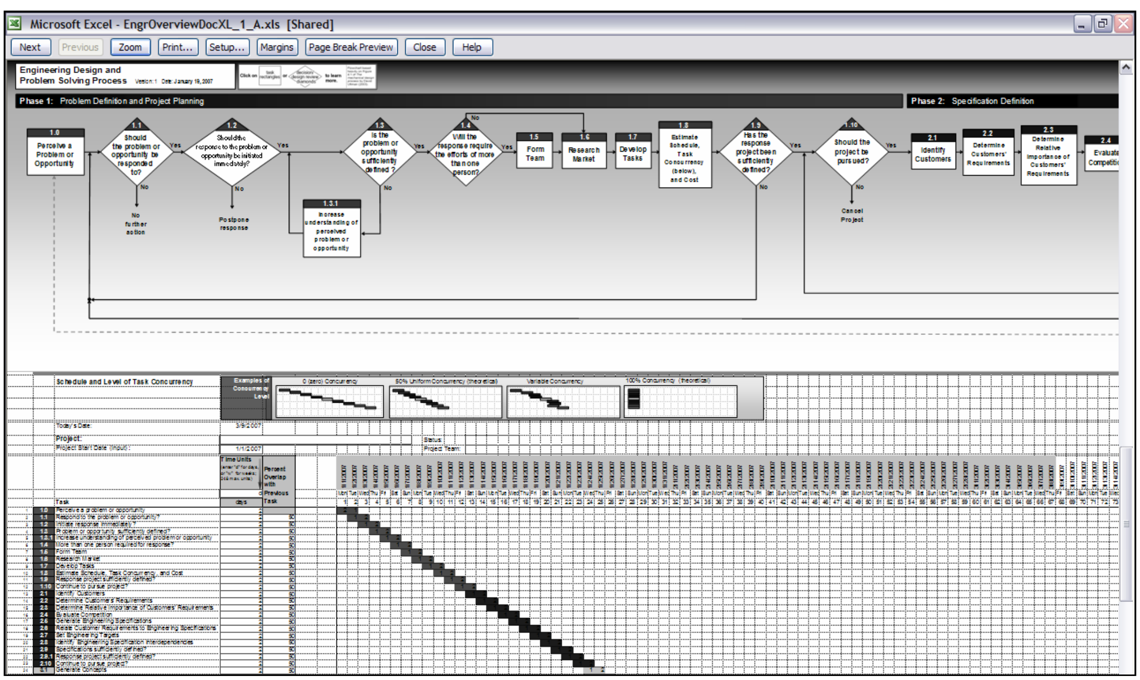


Figure 125: A portion of the Main Page as viewed in black and white

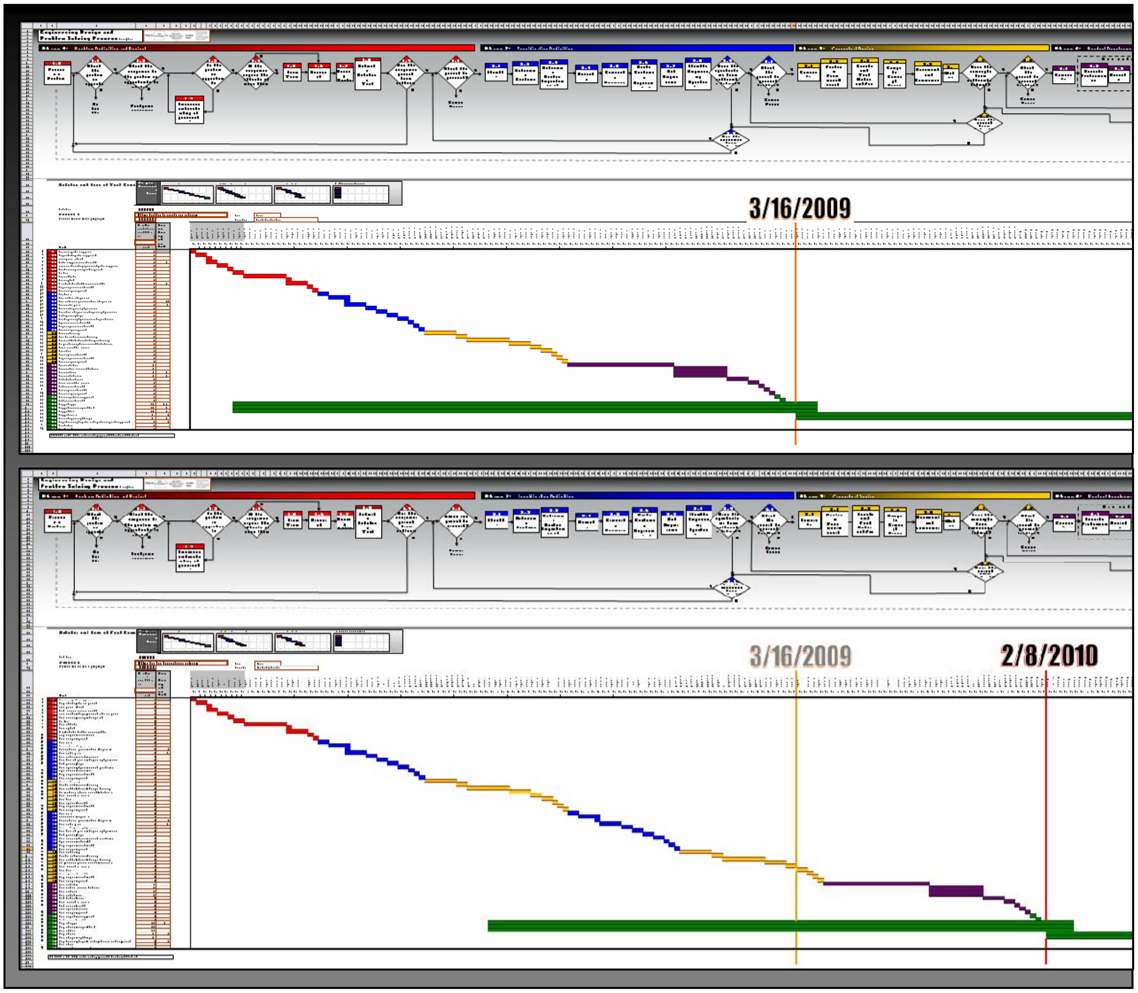


Figure 126: The impact of repeating Phases 2 and 3 upon the completion date of a hypothetical project

3.3 The Design Problem

Prior to identifying a particular design problem for the experiment, the characteristics of situations in which the engineering design and problem solving process is used were defined. Potential problems could then be checked for the presence of these characteristics. The seven characteristics are:

1. A given dynamic physical environment
   (consisting of matter and energy, with information
   being made-up of matter and energy)
   is transformed...

2. ...through the intentional...

3. ...and systematic...

4. ...not obvious...

5. ...application of scientific and mathematical principles,...

6. ...resulting in an altered physical environment,
including the mental and emotional states of humans,
that was perceived prior to the alteration
as preferable to the physical environment
that was perceived prior to the alteration
would have existed without the alteration,...

7. ...with the particular characteristics of the alteration being,
initially, poorly defined.

Notably, design involves a lack of clarity with respect to the application of principles and, at the start, what the characteristics of the resulting alteration will be. This uncertainty stems from a defining feature of design problems – they are ill-defined (Ullman, 2003).

The design problem used in the experiment was selected from four potential problems. All four related to passenger airline flight. The chosen problem was based on current events. More specifically, the possible introduction of cell phone use during entire airline flights was considered. Of the news articles found describing the opportunity and associated problems, four were chosen, and copies were provided to the design teams in the experiment. Also, some Federal Aviation Regulations (or FARs) were provided. It is worth also noting that the design problem was not stated in the form of, 'Redesign a _____,' or 'Come up with a thing that does [this], [that], and [something else]'. The intentional ambiguity was to make the design situation more realistic.

3.4 The Subjects

Senior level undergraduate Oregon State University students were recruited for the experiment. More specifically, the students recruited had majors that might be represented on a non-academic multi-disciplinary engineering design team. A minimum of six subjects were needed to participate in the three person control group and the three person experimental treatment group. Four majors were recruited: 1) Mechanical Engineering (ME), 2) Industrial and

Manufacturing Engineering (IME), 3) Design and Human Environment (DHE), and 4) Exercise and Sports Science (EXSS). To help insure that at least two appropriately qualified subjects from, at least, one non-engineering major showed up to participate in an engineering department experiment, two non-engineering majors were recruited (i.e., DHE and EXSS).

Recruiting efforts included posters and emails. Forty recruiting posters were evenly divided (i.e., ten per major) and posted throughout academic buildings frequented by seniors in the recruited majors. In addition, email recruiting announcements were sent out by major departments.

Twelve potential subjects showed up for the recruiting meeting, with eleven choosing to be considered for participation after reviewing the Informed Consent Document. Potential subjects filled-out pre-experiment surveys. They were also informed that notification of selection or non-selection would occur by email.

3.5 The Setting

Two unoccupied faculty offices were found and reconfigured with similar furnishings into design team project rooms. The rooms included the following: two tables, one desk, three chairs, three pads of paper, four new mechanical pencils (as well as other office supplies), one clock, one set of thirty references (including a dictionary), and one computer (i.e., a PC) with software limited to five Microsoft Office programs and a calculator. Notably, the computers were intentionally set-up to be isolated; that is, with no Internet connection. Included in the experimental group room was the experimental treatment of an engineering design and problem solving process overview document set, made up of: 1) two Excel files (one blank, and one a partial hypothetical example project), 2) a three-ring notebook version, and 3) a large poster.

Additionally, the windows of the rooms were mostly covered with dark window tinting and black construction paper to limit the ability of those outside of the building to see into the rooms. Similarly, a tall bookshelf was positioned close to the door of each room. While serving as storage places for provided office supplies, the shelves' primary purpose was to obstruct the views of the far walls as individuals entered the rooms or exited. Since the two rooms differed significantly inside from a visual standpoint, due to the presence of a large poster in one and a blank wall in the other, obstructing views was deemed as a necessary precaution against contamination. Figure 127, on the next page, shows the layout of the furniture in the rooms. The experimental treatment difference is evident in the two video-image mosaic illustrations of

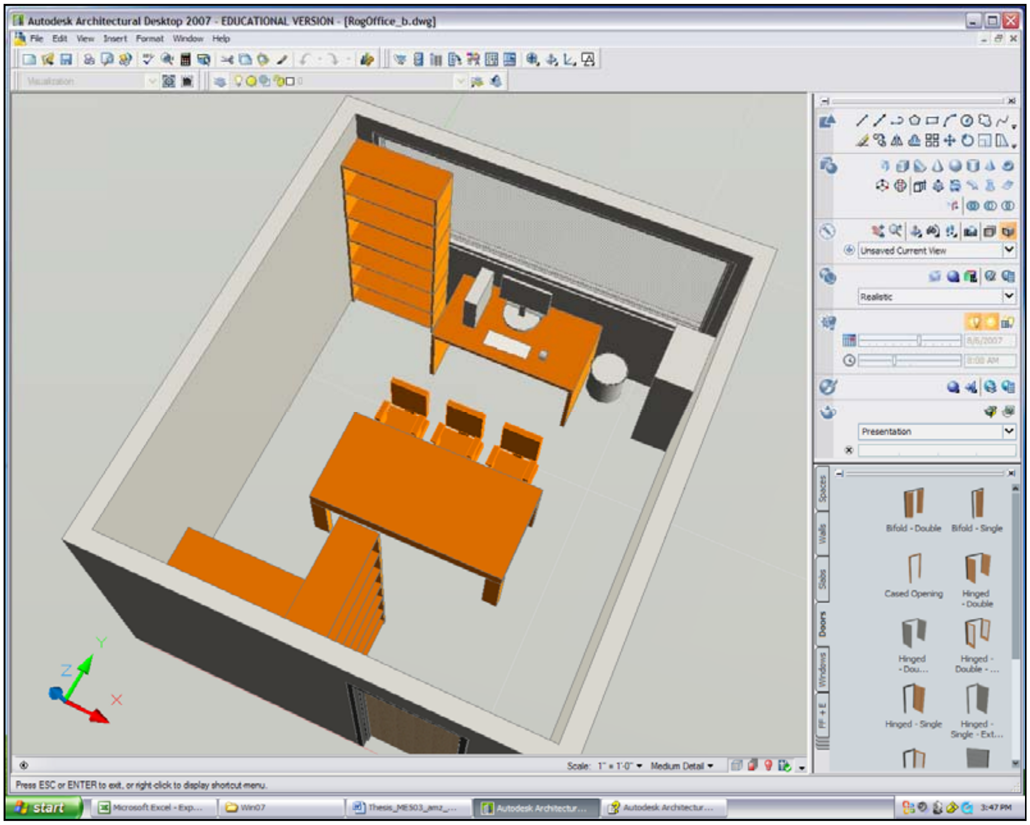


Figure 127: A model of the furniture lay-out in the two experimental rooms

the actual experimental set-ups in Figure 128, on the next page.

The reference book sets had five primary characteristics. First, design process books and other basic mechanical engineering references (i.e., statics, dynamics, etc.) were included. Second, at least two references that are specific to each of the other three recruited majors were included. DHE majors would find two interior design books, for example. Third, a few references more specific to the design problem (e.g., an acoustical engineering book) were provided. Fourth, a spiral bound set of articles and course notes referenced in the overview document were included in both reference sets (though not explicitly referring to that document). In fact, books and articles referenced in the overview document were provided to both groups. Lastly, the two sets were identical as was possible. Both sets of references had the same version of each book, with one exception. (Efforts to obtain two copies of one statics text prior to the start of the experiment were not successful.) Figure 129, on page 81, shows images of the two reference sets. A complete listing of the references used is presented in Table 3.1 (see page 82).

Figure 128: Video-image mosaic illustrations of the experimental room set-ups (control, top)

3.6 The Procedure

After the recruiting meeting, the number of potential subjects was reduced to nine, due to a graduate student status and missing contact information. Those remaining were then divided into three groups in two steps; with the criterion for the first step being major. Priority for major selection was (from highest to lowest): 1) ME, 2) IME, 3) DHE, and 4) EXSS. The second step was based on the combination of GPA and project team experience level. This process yielded three pools of two or more potential subjects, from which three balanced-pairs (i.e., one pair from each pool) were selected using probabilistic methods. Coin tosses for each pair then determined group assignments. Subject selection resulted in each three-person design team having two Mechanical Engineering majors and one Design and Human Environment major.

After receiving email notification of selection, each trio of subjects met at the site of their designated project team room. Initial meetings were about thirty minutes in length. The starts of the two meetings were staggered by one hour, with the experimental treatment group meeting occurring second. (The control group meeting was expected to be shorter and less likely to run-over.)

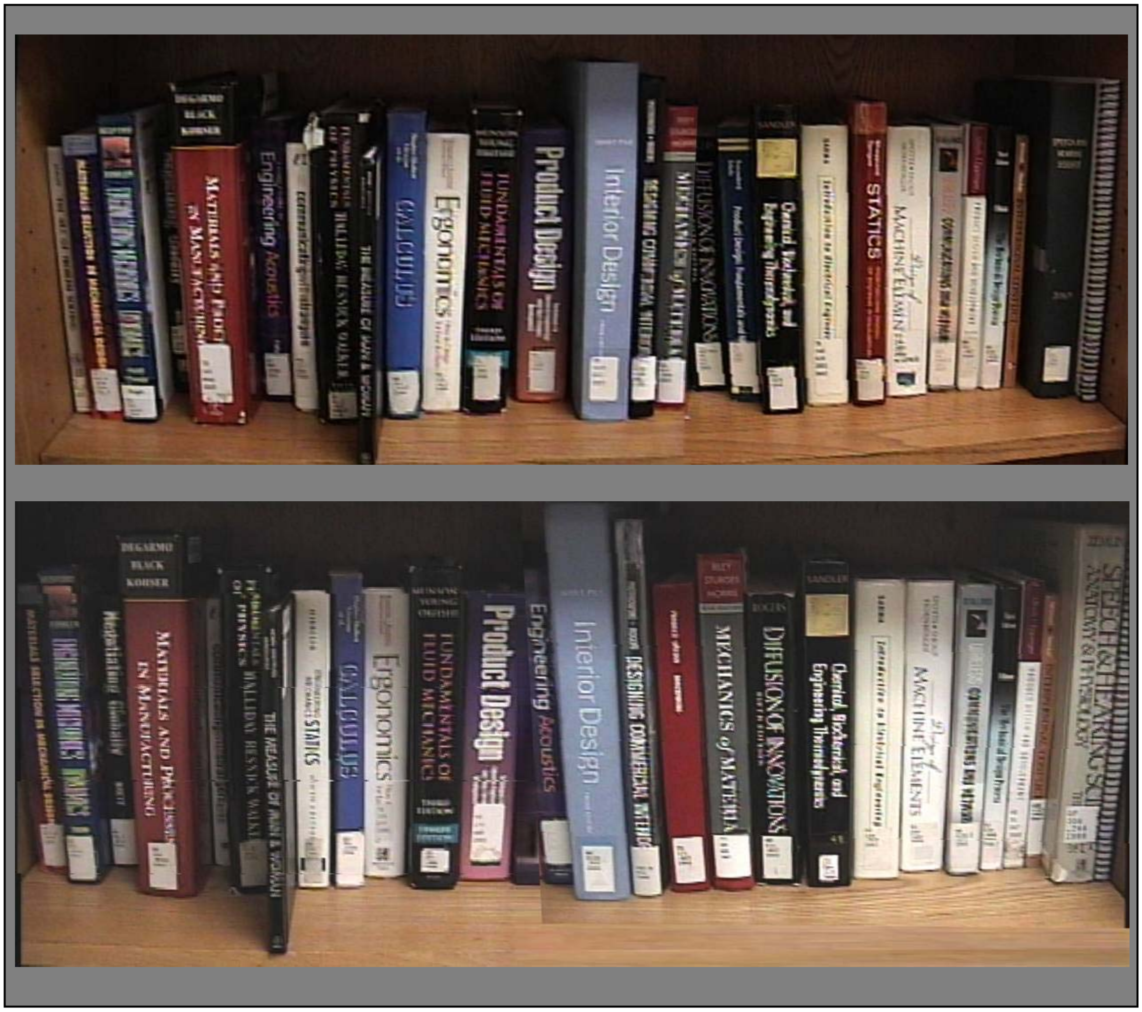


Figure 129: Video-image mosaic illustrations of the two reference sets (control, top, and experimental treatment, bottom) (Note: these are post-experiment images, taken after some quick book re-shelving by the experimenter, in which the book arrangements may not be in the start-of-the-experiment alphabetical order by author)

During the initial group meetings, each group was instructed that they are a new product design team at an aircraft interior product company. Each group's attention was directed towards a folder which was described as having a print-out of an email from their boss and other information. That other information included the four news articles, the federal regulations, and a diagram of a passenger airplane interior with dimensions.

The group members were further instructed that they were to work together a total of twenty hours in the project room over the next two weeks (which were during February 2007). In addition, they were to reach a consensus solution that they would submit, in person, in their project rooms at the same time of day as the initial meeting. They were provided forms and

Table 3.1: Reference books provided to the two groups in the design experiment

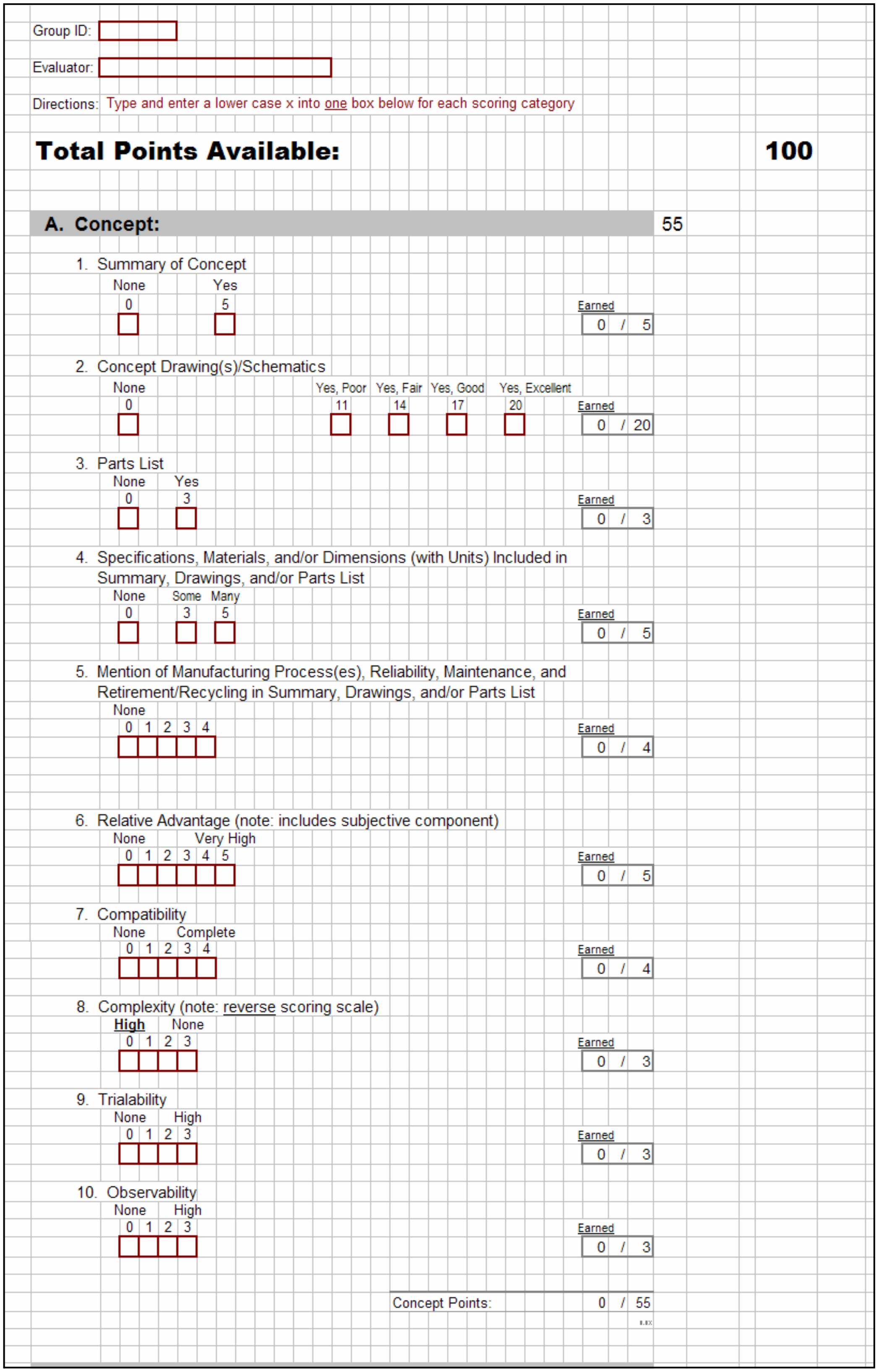
Item #	Author(s)	Title	Publisher	Year	Ed.	Control Group	Experimental Treatment Group
	References Used in Design Experiment					Included In Set for:	
1	Ackoff, R. L.	**The art of problem solving: Accompanied by Ackoff's fables**	New York: Wiley	1978		✓	✓
2	Ashby, M. F.	**Materials selection in mechanical design**	Oxford ; Boston: Butterworth-Heinemann	1999	2nd	✓	✓
3	Bedford, A.& Fowler, W.	**Engineering mechanics : Dynamics**	Upper Saddle River, N.J.: Prentice Hall	2002	3rd	✓	✓
4	Brett, J. M.	**Negotiating globally : How to negotiate deals, resolve disputes, and make**	San Francisco: Jossey-Bass	2001	1st	✓	✓
5	Degarmo, E. P.; et al.	**Materials and processes in manufacturing**	New York: Wiley	2003	9th	✓	✓
6	Fahy, F.	**Foundations of engineering acoustics**	San Diego, Calif.: London: Academic	2001		✓	✓
7	Gudykunst, W. B. & Kim, Y. Y.	**Communicating with strangers : An approach to intercultural communication**	Boston: McGraw-Hill	2003	4th	✓	✓
8	Halliday, David; et al.	**Fundamentals of physics**	New York: Wiley	1997	5th	✓	✓
9	Hughes-Hallett, D.; et al.	**Calculus**	New York: Wiley & Sons	1994		✓	✓
10	Hibbeler, R. C.	**Engineering mechanics: Statics**	Upper Saddle River, NJ: Prentice Hall	2001	9th		✓
11	Kay, D. A.	**Trigonometry**	Lincoln, Neb.: Cliffs Notes	1994	1st	✓	✓
12	Kroemer, K. H. E.; et al.	**Ergonomics : How to design for ease and efficiency**	Englewood Cliffs, NJ: Prentice Hall	1994		✓	✓
13		**The Merriam-Webster Dictionary** [paperback]	Springfield, MA: Merriam-Webster, Incorporated	2004		✓	✓
14	Munson, B. R.; et al.	**Fundamentals of fluid mechanics**	New York: John Wiley	1998	3rd update	✓	✓
15	Otto, K. N.& Wood, K. L.	**Product design : Techniques in reverse engineering and new product development**	Upper Saddle River, NJ: Prentice Hall	2001		✓	✓
16	Pile, John F	**Interior design**	New York: Harry N. Abrams	2003	3rd	✓	✓
17	Piotrowski, C. & Rogers, E. A.	**Designing commercial interiors**	New York: John Wiley	1999		✓	✓
18	Riley, W. F.; et al.	**Mechanics of materials**	Hoboken, N.J.: John Wiley	2007	6th	✓	✓
19	Rogers, E. M.	**Diffusion of innovations**	New York: Free Press	2003	5th	✓	✓
20	Roozenburg, N. F. M. & Eekels. J.	**Product design : Fundamentals and methods**	Chichester; New York : Wiley	1995		✓	✓
21	Sandler, S. I.	**Chemical, biochemical, and engineering thermodynamics**	Hoboken, NJ: John Wiley & Sons	2006	4th	✓	✓
22	Sarma, M. S.	**Introduction to electrical engineering**	New York: Oxford University Press	2001		✓	✓
23	Sheppard, S.; et al.	**Statics : Analysis and design of systems in equilibrium**	Hoboken, NJ: Wiley	2007		✓	
24	Spotts, M. F.; et al.	**Design of machine elements**	Upper Saddle River, N.J.: Pearson Prentice Hall,	2004	8th	✓	✓
25	Stallings, W.	**Wireless communications and networking**	Upper Saddle River, N.J.: Prentice Hall	2002		✓	✓
26	Tilley, A. R.	**The measure of man and woman : Human factors in design**	New York: Wiley	2002	Rev.	✓	✓
27	Ullman, D. G.	**The mechanical design process**	Boston, Ma.: McGraw-Hill	2003	3rd	✓	✓
28	Ulrich, K. T.; & Eppinger, S. D.	**Product design and development**	Boston: Irwin/McGraw-Hill	2000	2nd	✓	✓
29	Wilmot, W. W.; & Hocker, J. L.	**Interpersonal conflict**	Boston, MA: McGraw-Hill	2001	6th	✓	✓
30	Zemlin, W. R.	**Speech and hearing science : Anatomy and physiology**	Englewood Cliffs, N.J.: Prentice-Hall	1988	3rd	✓	✓
31		**[Articles and Notes]**				✓	✓

asked to maintain daily journals documenting their work. The experimental treatment group had journal items referring to the overview document, while the control group did not. Also, the groups were provided a key for their project room door. They were told to use the room during regular building hours (i.e., 7:00 AM to 12:00 midnight). Further, they were told to keep the project to themselves, and instructed to use any of the reference materials provided in the project room. Again, for the treatment group, the reference set included the overview document set, which was described and demonstrated to them for about fifteen minutes. The brief presentation included a look at both the unaltered overview document Excel file, and the partially altered hypothetical project Excel file.

During the next two weeks, the groups worked by themselves to accomplish their task.

After the two weeks, the groups met in their respective project rooms and submitted the results of their efforts, including journals. Subjects then completed a post-experiment survey. The survey requested responses to twenty-five statements. Some of the statements on the experimental group survey referred to the overview document, while the control group's did not. After questions were answered, the subjects were reminded of payment arrangements, asked not to talk about the experiment to other students for the next twenty-four hours (so as to avoid 'contaminating' other subjects who had yet to complete their participation), thanked, and released.

Concept scoring and data analysis began the next day. Identification of the 'best concept' was to be based on scored evaluations of: 1) information provided necessary for making the concept a reality, 2) concept characteristics related to the diffusion of innovations, and 3) captured design knowledge. A total of one-hundred points was available. Fifty-five of those points were for the concept and forty-five were for evidence of design work. The concept points were further sub-divided into thirty-seven points for information needed to turn the concept into reality, and eighteen for innovation diffusion characteristics. The thinking behind the scoring is as follows: an excellent concept without evidence (55-points) is worth more than evidence of excellent groundwork (i.e., captured knowledge) without a concept (45-points), which is better than a poor concept without evidence (37-points). Figure 130, which begins on the next page, shows an image of the Excel file scoring sheet. Also, the scoring criteria for design work evidence (i.e., the number of customers identified, etc.) is based on the assumption that doing QFD-like steps are better for design than not doing them. The best concept was determined by averaging the scores of three evaluators (i.e., the thesis major advisor, thesis major co-advisor, and student researcher).



Group ID:

Evaluator:

Directions: Type and enter a lower case x into one box below for each scoring category

Total Points Available: **100**

A. Concept: 55

1. Summary of Concept

None	Yes	
0	5	Earned 0 / 5

2. Concept Drawing(s)/Schematics

None	Yes, Poor	Yes, Fair	Yes, Good	Yes, Excellent	
0	11	14	17	20	Earned 0 / 20

3. Parts List

None	Yes	
0	3	Earned 0 / 3

4. Specifications, Materials, and/or Dimensions (with Units) Included in Summary, Drawings, and/or Parts List

None	Some	Many	
0	3	5	Earned 0 / 5

5. Mention of Manufacturing Process(es), Reliability, Maintenance, and Retirement/Recycling in Summary, Drawings, and/or Parts List

None

0 1 2 3 4 — Earned 0 / 4

6. Relative Advantage (note: includes subjective component)

None — Very High

0 1 2 3 4 5 — Earned 0 / 5

7. Compatibility

None — Complete

0 1 2 3 4 — Earned 0 / 4

8. Complexity (note: reverse scoring scale)

High — None

0 1 2 3 — Earned 0 / 3

9. Trialability

None — High

0 1 2 3 — Earned 0 / 3

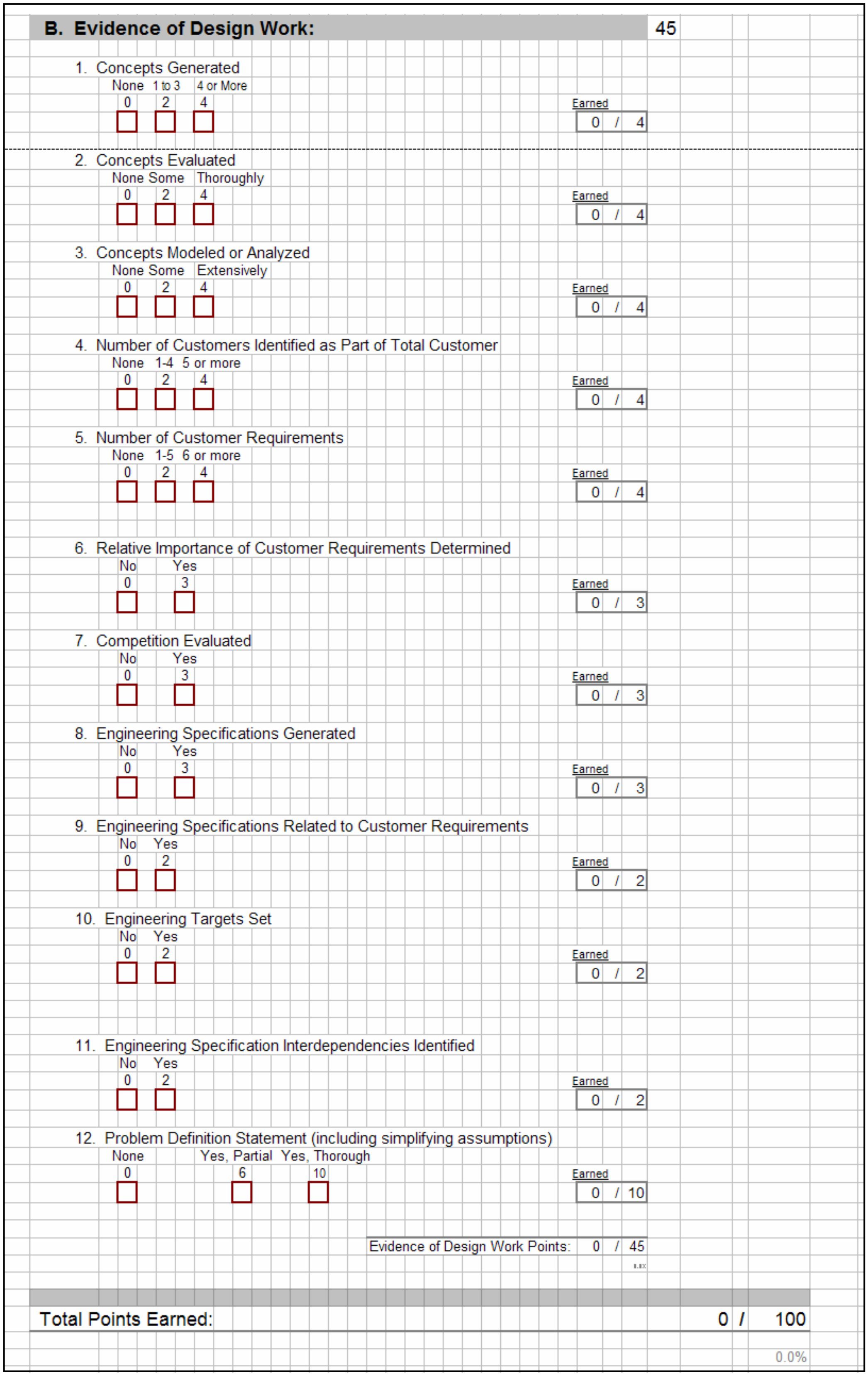
10. Observability

None — High

0 1 2 3 — Earned 0 / 3

Concept Points: 0 / 55

Figure 130 (part 1 of 2): The Excel file for scoring the best design concept



B. Evidence of Design Work: 45

1. Concepts Generated
   None 0 | 1 to 3 2 | 4 or More 4 — Earned 0 / 4

2. Concepts Evaluated
   None 0 | Some 2 | Thoroughly 4 — Earned 0 / 4

3. Concepts Modeled or Analyzed
   None 0 | Some 2 | Extensively 4 — Earned 0 / 4

4. Number of Customers Identified as Part of Total Customer
   None 0 | 1-4 2 | 5 or more 4 — Earned 0 / 4

5. Number of Customer Requirements
   None 0 | 1-5 2 | 6 or more 4 — Earned 0 / 4

6. Relative Importance of Customer Requirements Determined
   No 0 | Yes 3 — Earned 0 / 3

7. Competition Evaluated
   No 0 | Yes 3 — Earned 0 / 3

8. Engineering Specifications Generated
   No 0 | Yes 3 — Earned 0 / 3

9. Engineering Specifications Related to Customer Requirements
   No 0 | Yes 2 — Earned 0 / 2

10. Engineering Targets Set
    No 0 | Yes 2 — Earned 0 / 2

11. Engineering Specification Interdependencies Identified
    No 0 | Yes 2 — Earned 0 / 2

12. Problem Definition Statement (including simplifying assumptions)
    None 0 | Yes, Partial 6 | Yes, Thorough 10 — Earned 0 / 10

Evidence of Design Work Points: 0 / 45

Total Points Earned: 0 / 100

0.0%

Figure 130 (part 2 of 2): The Excel file for scoring the best design concept

After the best concept scoring had been completed, subjects were able to pick-up payment. Subject compensation was $10.00 an hour for a total of twenty hours; so that each participant received $200.00. Additionally, a $100.00 bonus was given to each member of the group that generated the best concept.

Next, the design journal entries were input into a spreadsheet. Coding of responses followed the rule that the number of reference acts would be scored as the average of the values in the range selected. For example, checking the circle for “4 to 6” reference acts was scored as a five. Also, “10 or more” was scored as eleven. The average number of reference acts per hour for each journal item was calculated for each subject. Statistical summaries were prepared and the hypotheses tests conducted. Responses to the post-experiment survey, including items related to the research questions, were also input into a spreadsheet and tabulated.

[Copies of the experimental protocol and other documents (i.e., recruiting items, survey instruments, news articles, etc.) are included in the Appendix.]

Chapter 4 ─ Results and Interpretation

No statistically significant difference was found for either of the two hypotheses tests. In turn, neither null hypothesis can be rejected. In the first of the four chapter sections, these results are clarified. Next, the answers to the research questions, which are based on responses to post-experiment surveys, are presented. The third section provides other feedback data. Lastly, the scored results of the two team design efforts are summarized.

4.1 Hypotheses Tests

The results for the second journal question about clarification of procedures will be presented first. Next, the results for question 3 about the analysis of the problem or task are provided.

4.1.1 Results for Clarifying Procedures (i..e., Journal Question 2)

4.1.1.1 Summary of Statistics

Table 4.1, below, presents reference acts per hour to clarify procedures for each subject in the two groups. All control subjects reported less than one reference act per hour, while two treatment subjects reported more than one per hour. The control group average, or mean, was 0.6833, with a standard deviation of 0.2041; while the treatment group's average was 1.3453, with a standard deviation of 0.5273. The observed difference between the sample means (*xbar1-xbar2*) is -0.662. More summary statistics are shown in Table 4.2, on the next page. A box-plot and frequency histogram of the data are shown in Figures 131 and 132, respectively (which are also on the next page).

Table 4.1: Reference acts per hour, for each subject in both groups, with respect to clarification of procedures (i.e., journal question 2)

Q2 Cntrl	Q2 Expr
0.8500	1.4884
0.6000	0.7612
0.6000	1.7863

Table 4.2: Summary statistics with respect to clarification of procedures (question 2)

Group Number	Group	Count, n	Mean, $\bar{x}$	Median, M	Standard Deviation, S	Variance, S^2	Minimum	Maximum
1	Control	3	0.6833	0.6833	0.2041	0.0415	0.60	0.85
2	Experimental Treatment	3	1.3453	1.4900	0.5273	0.2781	0.76	1.79

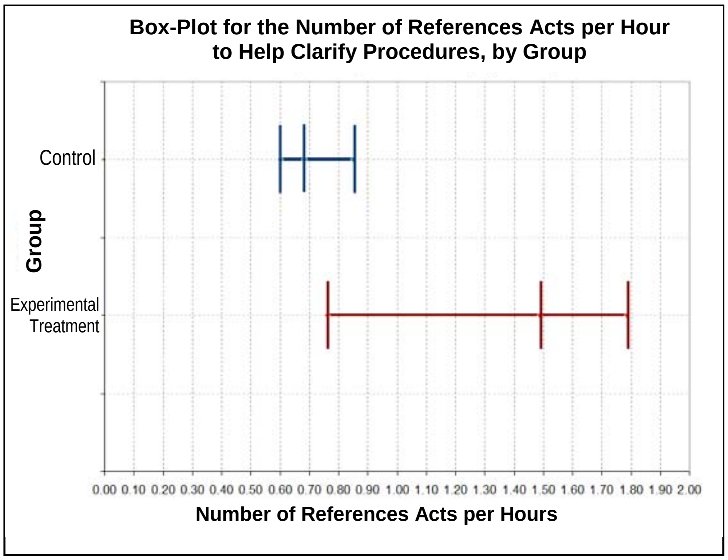


Figure 131: Box-plot of clarification of procedures data

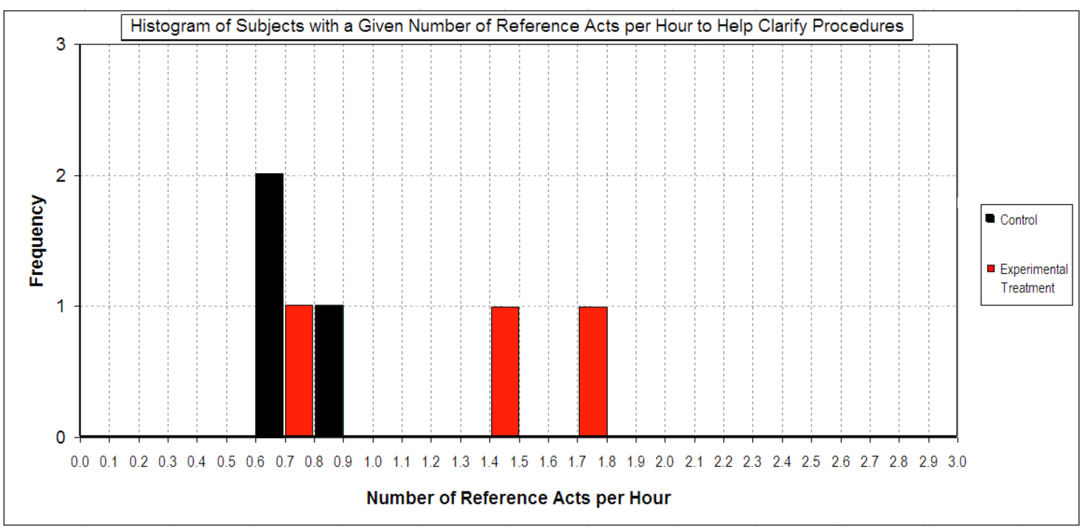


Figure 132: Frequency histogram of clarification of procedures data

4.1.1.2 Assumptions

Four primary assumptions were made for the hypothesis test. First, the study subjects were randomly assigned to the groups. All subjects were given identical instructions, so it is assumed that the study is unbiased. Third, there is symmetric data distribution for both groups and no outliers. Fourth, with sample sizes of three per group, it cannot necessarily be assumed that the sampling distribution of (*xbar1-xbar2*) is normal. In this case, normalcy is assumed. If the sample sizes were on the order of thirty, the normalcy of the sampling distributions is readily assumable, even if some skewness is evident in the data distributions. An F_{max} test for equality of variances must be performed before an assumption can be made that the two population variances are equal (LeBlanc, 2004).

4.1.1.3 Hypothesis Test

4.1.1.3.1 F_{max} test

An F_{max} was calculated of 6.67. For a level of significance, α, of 0.05, two groups and two degrees of freedom (*df*), the $F_{max\_critical}$ is equal to 39.0 (LeBlanc, 2004). Since the calculated F_{max} is smaller than the $F_{max\_critical}$, the pooled-variance two-sample *t*-test is most appropriate.

4.1.1.3.2 Statement of hypotheses

For a one-tailed test, the hypotheses are:

H_o: $(\mu_1-\mu_2) = 0$

H_a: $(\mu_1-\mu_2) < 0$

The null hypothesis is that the average communicative acts to help clarify procedures by the control group and the experimental treatment group are equal; that is, the difference between the two is equal to zero. An alternative hypothesis is that the number acts exhibited by the treatment group is greater than that for the control group.

4.1.1.3.3 Sampling distribution of (xbar1-xbar2)

The error distribution for the difference of the sample means was assumed to be equal to zero. Spread of the distribution was calculated to be 0.326. The shaded area in the sampling distribution in Figure 133 shows the corresponding one-tailed *p*-value.

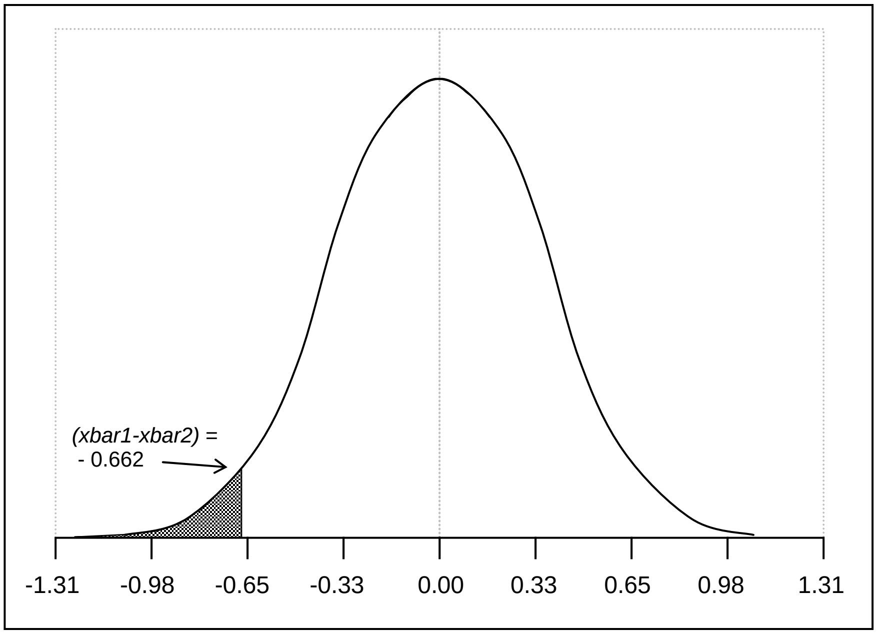


Figure 133: Probability distribution shape for clarification of procedures data hypothesis test

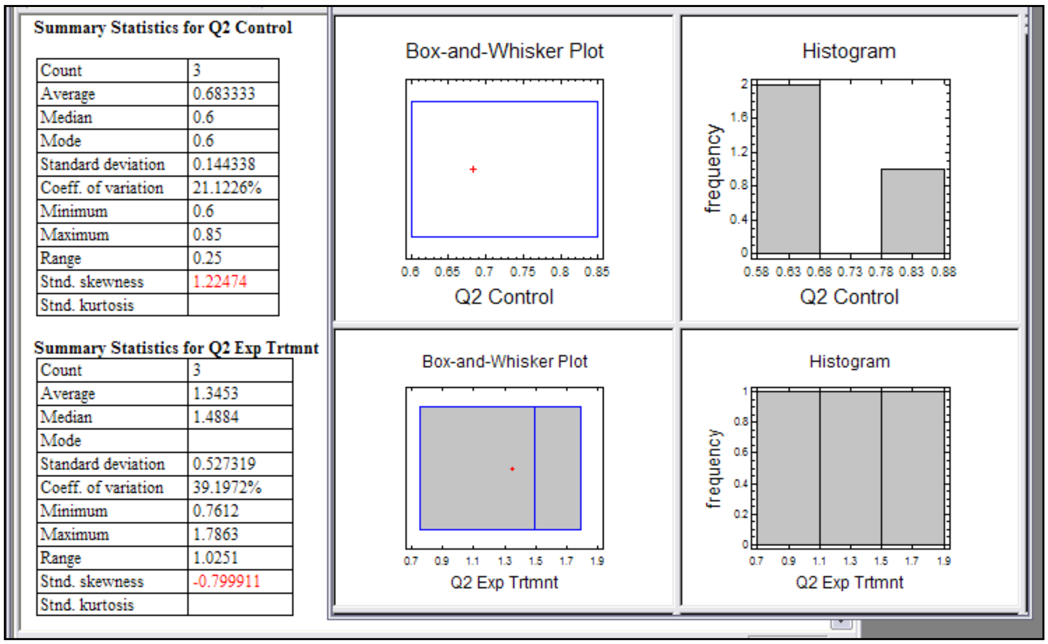
4.1.1.3.4 Test of significance

The calculated test statistic, or t_{test}, was -2.028. For a t_{test} statistic of |-2.028| and two degrees of freedom, the *p*-value of approximately 0.08 is obtained (LeBlanc, 2004).

This result is interpreted as indicating that the observed difference between the two sample means (*xbar1*-*xba*r2) of -0.662 is 2.028 times larger than the expected difference due to random variation. A difference as great as that observed resulting from random variation has a probability of about $p = 0.08$ or 8-percent. The result is not statistically significant. Put differently, there is insufficient evidence to reject the null hypothesis, H_o, that the population means are equal (i.e., μ_1-μ_2 = 0).

4.1.1.3.5 Double Check

As a double check of the statistical analysis, the data was input into, and analyzed with, Statgraphics statistical software. Figure 134, below, includes the resulting summary statistics and graphical representations. Output of the hypothesis test is shown in Figure 135, also below. The calculated *t*-test statistic and *p*-value were comparable to those determined previously, and reinforce the inability to reject the null hypothesis.



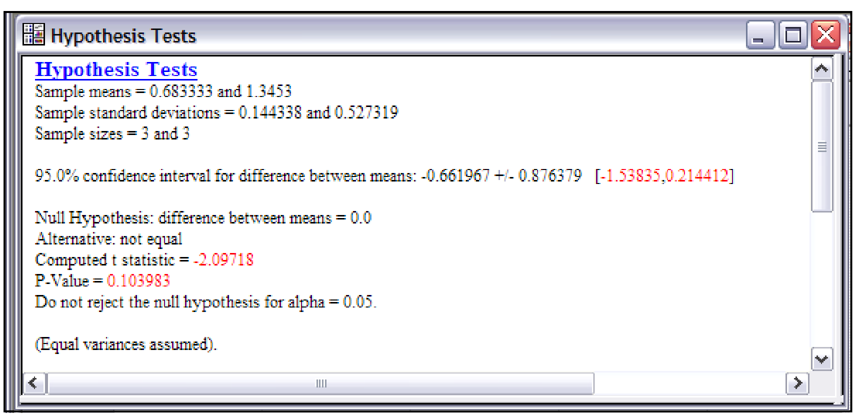
Summary Statistics for Q2 Control

Count	3
Average	0.683333
Median	0.6
Mode	0.6
Standard deviation	0.144338
Coeff. of variation	21.1226%
Minimum	0.6
Maximum	0.85
Range	0.25
Stnd. skewness	1.22474
Stnd. kurtosis	

Summary Statistics for Q2 Exp Trtmnt

Count	3
Average	1.3453
Median	1.4884
Mode	
Standard deviation	0.527319
Coeff. of variation	39.1972%
Minimum	0.7612
Maximum	1.7863
Range	1.0251
Stnd. skewness	-0.799911
Stnd. kurtosis	

Figure 134: Statistical summary and graphical representations of clarification of procedures data, as done in Statgraphics software



Hypothesis Tests

Hypothesis Tests
Sample means = 0.683333 and 1.3453
Sample standard deviations = 0.144338 and 0.527319
Sample sizes = 3 and 3

95.0% confidence interval for difference between means: -0.661967 +/- 0.876379 [-1.53835,0.214412]

Null Hypothesis: difference between means = 0.0
Alternative: not equal
Computed t statistic = -2.09718
P-Value = 0.103983
Do not reject the null hypothesis for alpha = 0.05.

(Equal variances assumed).

Figure 135: Hypothesis test of clarification of procedures data, as done in Statgraphics software

4.1.2 Results for Analyzing the Problem or Task (i.e., Journal Question 3)

4.1.2.1 Summary of Statistics

Table 4.3, below, shows the reference acts per hour to analyze the problem or task for each subject in the two groups. One of the control subjects and two of the treatment subjects reported more than one act per hour. The control group average was 0.6833, with a standard deviation of 0.3215. An average of 1.2233 was calculated for the treatment group, as was a 0.3655 standard deviation. Also, the observed difference between the two sample means (*xbar1*-*xbar2*) is -0.540. Table 4.4, also below, provides a summary of statistics. On the next page, Figure 136 shows a box-plot, and a frequency histogram is presented in Figure 137.

Table 4.3: Reference acts per hour, for each subject in both groups, with respect to analysis of the problem or task (i.e., journal question 3)

Q3 Cntrl	Q3 Expr
1.0500	1.4884
0.5500	0.8060
0.4500	1.3740

Table 4.4: Summary statistics with respect to analysis of the problem or task (question 3)

Group Number	Group	Count, n	Mean, $\bar{x}$	Median, M	Standard Deviation, S	Variance, S^2	Minimum	Maximum
1	Control	3	0.6833	0.5500	0.3215	0.1033	0.45	1.05
2	Experimental Treatment	3	1.2233	1.3700	0.3655	0.1336	0.81	1.49

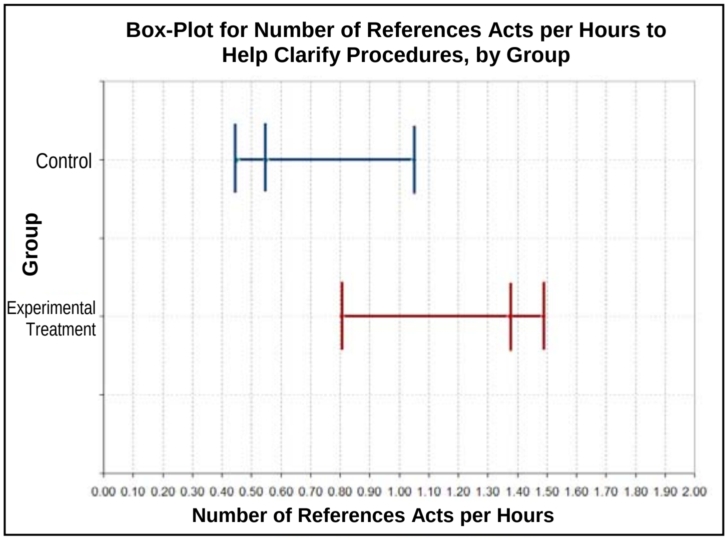


Figure 136: Box-plot of analysis of problem or task data

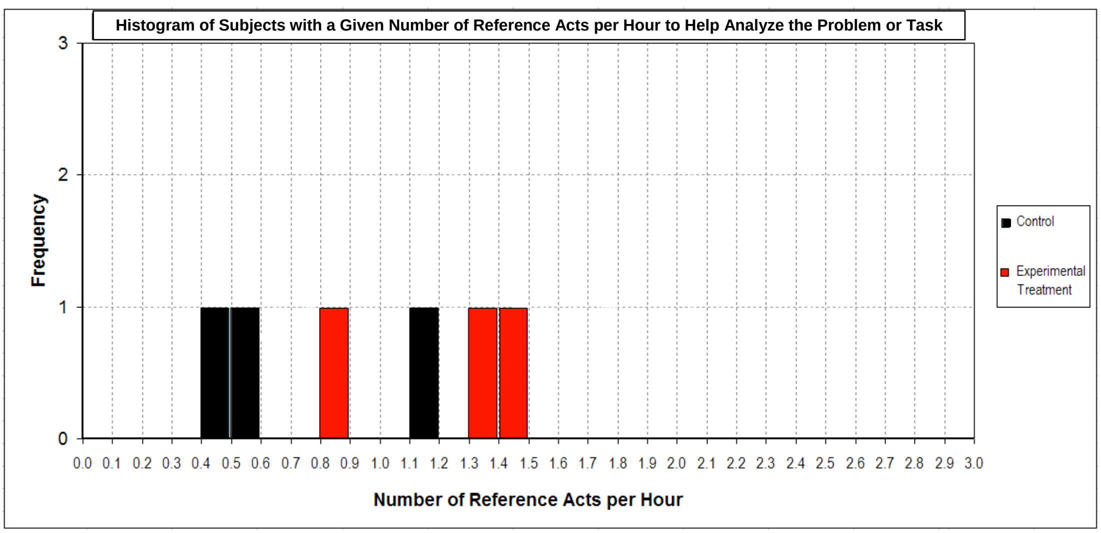


Figure 137: Frequency histogram of analysis of problem or task data

4.1.2.2 Assumptions

The assumptions made for the analysis of the data associated with question 2 were also made for question 3.

4.1.2.3 Hypothesis Test

4.1.2.3.1 F_{max} Test

An F_{max} was calculated of 1.30. Again, the $F_{max\_critical}$ is equal to 39.0. Since the calculated F_{max} is smaller than the $F_{max\_critical}$, the pooled-variance two-sample *t*-test is most appropriate.

4.1.2.3.2 Statement of hypotheses

For a one-tailed test, the hypotheses are:

H_o: $(\mu_1-\mu_2) = 0$
H_a: $(\mu_1-\mu_2) < 0$

The second null hypothesis is that the average communicative acts to help analyze the problem or task for the control group and the experimental treatment group are equal; that is, the difference between the two is equal to zero. An alternative hypothesis is that the number of acts exhibited by the treatment group is greater than the number for the control group.

4.1.2.3.3 Sampling Distribution of (xbar1-xbar2)

The error distribution for the difference of the sample means was assumed to be equal to zero. Spread of the distribution was calculated to be 0.281. The shaded area in the sampling distribution in Figure 138, on the next page, shows corresponding one-tailed *p*-value.

4.1.2.3.4 Test of Significance

The second test statistic, or t_{test}, was calculated to be -1.922. For a t_{test} statistic of |-1.922| and 2 *df*, the *p*-value of approximately 0.09 is obtained (LeBlanc, 2004).

This result is interpreted as indicating that the observed difference between the two sample means (*xbar1-xbar2*) of -0.540 is 1.922 times greater than the expected difference due to

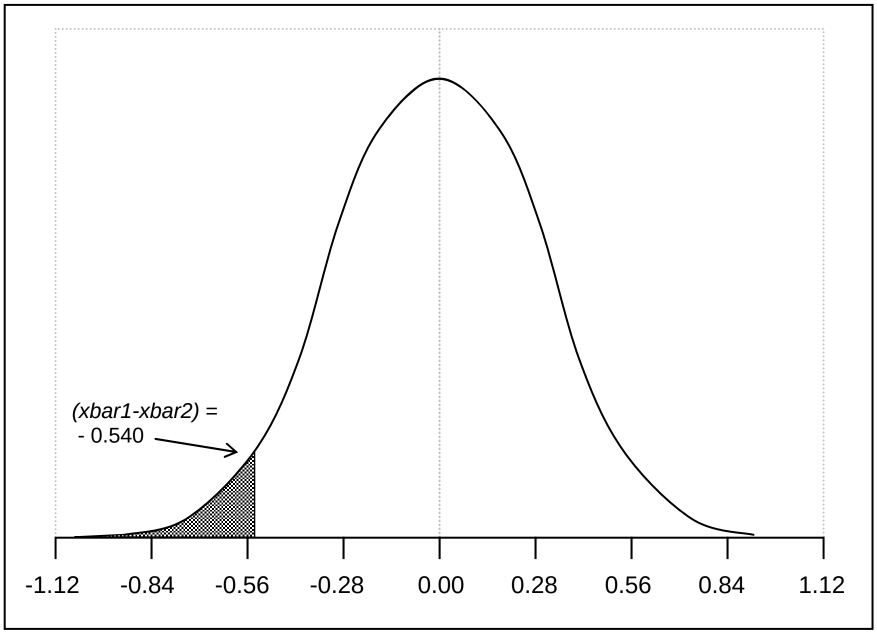
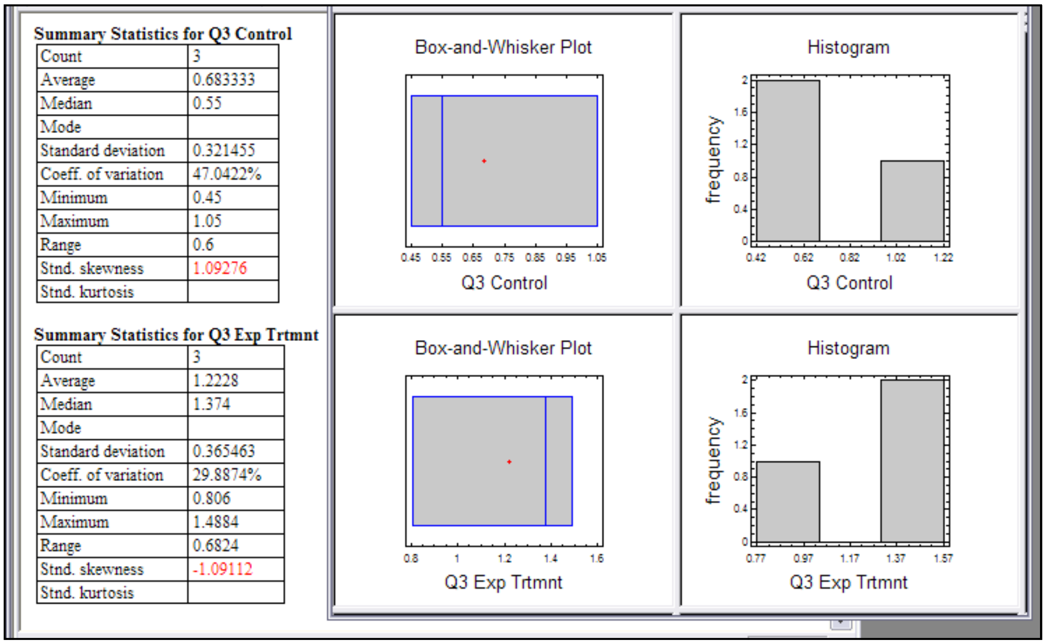


Figure 138: Probability distribution shape for analysis of problem or task data hypothesis test

random variation. A difference as great as that observed resulting from random variation has a probability of about p = 0.09 or 9-percent. The second result is not statistically significant. Put differently, there is insufficient evidence to reject the null hypothesis, H_o, that the population means are equal $(\mu_1\text{-}\mu_2) = 0$.

4.1.2.3.5 Double Check

The Statgraphics statistical summary and graphical plots are shown in Figure 139, on the next page. Hypothesis test results are shown in Figure 140, also on the next page. The *t*-test statistic and *p*-value are similar to those calculated previously; further clarifying that the null hypothesis cannot be rejected.



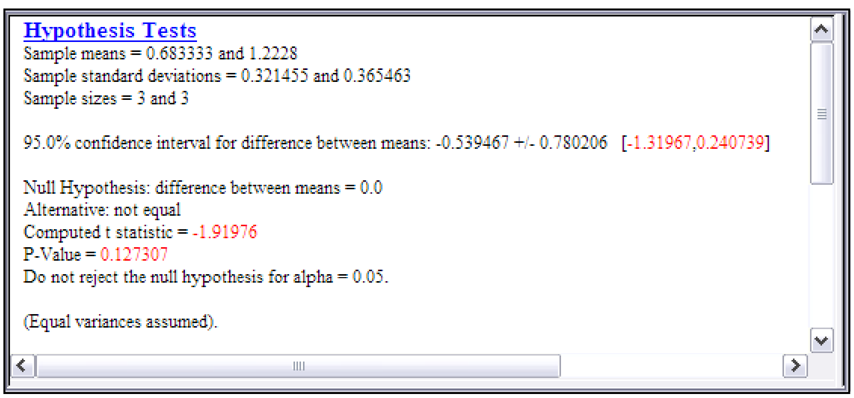
Summary Statistics for Q3 Control

Count	3
Average	0.683333
Median	0.55
Mode	
Standard deviation	0.321455
Coeff. of variation	47.0422%
Minimum	0.45
Maximum	1.05
Range	0.6
Stnd. skewness	1.09276
Stnd. kurtosis	

Summary Statistics for Q3 Exp Trtmnt

Count	3
Average	1.2228
Median	1.374
Mode	
Standard deviation	0.365463
Coeff. of variation	29.8874%
Minimum	0.806
Maximum	1.4884
Range	0.6824
Stnd. skewness	-1.09112
Stnd. kurtosis	

Figure 139: Statistical summary and graphical representations of analysis of problem or task data, as done in Statgraphics software


Hypothesis Tests
Sample means = 0.683333 and 1.2228
Sample standard deviations = 0.321455 and 0.365463
Sample sizes = 3 and 3

95.0% confidence interval for difference between means: -0.539467 +/- 0.780206 [-1.31967,0.240739]

Null Hypothesis: difference between means = 0.0
Alternative: not equal
Computed t statistic = -1.91976
P-Value = 0.127307
Do not reject the null hypothesis for alpha = 0.05.

(Equal variances assumed).

Figure 140: Hypothesis test of analysis of problem or task data, as done in Statgraphics software

4.2 Research Questions

Six statements on the experimental treatment group's post-experiment survey were tied to the five research questions related to the possible diffusion of the process overview document innovation. The responses indicate that the overview document may have some characteristics that are consistent with its diffusion. Figure 141, on the next page, shows the statements and responses from the three subjects.

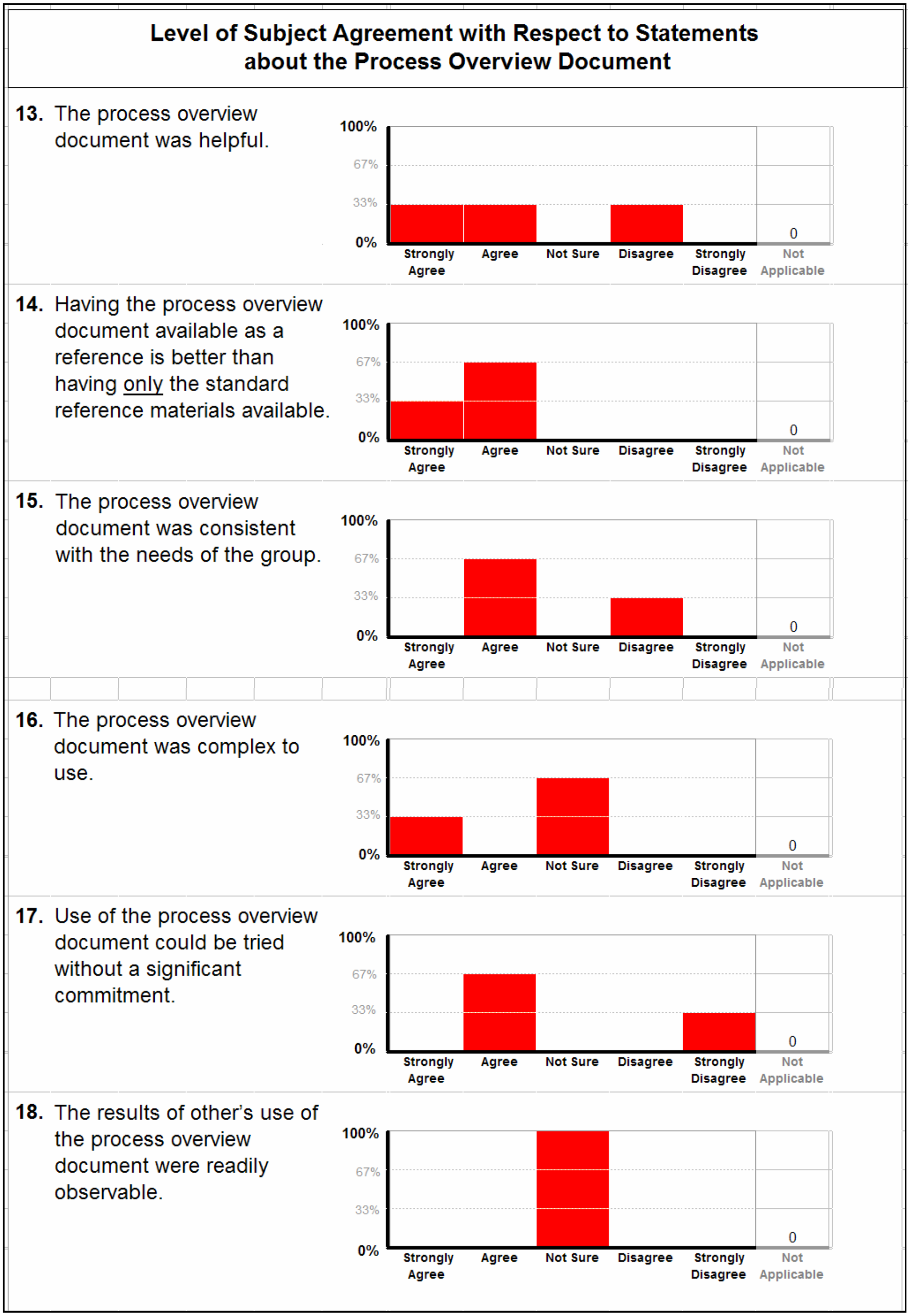


Figure 141: Responses to statements related to the diffusion of innovations

Statements thirteen and fourteen attempt to measure relative advantage, which is a characteristic that Research Question 1 seeks to assess (i.e., "Is the created process overview document perceived as having relative advantage?"). Two subjects agreed or strongly agreed that the document was helpful. All three subjects agreed (one strongly) that having the overview document available, in addition to other reference materials, is better than not having it available.

Each of the remaining four statements is linked to one of the remaining four research questions. Two subjects agreed with the statement that the document was "consistent with needs of the group," and one subject disagreed. Statement 16, about the document being complex, was strongly agreed to by one subject, and the two others were not sure. Two subjects agreed that the document could be tried without significant commitment, and one subject strongly disagreed. Finally, all three of the subjects were not sure about the Statement 18, or that the results of other's use of the document were readily observable.

4.3 Other Feedback Data

Three types of other data that provide feedback are: 1) responses to the nineteen other post-experiment survey items, 2) written comments on the subjects' post-experiment surveys, and 3) captured knowledge regarding the design process due to the overview document's change-tracking capability.

4.3.1 Other Post-Experiment Survey Responses

The primary purpose of the nineteen other statements on the post-experiment survey was to get feedback regarding the experimental model. Statements were organized into three sections: 1) the design problem, 2) the solution or response developed, and 3) the process.

Most subjects agreed (or strongly agreed) with all five statements about the design problem (see Figure 142, which begins on the next page). That is, most subjects agreed that the problem was ill-defined, that there was uncertainty regarding the solution, the problem was related to major course work, the expectation of confidentiality was realistic, and there were identifiable constraints. One statement (i.e., the confidentiality item), had no disagreement, while the others had one or two subjects disagreeing to one degree or the other.

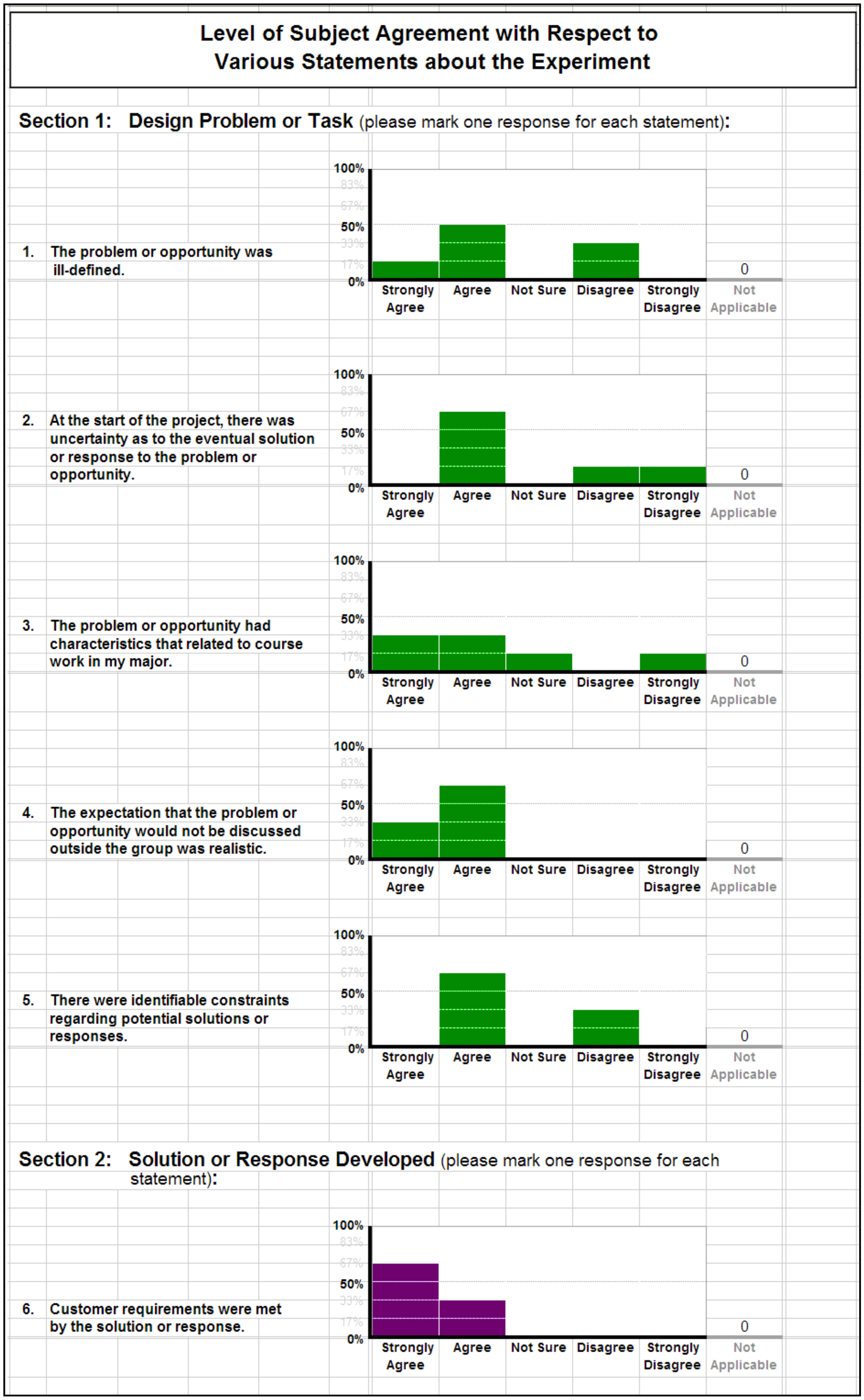


Figure 142 (part 1 of 3): Responses to statements related to the experiment

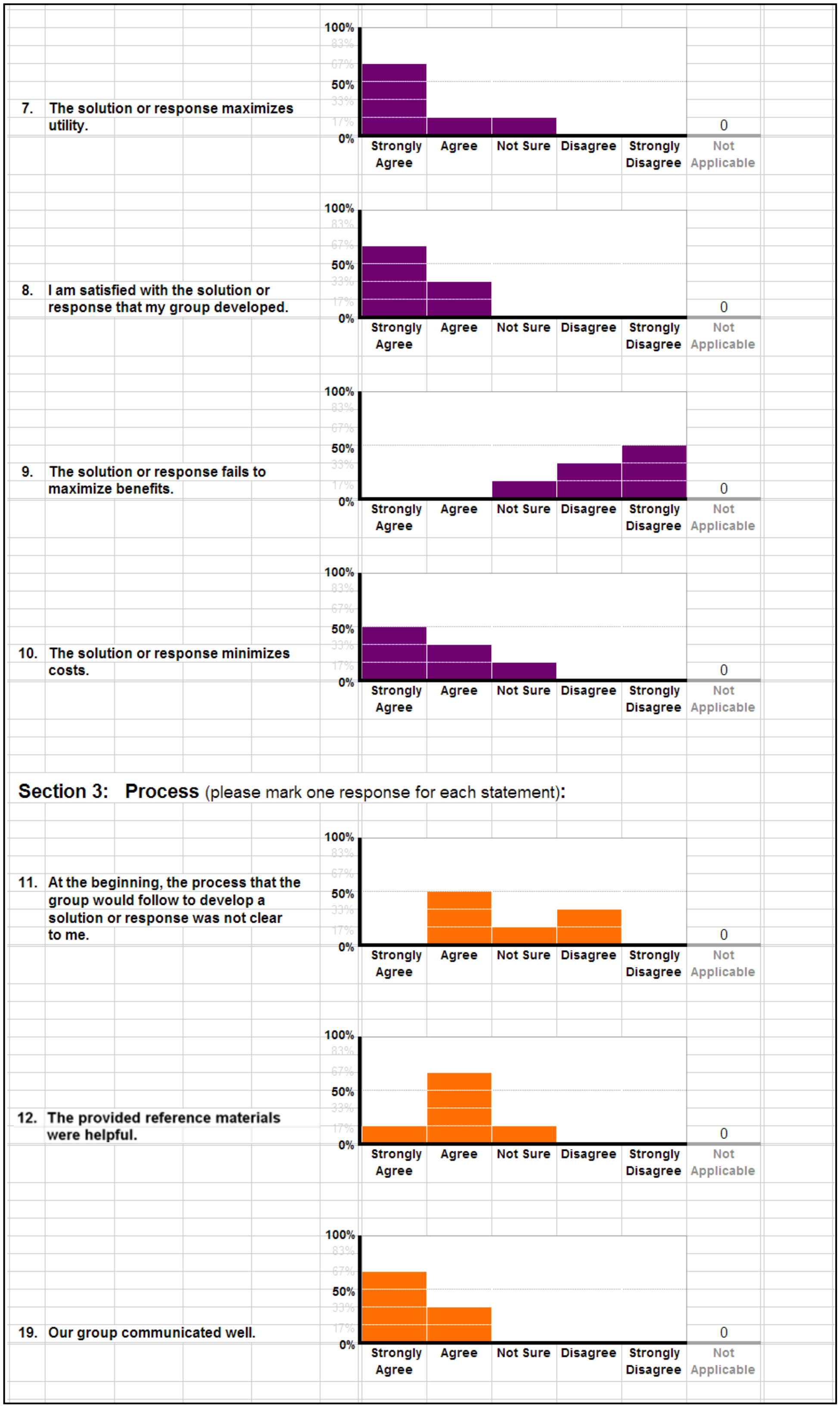


Figure 142 (part 2 of 3): Responses to statements related to the experiment

Figure 142 (part 3 of 3): Responses to statements related to the experiment

Feedback to statements regarding the solution or response developed leans heavily towards favorable perceptions of what the teams came up with. Meeting customer requirements, maximizing utility, being satisfied with the solution, and minimizing costs were all strongly agreed to by at least half of the subjects. Similarly, half of the subjects strongly disagreed with the statement that their solution failed to maximize benefits.

The remaining nine statements, which were about the process, generated some unique results. Subjects were fairly split over Statement 11, which is about procedural uncertainty at the start of the project. Most agreed, however, that the provided reference material was helpful, their group communicated well, and the journal was easy to keep. Also, subjects tended to disagree that their teams were stressed for time. The statements about information sharing and constructive groups (i.e., 22 and 23) were agreed to quite strongly. Statement 24 was a bookend statement to number 11 about procedural uncertainty. One subject agreed that the process followed to reach a solution was not clear in the end, while the others disagreed fairly strongly. The final statement, “I would be happy to work with my group again,” was the only statement to which all the subjects responded the same – 100-percent strongly agreed.

4.3.2 The Subjects’ Written Comments

Subjects were given the option to provide written comments after each of the sections of the post-experiment survey. With respect to the design problem or task, a control group subject thought that, “it was very opened ended,” and “that made for a more natural design process.” “Our group was not given a specific direction, such as whether to pursue one way or the other,” a member of the experimental treatment group adds, “however, that freedom allowed for a greater potential for ideas.” Another treatment group member states that the team took, “a fair amount of time to work through just what was being asked for,” including figuring out what their “company” did and how it fit into the problem. The third member of that same group was not sure what was expected at the end, such as the “material presented,” “level of specification,” or if it was to be a production ready product or a concept.

About the solution developed, the same control group member as was quoted first above felt that the team did a “very good job weighing the costs/benefits…and benchmarking them against other options.” The first experimental treatment team member quoted above saw the group as confronting a “huge task” to which it was “meticulous in finding solutions.” Further, the person wrote that the groups’ “multi-faceted and adaptable” design would maximize customer convenience and comfort, and airlines’ ease and profit. The second treatment group subject writes about their solution having, “[t]he beauty of modularity,” and being “highly configurable” with minimal engineering effort and using cost saving pre-existing parts.

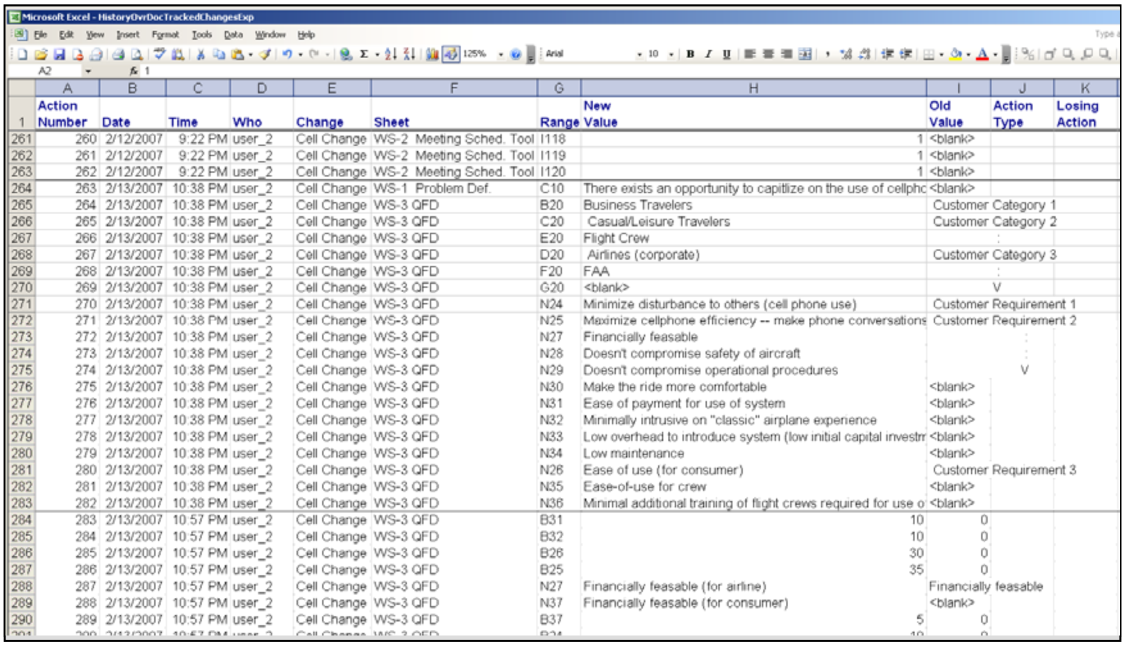
With respect to the process, a second control group member found the reference materials "varied in ease of use," with some "totally unrelated," and others, like the acoustics book, being beyond his or her level of understanding. The order of items in the journal "was a bit confusing" to the second treatment group member, who felt that the overview document items should have been listed ahead of the general reference items. "Our group was methodical, incredibly efficient, and very aware" of "customer and service provider" needs, as well as "diligent," maximizing resources available, wrote the first treatment group member. The third experimental treatment group subject, who previously expressed uncertainty about what was expected, adds the following about the process: "The spreadsheet helped a lot in stepping through the problem, instead of getting stuck near the beginning without knowing where to go."

4.3.3 Changes Tracked by the Overview Document

Again, a feature of the overview document is that changes to the shared file are tracked and can be viewed, if desired, on a history sheet or where they occurred. Experimental treatment subjects were aware of these capabilities. Further, they had also been informed that only changes that were saved are tracked.

As part of the documentation submitted by the treatment group, at the end of the experiment, was an altered overview document file. The history of changes lists 481 actions. On the evening of the initial group meeting, and saved at 9:22 PM, are 262 changes to cells in the Meeting Scheduling Tool worksheet. That worksheet allows numerous individuals to enter the times during the week that they are unavailable, and then see a display that shows times when everyone is available to possibly meet.

The next batch of saved actions is on the next night, and includes changes to the Problem Definition and QFD worksheets. Two more sets of saved changes to the QFD House of Quality follow later that same night, with the last being at 11:08 PM. Six nights later, two more sets of changes to the QFD worksheet are saved. "The history ends with the changes saved on 2/19/2007 at 5:32 PM," states a line output by the Excel file at the bottom of the tracked-change history page. Based on team time sheets, the last save of changes to the overview document occurred six-and-a-half hours into the project, or just after about 30-percent of the allocated twenty hours had elapsed. After the 19th of February, the team reports referring to overview document about forty-five more times. Figure 143, on the next page, shows some lines from the tracked history.



	Action Number	Date	Time	Who	Change	Sheet	Range	New Value	Old Value	Action Type	Losing Action
261	260	2/12/2007	9:22 PM	user_2	Cell Change	WS-2 Meeting Sched. Tool	I118	1	<blank>		
262	261	2/12/2007	9:22 PM	user_2	Cell Change	WS-2 Meeting Sched. Tool	I119	1	<blank>		
263	262	2/12/2007	9:22 PM	user_2	Cell Change	WS-2 Meeting Sched. Tool	I120	1	<blank>		
264	263	2/13/2007	10:38 PM	user_2	Cell Change	WS-1 Problem Def.	C10	There exists an opportunity to capitlize on the use of cellphc	<blank>		
265	264	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	B20	Business Travelers	Customer Category 1		
266	265	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	C20	Casual/Leisure Travelers	Customer Category 2		
267	266	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	E20	Flight Crew		:	
268	267	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	D20	Airlines (corporate)	Customer Category 3		
269	268	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	F20	FAA		:	
270	269	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	G20	<blank>		V	
271	270	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N24	Minimize disturbance to others (cell phone use)	Customer Requirement 1		
272	271	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N25	Maximize cellphone efficiency -- make phone conversations	Customer Requirement 2		
273	272	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N27	Financially feasable		:	
274	273	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N28	Doesn't compromise safety of aircraft		:	
275	274	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N29	Doesn't compromise operational procedures		V	
276	275	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N30	Make the ride more comfortable	<blank>		
277	276	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N31	Ease of payment for use of system	<blank>		
278	277	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N32	Minimally intrusive on "classic" airplane experience	<blank>		
279	278	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N33	Low overhead to introduce system (low initial capital investm	<blank>		
280	279	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N34	Low maintenance	<blank>		
281	280	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N26	Ease of use (for consumer)	Customer Requirement 3		
282	281	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N35	Ease-of-use for crew	<blank>		
283	282	2/13/2007	10:38 PM	user_2	Cell Change	WS-3 QFD	N36	Minimal additional training of flight crews required for use o	<blank>		
284	283	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	B31	10	0		
285	284	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	B32	10	0		
286	285	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	B26	30	0		
287	286	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	B25	35	0		
288	287	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	N27	Financially feasable (for airline)	Financially feasable		
289	288	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	N37	Financially feasable (for consumer)	<blank>		
290	289	2/13/2007	10:57 PM	user_2	Cell Change	WS-3 QFD	B37	5	0		

Figure 143: Some lines from the tracked changes history in the altered overview document submitted by the experimental treatment group

4.4 Evaluations of the Teams' Design Efforts

The experimental treatment group's multiple concept approach was scored higher by all three evaluators; having an average score that is nine points better than the control group average. Four different expandable module ideas, including a standing cell phone lounge and a "sky bar," were proposed by the treatment group. The control group's concept was a cell phone lounge in the back of the airplane using existing first-class seats and new components. Greater evidence of design work, in the form of a mostly completed QFD House of Quality, provided much of the scoring advantage for the experimental treatment group.

Chapter 5 – Discussion

Since only three data points were gathered from the control group and three from the experimental treatment group for the testing of each of the hypotheses, results of the experiment cannot be generalized. Otherwise, the experimental model seems to be doable, and repeatable. This chapter continues with discussion of the results. Then the discussion returns to the limitations, before moving to lessons learned and implications for further research. The implications section includes some questions that arise and the description of the second design process model developed.

5.1 Discussion of the Results

Six points of discussion begin with the experimental model. The experiment was accomplished much as it had been envisioned, including the use of multi-disciplinary design teams (i.e., ME and DHE majors). Further, the experiment had a long list of other features that added to realism. Amongst those features are: an appropriately furnished dedicated team office, with tools and supplies; a key to the room and a window; pay, plus a possible bonus; time sheets and a limit to hours put in; a project spanning weeks; a poorly-defined problem or opportunity; and an expectation of confidentiality. Also, the acquisition of communicative act data, and the hypotheses tests seem readily repeatable. Additionally, sufficient design information was created and captured to observe the designers' work and differentiate the quality of that work. However, so much data was not created so as to overwhelm researchers. All of the preceding helps establish a model.

Second, as noted above, the hypotheses tests did not reject the null. However, the power of the hypotheses tests are relatively low, due to the relatively small sample sizes. "In general, increasing the sample size is the most straightforward way to increase the probability that statistical significance will be attained *when an effect is present in the population to be discovered*" (Anderson & Finn, 1996). Put differently, the likelihood of erroneously not rejecting a false null hypothesis, that is, making a Type II error, decreases with larger sample sizes (Montgomery, 1997).

It may also be the case that reference act quantity is impacted by the *quality* of available reference material. An argument can be made that those who are not finding that which they are looking for will need more actions to find it. Similarly, a design team that is attempting to clarify a problem or the procedures for its solution, might keep looking at one reference source after another; thus, engaging in a relatively high number of communicative acts. A more useful reference might clarify matters sooner. In turn, a design group with access to such a reference might not perform more communicative acts.

Another possible explanation for the lack of statistical significance is the fact that there appears to have been some confusion, with respect to what the journal questions were asking for, for at least two members of the experimental treatment group. Both groups' journals had the same first three questions, about: 1) total reference acts by the individual, 2) reference acts to clarify procedures by the individual, and 3) reference acts to analyze the problem or task by the individual. The second three questions in the treatment group journal asked the same type of questions, but limited the acts to references to the process overview document. In contrast, the control group's form asked for an assessment of the *group's* total reference acts, the *group's* reference acts to clarify procedures, etc. Thus, for the treatment group, the number of acts reported in response to the second set of three questions should have been equal to or lower than for the first three questions; and for the control group, the numbers should have been equal to or *greater*. For two of the treatment group subjects, in five of six comparisons, more references to the overview document were reported than to reference material, in general. Perhaps, the subjects did not view the overview document as a subset of the greater reference set. Also, the average acts per hour for the whole group were greater with respect to the overview document than the averages reported in the Results section for reference material, generally. One more journal entry anomaly involved one of the same treatment subjects not filling in a single response bubble for one day in which four work hours were recorded.

The remaining discussion points, three through six, begin with the overview document as an innovation. Post-experiment survey responses and actual usage provide some evidence that the overview document might have characteristics of an innovation that diffuses. Fourth, the problematic opportunity seemed appropriately ill-defined. Also, due to change tracking, the overview document captured evidence of the design process followed by the experimental treatment group, including the approximate portion of the project time used to get through the specification definition phase. Sixth, the treatment group's design concept scored significantly better than the control group with respect to specification definition. The mechanical engineering majors on the two teams should have had the same familiarity with the QFD House of Quality approach to defining specifications. Both groups also had access to the references and software (i.e., Excel) used to develop the overview document's QFD worksheet.

5.2 Limitations of the Study

As stated earlier, the experimental results are not generalizable, or *externally valid.* That is, the results cannot be extended to a larger population beyond the subject sample in the experiment. This is the first of five limitations. To be generalizable, more data points are necessary; perhaps, at least thirty. Limited available payment funds were a second limitation that contributed to holding down the number of teams in the experiment. Also, the assignment of subjects to groups by using a 'balanced-pair' approach combined with probabilistic methods may undermine validity by not being an entirely random assignment. However, the balanced-pairs approach sounds similar to *matching*. Used to avoid confounding factors, matching involves "assigning subjects to groups so that both groups have a similar distribution of sex, age, IQ, and so on" (Cardinal & Aitken, 2006). A fourth limitation is the reliance on self-reporting by the subjects. This data gathering technique introduces potential bias, because the subjects knew that the experimenter was interested in their referencing frequencies. Finally, data was gathered for only part of the design process. As a result, actual utility assessments of designs were not possible.

5.3 Lessons Learned

Conducting an experiment that balances realism and do-ability is challenging and logistically very complex. Finding and preparing two comparable rooms with appropriate furnishings, books, etc., was more difficult than anticipated. In turn, even if funds had permitted more teams, the arrangement of more rooms, as defined, was likely not possible. A second of six lessons learned relates to the creation of the overview document. That document describes the process followed when designing something. As the overview document itself was being designed, it influenced its own further development. Also, based on design journal entry inconsistencies, a third lesson is that any future design journals would have to be simpler and/or clarified better at the start of an experiment. Fourth, the ethical treatment of human subjects training is valuable, and could be beneficial for others who are not necessarily conducting experiments. The fifth and final lesson learned is that, even though treatment group test subjects were only given a fifteen minute explanation of the overview document – which is an extensive innovation – they still made considerable use of it. Perhaps, some additional training would increase the document's usefulness even more.

5.4 Implications for Further Study

Eight implications will be identified. First, sharing the overview document, at this point, can lead to potential contamination of possible future experimental subjects, compromising future experimental efforts. Secondly, future experiments should certainly pursue more design teams, as well as more team members from more disciplines, more computer-aided design tools, and examine of the entire design process. At some point, multi-locational, multi-national and inter-cultural design teams require attention. Further, the study of the impact of sex differences in communication during overview document facilitated design might be worthwhile. Finally, experiments that provide different subsets of the overview document set (i.e., Excel file, notebook, and poster) to different teams could provide valuable insight.

A third implication is that the overview document, as well as the model to be presented later in this section, could inspire a board game or a video game that might generate increased interest in engineering design amongst children.

Questions that arise due to the experiment are a fourth implication. The first of four questions is: *How far should a design team get in twenty hours?* For both teams, there seemed to be a lack of engineering analysis (e.g., weight estimates, simple strength of materials calculations, etc.). Perhaps, there was insufficient time. Also, building a QFD House of Quality is relatively time consuming, but it is known to pay off later in the process (Ullman, 2003).

A second question is: *Does the availability of traditional blackboards and whiteboards reduce knowledge captured during design?* Neither type of board was made available to the design teams in the experiment. While the boards may facilitate communication, capturing what was done on them requires extra effort.

The third question is: *How well should senior level mechanical engineering students be able to handle a realistically ill-defined design problem situation?* An implied expectation of the experimental design was that senior level mechanical engineering students should have already begun the process of developing their abilities to make sense of the poorly defined situations from which design efforts proceed. That is, they have already begun to transition from being handed fairly clear-cut sets of design objectives, which were provided to them by someone else who has done most of the sense making, to being open-minded, pro-active, problem solvers. If senior level mechanical engineering students have considerable difficulty with ill-defined design problem situations, it may indicate the need for curricular changes.

A fourth and final question is: *What is the appropriate way to interact with* *experimental subjects when not in an experimental context?* When approached by a subject, it was a challenge to be friendly without introducing bias by, either, appearing to be friendlier towards certain subjects, or seeming like kind of a jerk when questioned about the experiment and trying to avoid providing potentially biasing information. Further, subjects expect to have confidentiality of their involvement in the experiment protected. So, if the graduate researcher only knows the subjects from the experiment, it is not clear if the researcher should even acknowledge an encountered subject outside the experimental context (including after the experiment has been completed) any more than any other stranger.

Another implication, this one being the fifth, is that the overview document could become the starting point for discussions about the design process. Some of the issues in such discussions could include how the process should be, and how the process differs from current representations. Figure 144, below, presents these relevant issues when trying to graphically

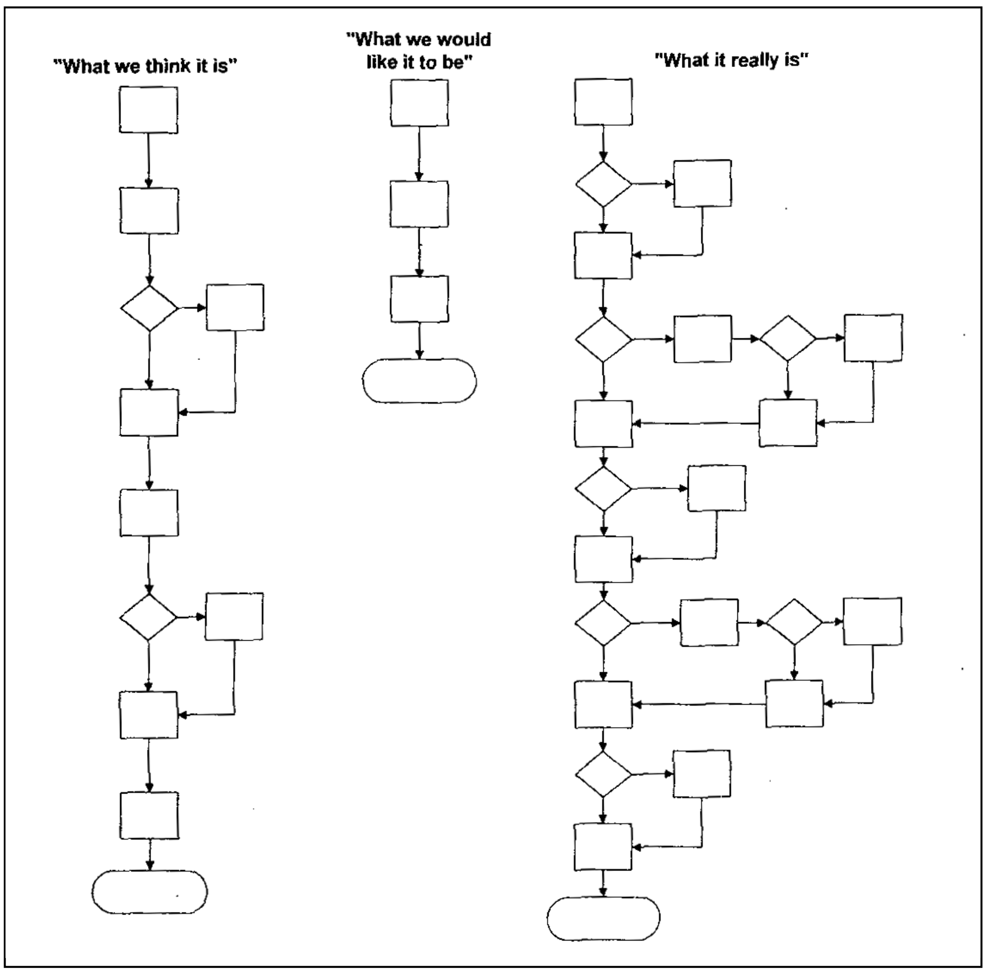


Figure 144: Process flow charts (process maps) (Smunt, 2000)

represent a process. Further, the overview document can be useful when trying to determine where research is lacking and future research could have the most benefit.

A sixth implication is that the initial draft of the overview document has already inspired application in another type of problem solving. More specifically, the author started with a soft system model used in natural resource conflict management efforts and converted it to the left-to-right overview document layout. The soft system model was previously presented (i.e., in Figure 96) and appears again in Figure 145, on the next page. Part of the proposed variation is shown in Figure 146, on page 112. One reason the redesign is seen as being preferable is because it shows a process that starts in one place and ends at a different and, hopefully, better place; avoiding the perception of ‘going around in circles and ending up where we started.’ Furthermore, the redesign still includes the potential for cyclical feedback looping.

“I’m not an engineer-hater like some of my colleagues,” states Mazda Global Design Director Moray Callum (Ponticel, 2006). A seventh implication is that an overview document could reduce the conflict experienced between engineering designers and others. Increased collaboration between engineering designers and those who do aesthetic design is being promoted in the automotive industry (Ponticel, 2006).

The eighth and final implication is the development of a second design process model. As mentioned in the introduction, preparation of the thesis paper led to thought about the design process that considers variability at the start, the constraints that arise during, and the probability for a viable product at the end. Further, the model helps clarify the intended contribution of the overview document to the design process. Figure 147, on page 113, shows a diagram of the design process by Ullman (2003). This figure identifies design process knowledge and domain-specific knowledge, and was the starting point for the development of Figure 148 (also on page 113); which was previously presented in Chapter 1 as Figure 2. Also in Chapter 1, the individual variability of procedural and domain knowledge was noted, as too was the high level of problem solving uncertainty for a mechanical design engineer confronting a complex design problem. Use of a design team made-up of multi-disciplinary experts that is the response to that high problem solving uncertainty was described. A new problem that arises with such a design team was clarified; that is, increased procedural uncertainty. Figure 149 (which was previously presented as Figure 8), shows the team at the corresponding levels of procedural and problem solving uncertainty (see page 114)

At this point, the items on the bottom portion of Figure 149 will receive attention. First,

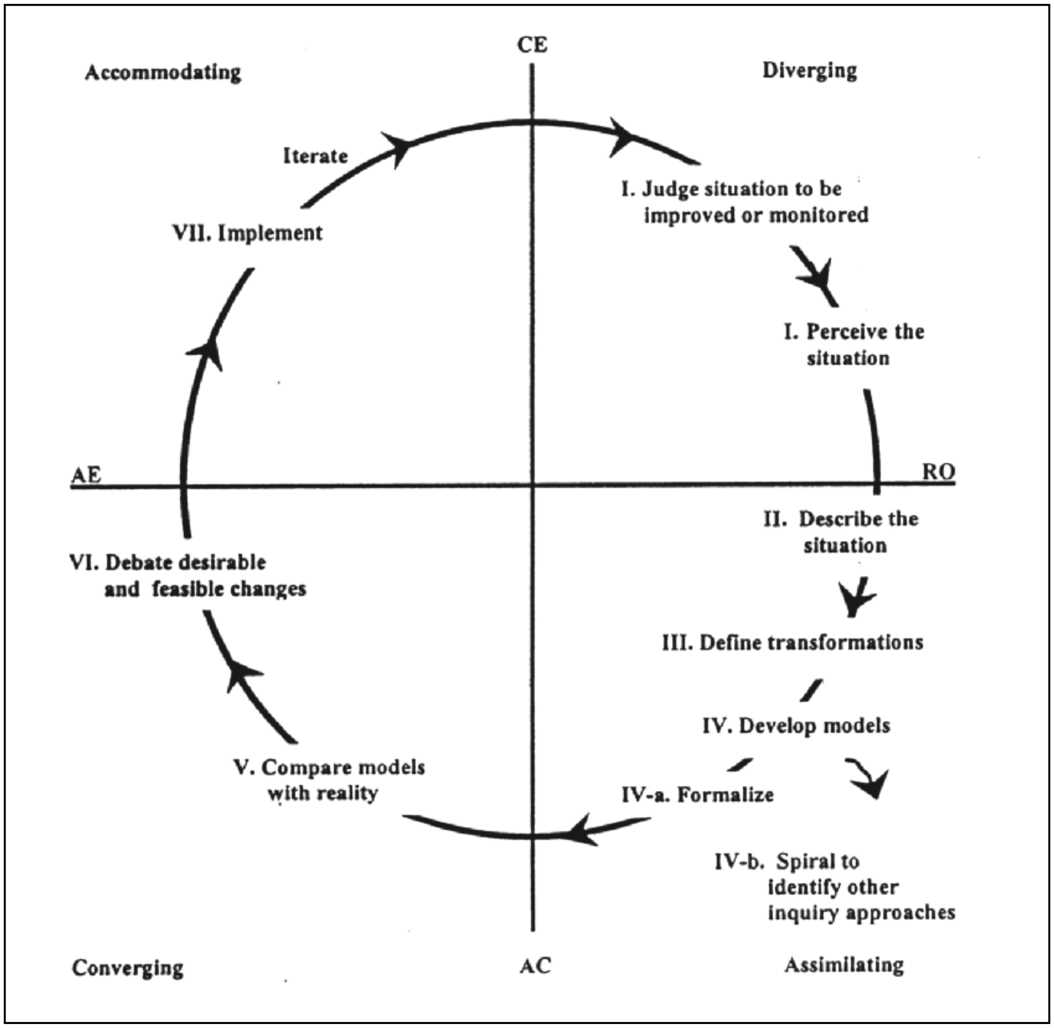


Figure 145: Wilson and Morren's modification of Checkland's [1981] soft system model, from Wilson and Morren (1990) (Daniels and Walker, 2001)

the potential responses to the problem or opportunity that are the output of the design process will be modeled (see Figure 150, also on page 114). Next, the input problem or opportunity is further defined. Third, the process paths during the design process are characterized.

The potential responses to a given problem or opportunity can be modeled as a frequency distribution that has a normal distribution shape; just like the distributions of human heights, weights, and scores on standardized tests (see Figure 151, on page 115). Not all possible responses or potential products are the same with respect to the benefits and costs associated. While most have similar levels of utility, and lie between plus and minus two standard deviations, a few clearly exceptional products are found to the right of plus three

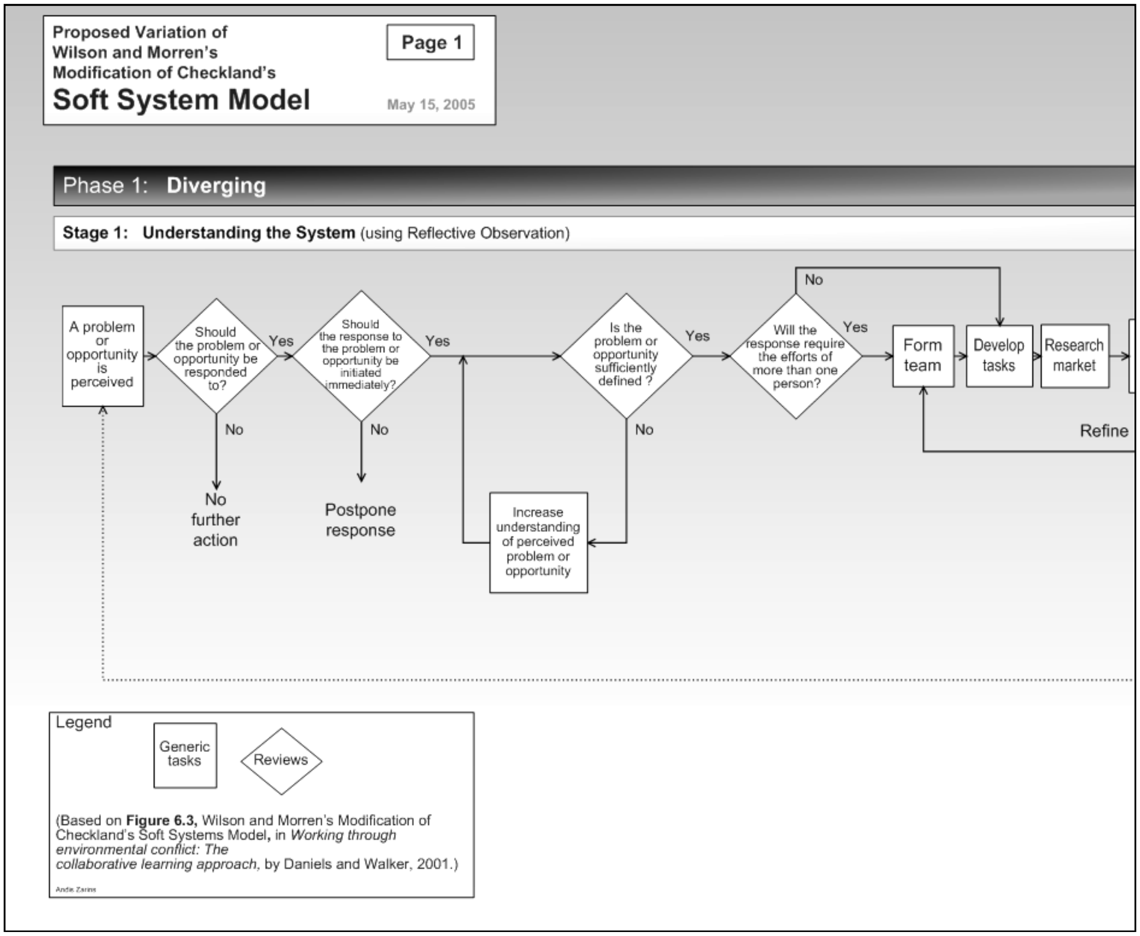


Figure 146: A portion of a soft system model that has been re-designed based on the process overview document concept

standard deviations. Further, another group of products, at the other end of the distribution, are harmful, and should not be marketed. Figure 152, also on page 115, presents utility on the *x*-axis. To the right of the harmful products are products with increasing utility. The separation line can be defined as the point where the benefits minus costs equals zero. However, a utility measurement is dependent upon the assumed time period (i.e., short-term or long-term) and who's utility is being included in the measurement. Some people's short-term high utility product can be harmful to others, or harmful to themselves over the long-term.

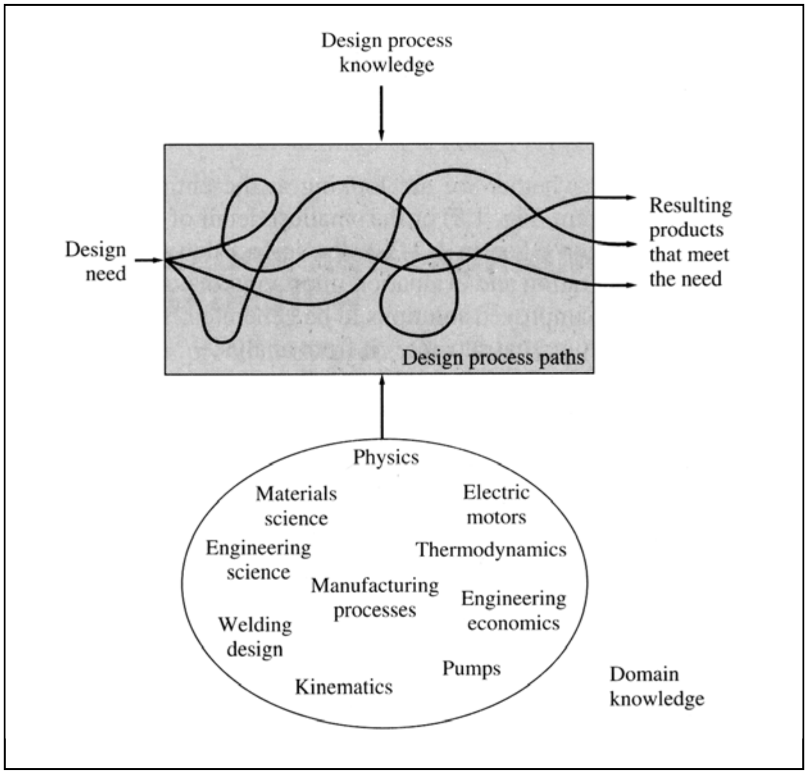


Figure 147: The many results of the design process (Ullman, 2003)

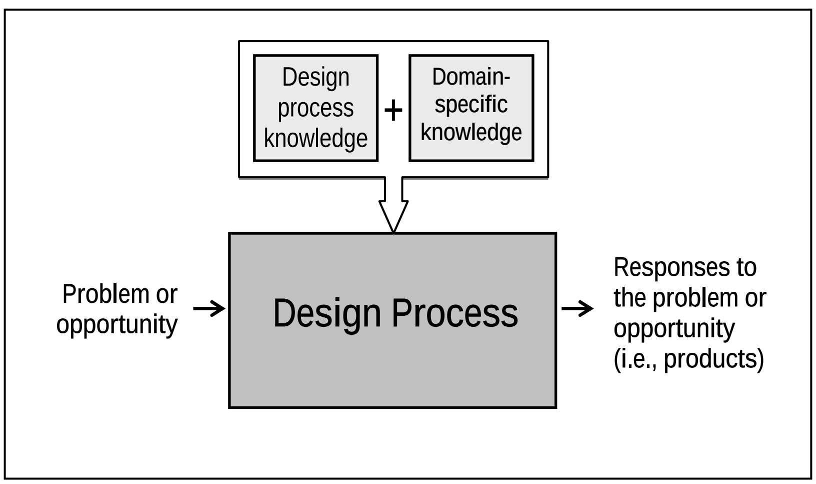


Figure 148: Two types of knowledge input to the design process model

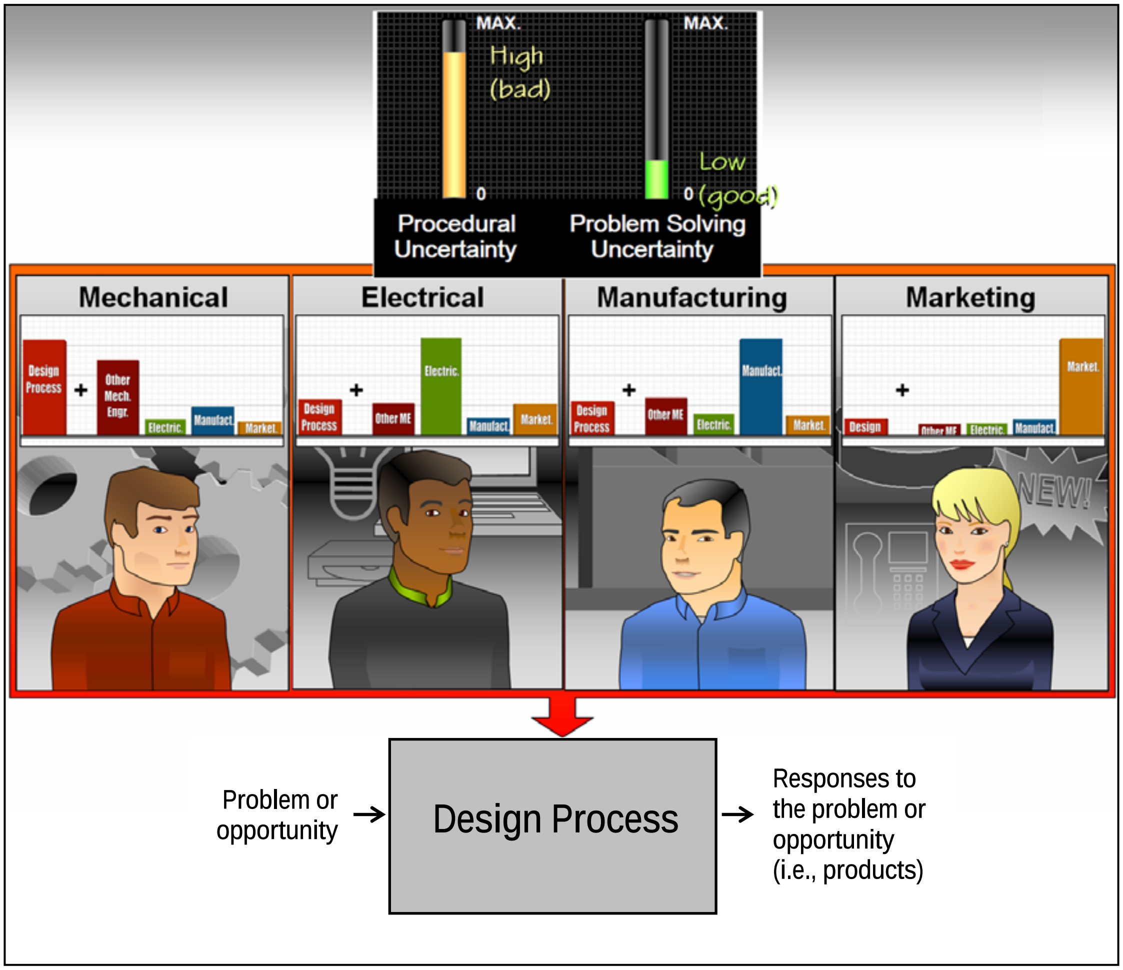


Figure 149: The decrease in problem solving uncertainty and the increase in procedural uncertainty resulting from the use of a multi-disciplinary design team

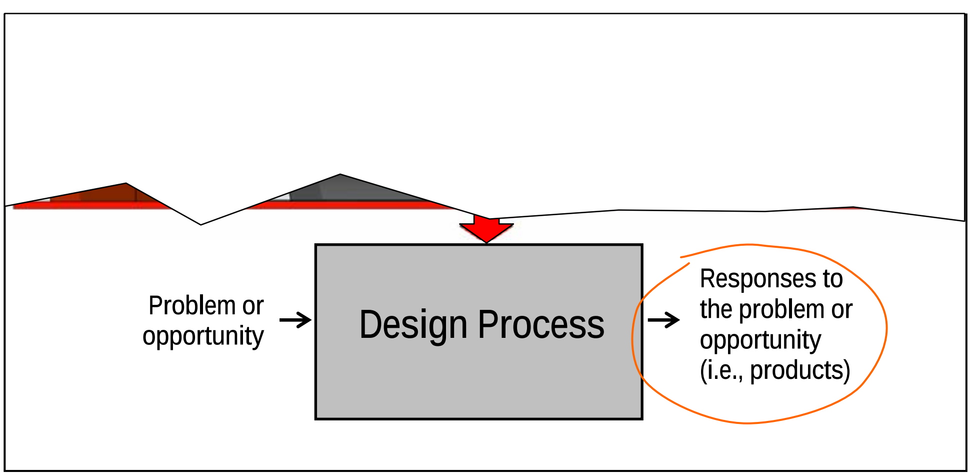


Figure 150: The bottom portion of the model developed so far

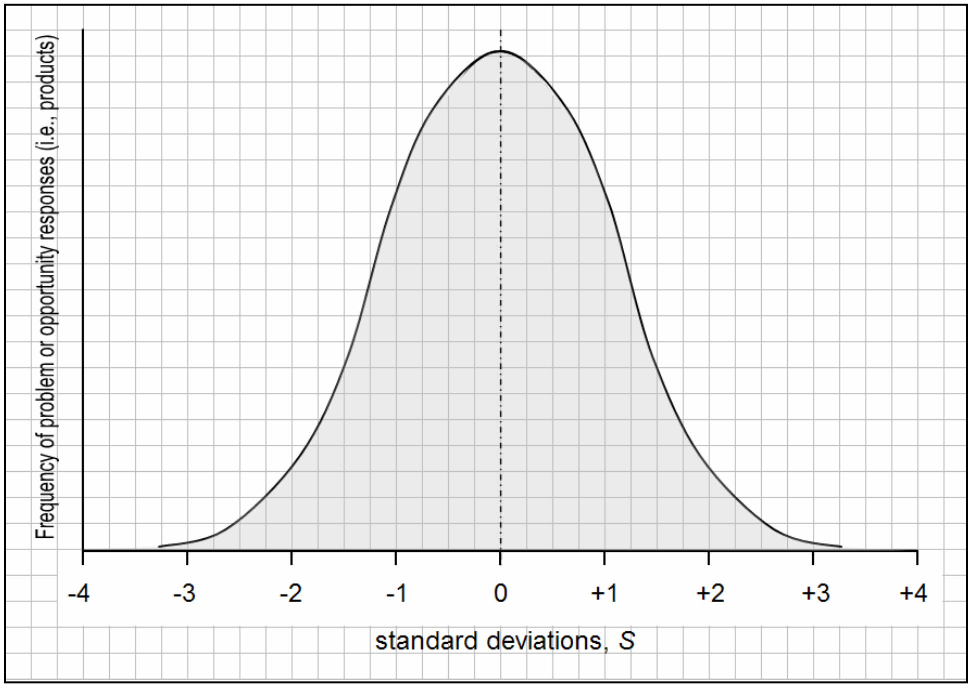


Figure 151: A possible normal distribution model for all the potential results of the design process for a given problem or opportunity

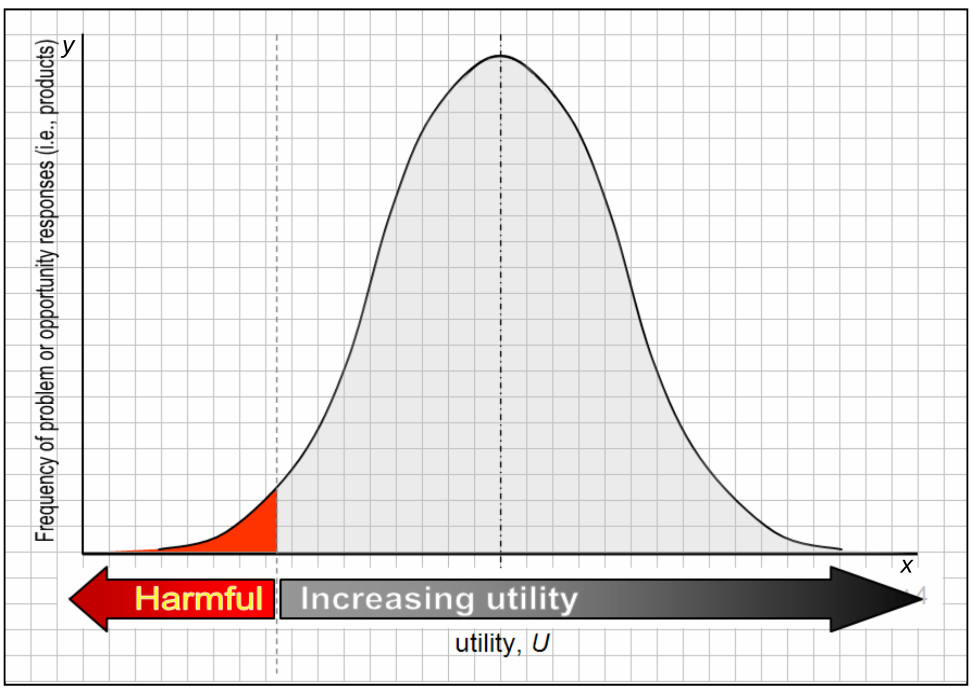


Figure 152: The potential product normal distribution based on product utility

Prior to placing this normal potential product distribution into the input/output design process model, a brief clarification about visual representation of positive and negative direction is helpful. A two-dimensional Cartesian coordinate system, with an *x*-axis and *y*-axis, is shown in Figure 153, below. Starting at the origin, which is defined as zero, and moving to the left

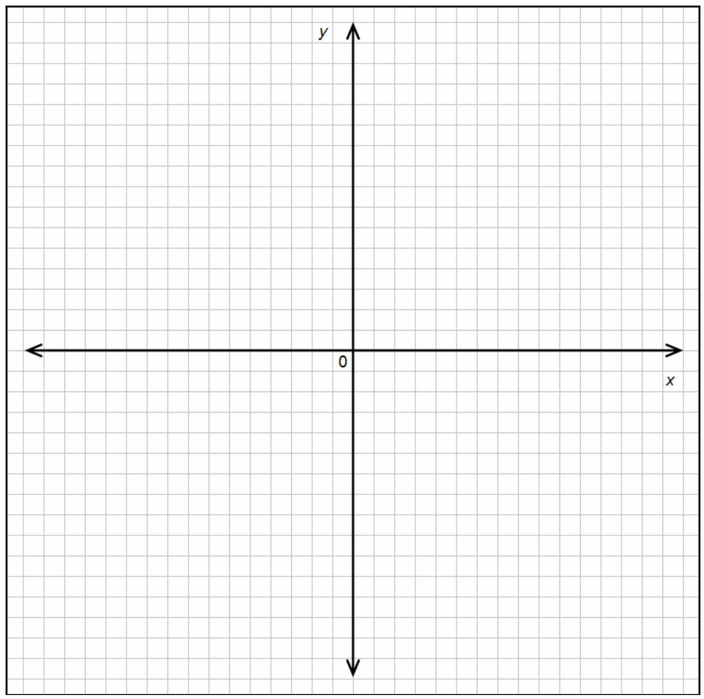


Figure 153: A Cartesian coordinate system

along the *x*-axis yields increasingly negative numbers (see Figure 154, on the next page). Conversely, moving to the right from the origin along the *x*-axis yields increasingly positive numbers. Similarly, moving towards the bottom of the page along the *y*-axis means encountering values that are increasingly negative. Further, increasingly positive values are realized when moving up towards the top of the page along the *y*-axis (see Figure 155, also on the next page). Figure 156, on page 118, presents a somewhat simpler variation of Figure 155 (i.e., no words) that is used in the remainder of the clarification.

A copy of Figure 156, if laid on the left-side of a table, and viewed from a point above and towards the center of the table, would look something like Figure 157 (also on page 118). The frequency totals of a normal distribution can also be displayed along the *z*-axis (i.e., up

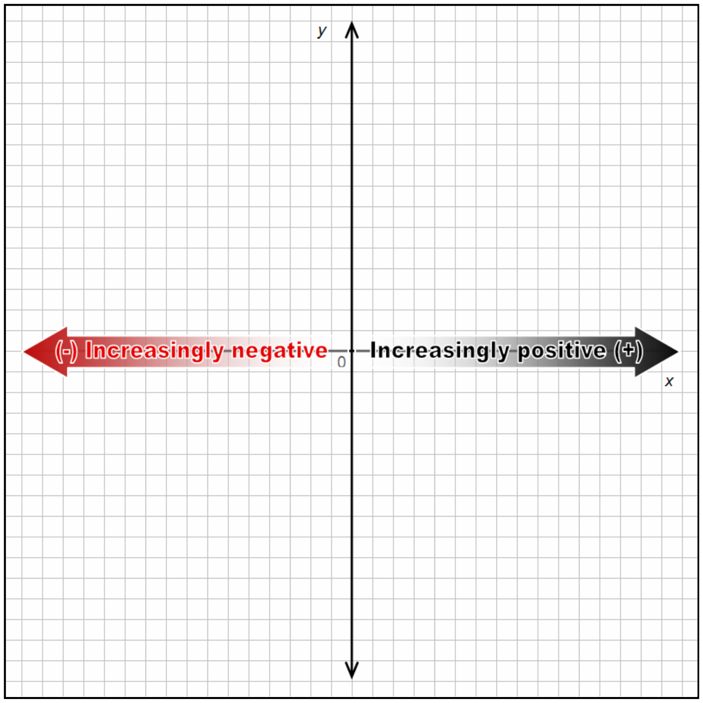


Figure 154: Increasingly negative and positive values when moving away from the origin in both directions along the *x*-axis

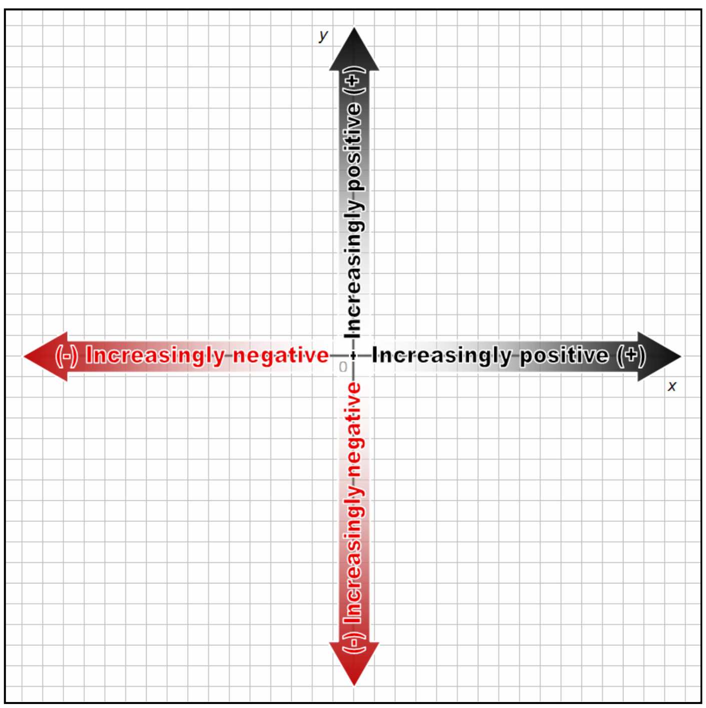


Figure 155: Increasingly negative and positive values when moving away from the origin in both directions along the *y*-axis, as well as the *x*-axis

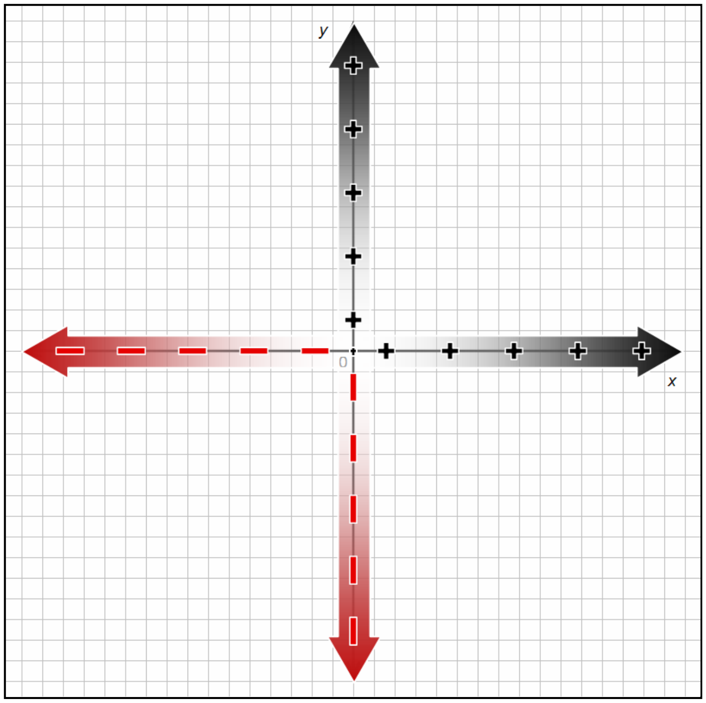


Figure 156: A simpler variation of Figure 155

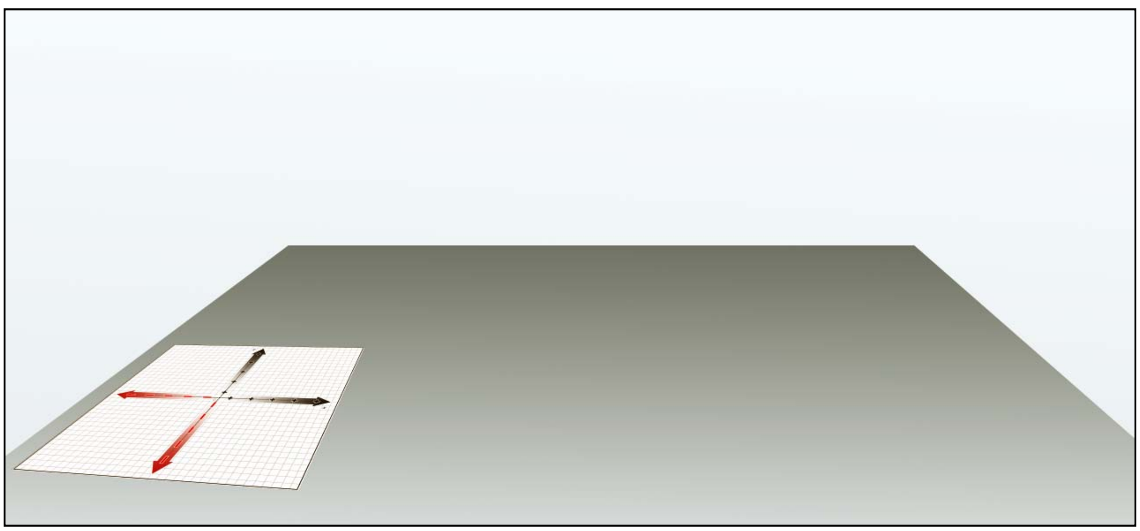


Figure 157: The Cartesian coordinate system of Figure 156 as seen when laid on the left side of a table

from the table surface), and the utility can be measured along the *y*-axis. Figure 158, on page 119, presents just this case, and has the potential product distribution (i.e., like Figure 152) set on its edge on the coordinate system (i.e., Figure 156). Note that the harmful products are

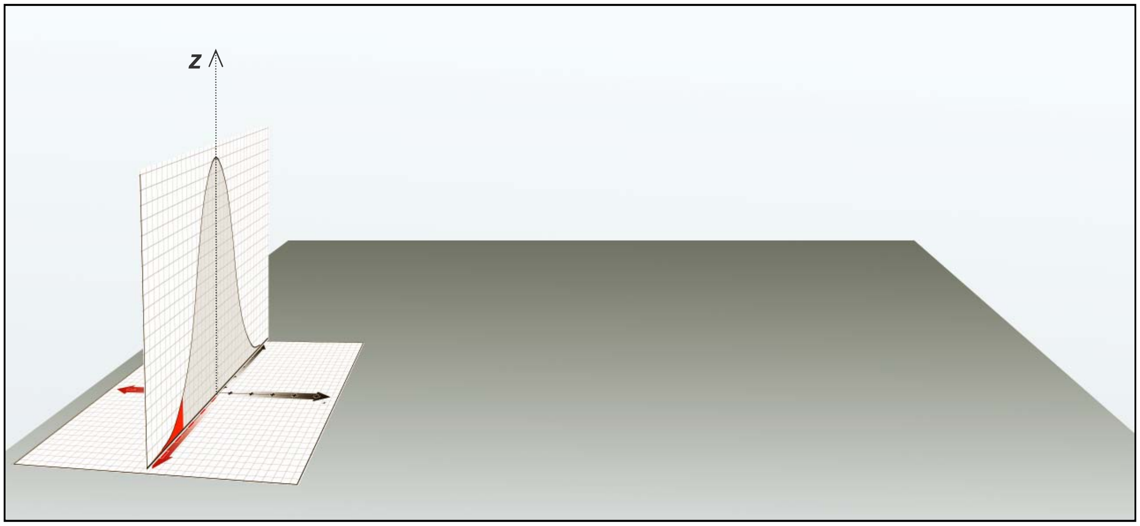


Figure 158: The normal distribution model placed on edge on the *y*-axis of the Cartesian coordinate system of Figure 156

towards the bottom of the page. Figure 156 can also be moved to the center of the hypothetical table (see Figure 159, below). A normal distribution, with utility plotted along the *x*-axis and frequency along the *z*-axis, appears as in Figure 160, on the next page. Finally, Figure 156 can be repositioned to the right side of the table and be seen as in Figure 161 (also on the next page). The normal distribution, plotted again with utility along the *y*-axis of Figure 156 and

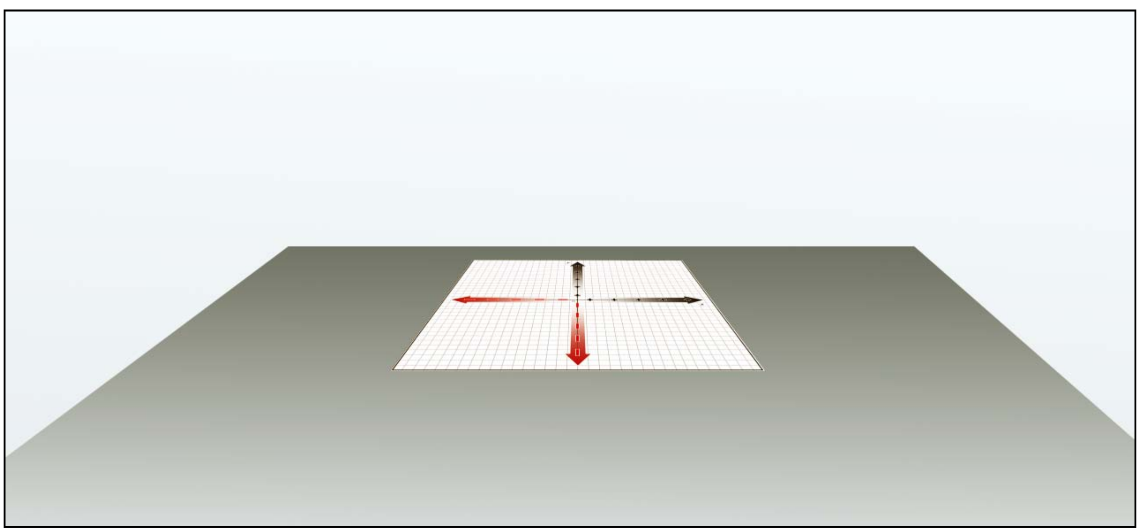


Figure 159: The Cartesian coordinate system placed near the center of a table

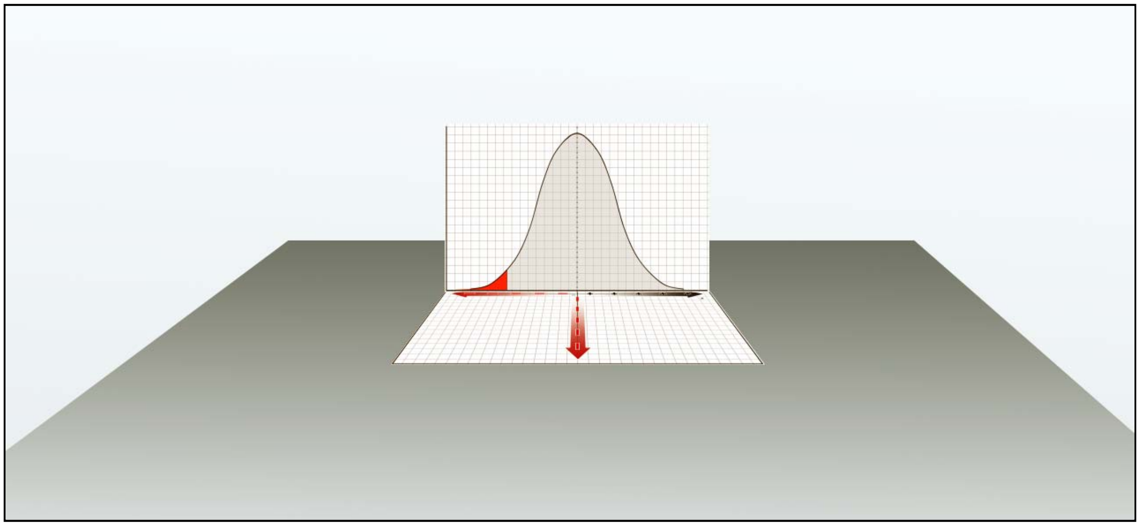


Figure 160: The normal distribution model placed on edge on the *x*-axis of the Cartesian coordinate system placed near the center of a table

frequency along the *z*-axis, appears as shown in Figure 162 (on the next page). Note that the harmful-products end of the distribution is towards the bottom of the page, just as in Figure 158.

Figure 163, also on the next page, introduces this normal product distribution perspective to the input/output design process model. Further, the design process rectangle is

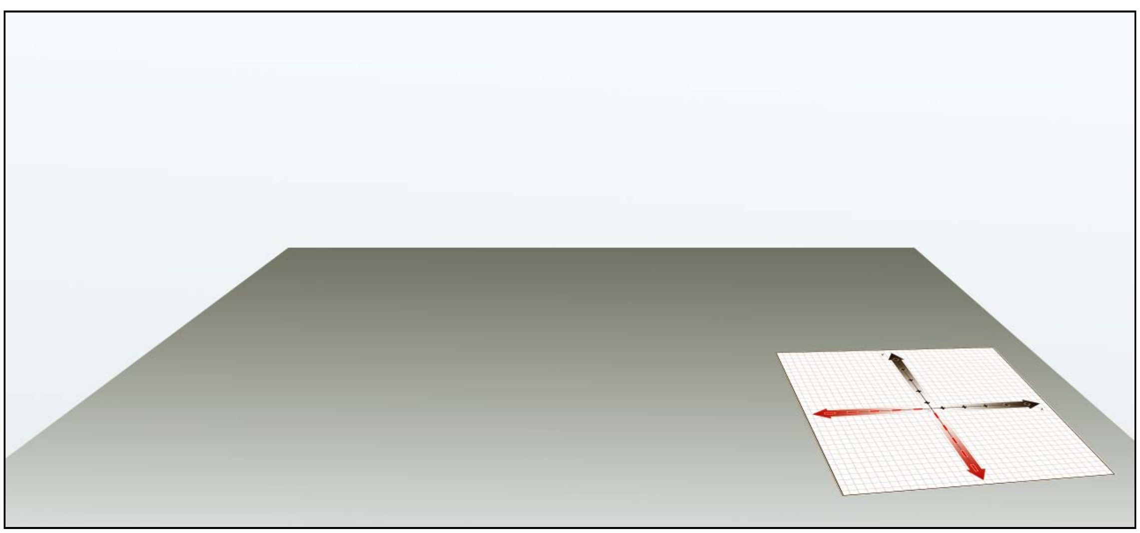


Figure 161: Placement of the Cartesian coordinate system on the right side of a table

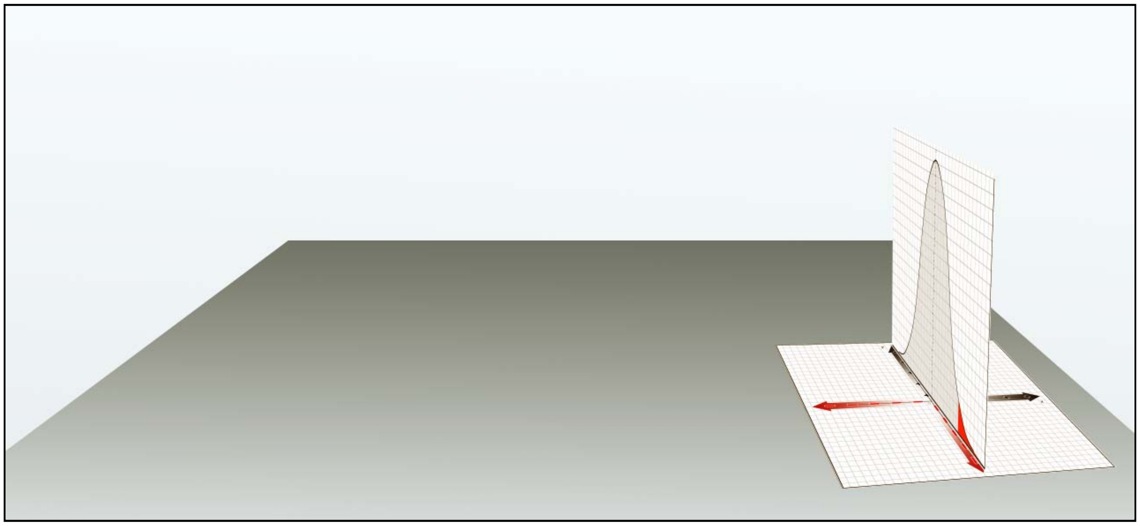


Figure 162: The normal distribution model placed on edge on the *y*-axis of the Cartesian coordinate system placed on the right side of a table

now also shown in perspective. Additionally, numerous arrows exit the design process, with their density increasing with the higher frequencies towards the center of the distribution.

Attention now turns towards the input end of the design process, or the problem or opportunity. Not every person or design team that encounters a given problem or opportunity perceives it the same. That is, there is no one starting point. Figure 164, on the next page, shows five input arrows entering the design process. The colored areas under each of the arrows

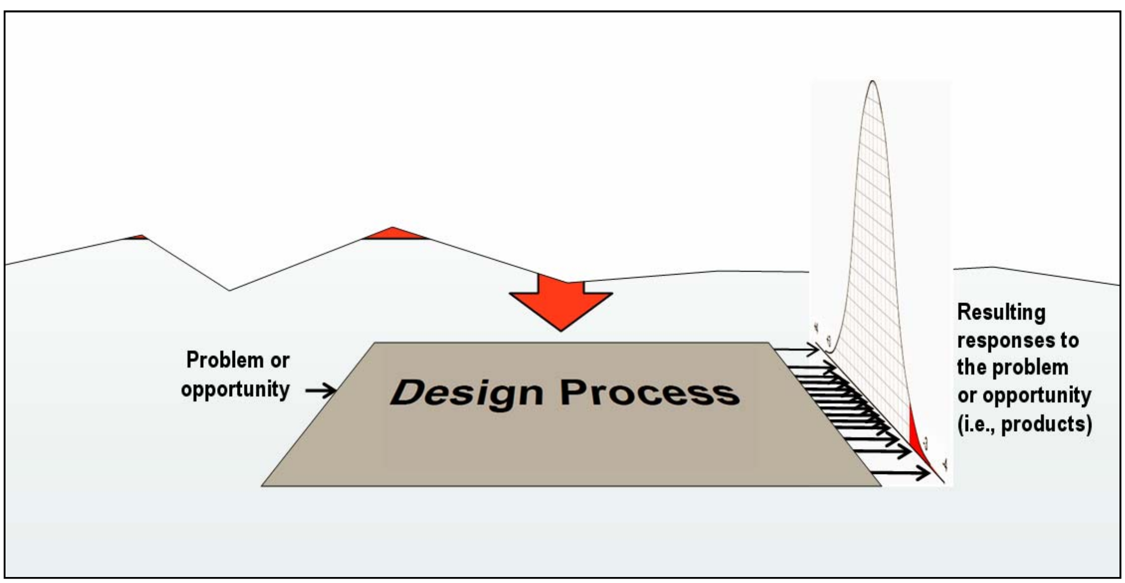


Figure 163: Addition of the potential product distribution to the design model

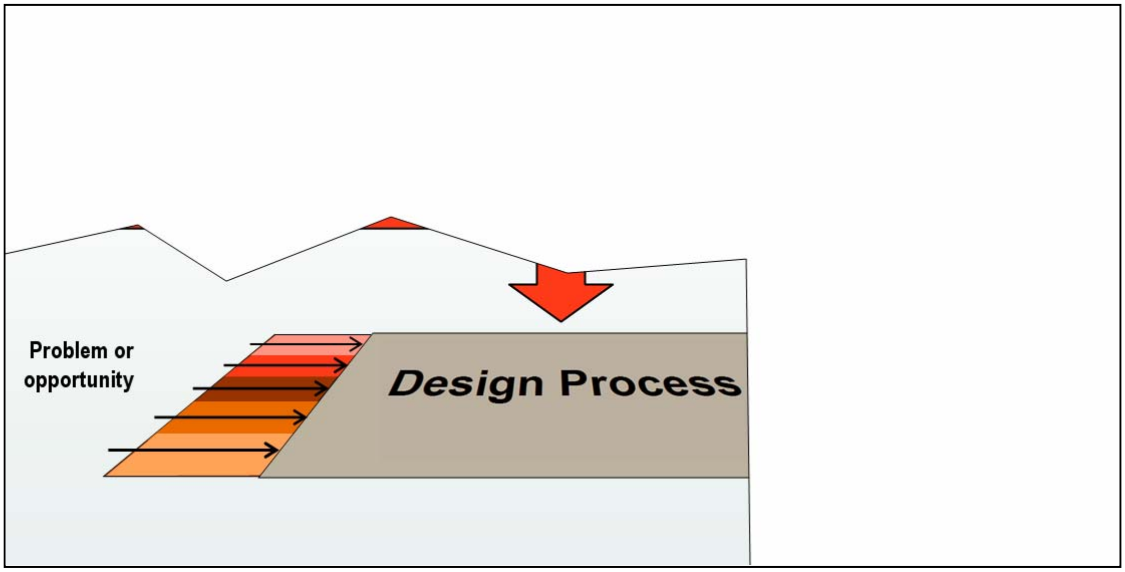


Figure 164: Variability of initial problem or opportunity understanding

represent a different perception of the same problem or opportunity. For the middle arrow, the area below it is the darkest or has the greatest density. This is the area where understanding of the problem or opportunity is the most complete. This is also the area which is least likely to be entered when first encountering the problem or opportunity. It is much more likely that the initial understanding of the situation is incomplete to one degree or another. The somewhat lighter areas directly adjacent to the central arrow area represent a mostly-complete partial understanding of the problem or opportunity. Thus, the lighter the area, then the more incomplete the understanding is. Also, the tint of the areas on each side of the central one is different. This difference is to represent that two incomplete understandings of one situation that have the same level of incompleteness are not necessarily the same. More specifically, each understanding may include something that is missing from the other.

Of course, the definition of five different areas is arbitrary. Further, a more correct model would have integrated areas that appear as a smooth continuum of colors and have an infinite number of possible arrows. Also, the darkest portion in the middle, or complete understanding of the problem or opportunity, is a theoretical concept that could never be realized by humans. For the purposes of this discussion, a discrete number of areas, and a central area with complete understanding that is sufficiently approximate so that a human design team can get there, will be used.

Since there are various levels of problem or opportunity understanding, it would seem to make sense that following the design process from each of these points would yield a different set of possible responses. Furthermore, the more incomplete the understanding, then the more limited the set of potential responses or products. Figure 165, below, shows three levels of understanding (on the left) and three corresponding response distributions (on the right). The central distribution is the largest, as it includes the greatest number of possible

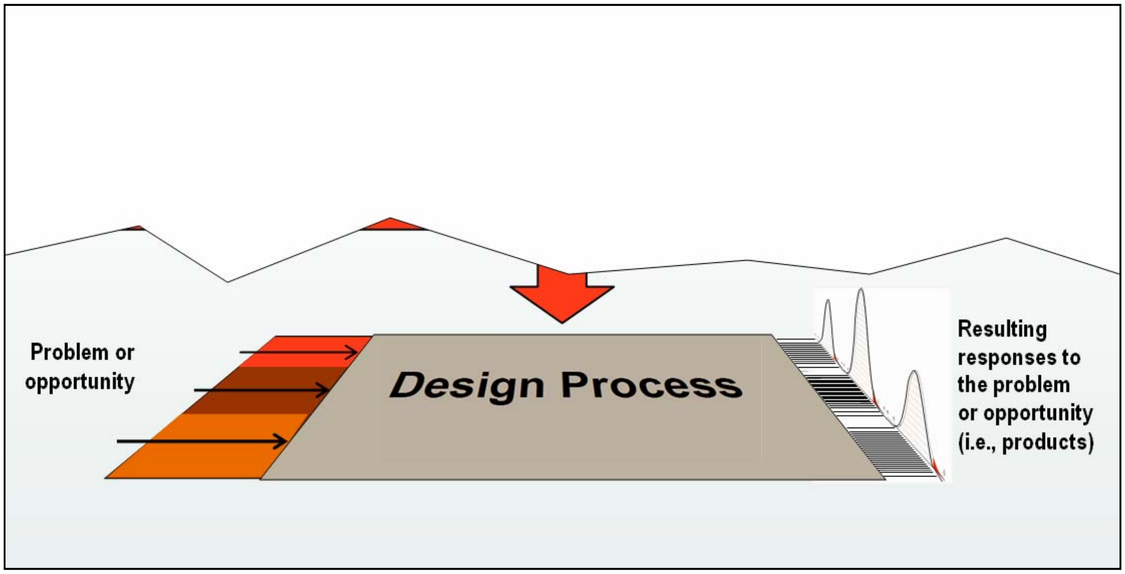


Figure 165: Multiple initial design process entry points and multiple potential product distributions

responses. Outlying distributions are smaller, and become increasingly so when moving away from the central distribution. Why this is the case will be clarified more, later.

The design process connects the problem or opportunity understanding arrows with the distributions, and is examined next. Connecting paths that are limited to being straight, parallel, and that directly connect the problem or opportunity understanding arrows to the distributions at the other side, seem far too simple to adequately approximate real design. The looping paths presented by Ullman (2003) in Figure 147, while reflecting process variability, do not show the impact of design process phases on process paths.

Two observations, when combined, lead to development of an analogy that is quite useful in clarifying the design process paths. The first observation is that the distributions on the right-hand side of Figure 165 look a lot like a range of mountains. Second, the multiple areas of varying problem or opportunity definition on the left side of Figure 165 can be likened to sections of a beach. The design process, then, will be modeled as a section of an island that connects a multi-sectioned beach with a mountain range with the same number of peaks as there are sections of beach. Specifically, where will be five of each (see Figure 166, below).

A design team washes up on the beach at one of the five points. While in the ocean, the

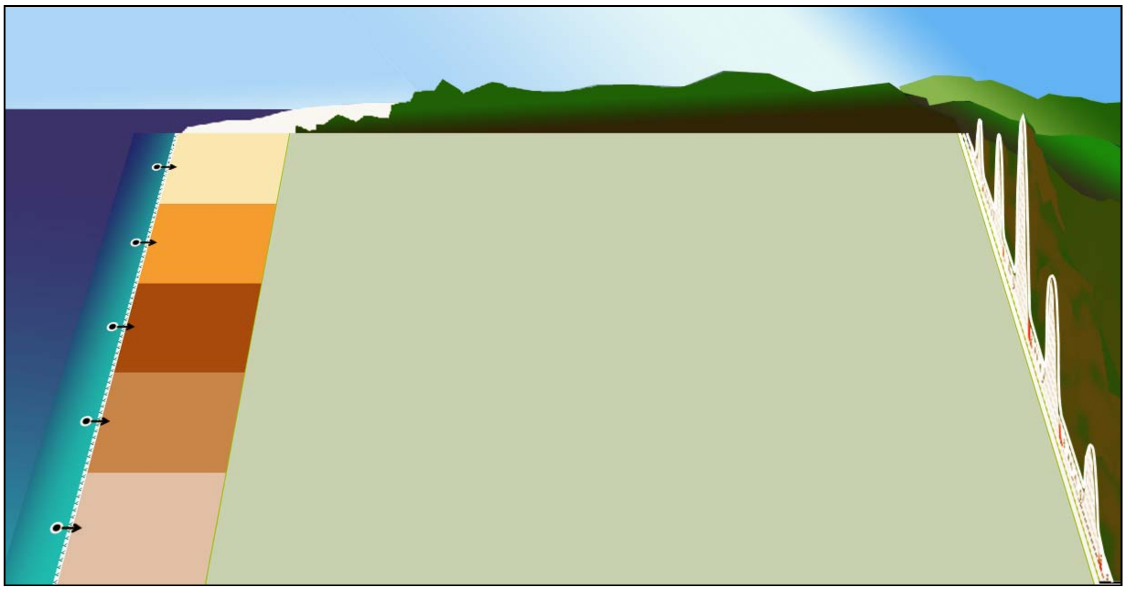


Figure 166: The initial contact with a problem or opportunity situation

team had never encountered the problem or opportunity. As they set foot on the beach, they do encounter the problem or opportunity for the first time and make sense of it, acquiring an understanding with a certain level of completeness. The design team has a familiarity with islands such as this one. Survival necessitates getting to one of the mountains; preferably, the biggest one. They also know that, at the bottom of one side of each mountain, the conditions are increasingly pleasant. For the largest mountain, the increasing pleasance reaches a paradise-like level. This place is the one the design team would most like to reach. Further, on the opposite side of the mountain, there is an area where conditions are actually dangerous; and the team knows that this is the case, and wants to avoid ending up there. The team also knows that they have to work together to get to their goal, and they need to do so in an efficient and timely manner; or, they may never get there.

With the surf-tide at their heels (or wheels), the design team has to decide how it is to proceed forward towards the mountains. One option is to go directly towards the vast vegetation between the beach and the distant mountains, taking the shortest path off of the beach. A second possibility is to search for an alternative side-path which angles along the beach. Such a choice, while resulting in a longer path, leads to an area of greater understanding of the problem or opportunity. These available paths are shown in Figure 167, below. A key factor in the decision making about how to proceed is the design team's ignorance about which portion of the beach they initially landed on. That is, they do not know how much they do not know about the problem or opportunity.

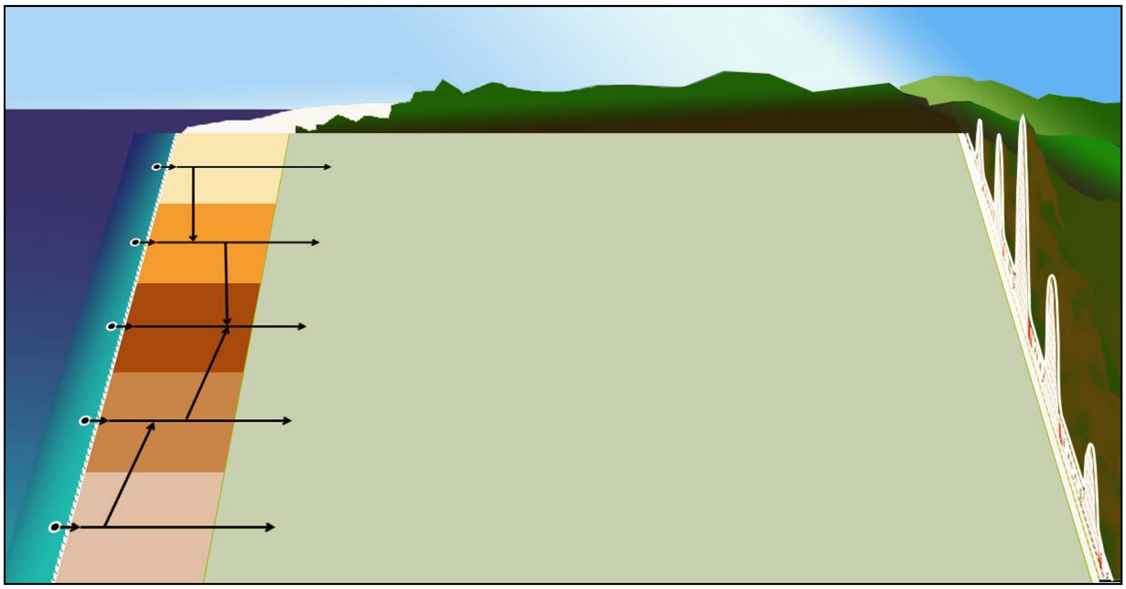


Figure 167: Possible paths through the initial understanding of a problem or opportunity for which a design response is to be generated

The mountains are quite distant and, as a result, it appears plausible from each area on the beach that a path directly off of the beach is inline with the largest mountain. A team with some experience amongst its members will likely have some sense that they may have landed near the center, if they have, or far away, if that is actually the case. Again, however, they do not know for sure. Further, any team moving inland on the beach can choose to look for, and take, an understanding improving side-path. Those landing in the center area, and preceding in such a manner, would find that, despite being attentive for opportunities to acquire additional understanding (i.e., angled side-paths), they encounter none. This would confirm that the team's understanding is quite complete.

Having left the beach with a certain level of understanding about the problem or opportunity, the design team enters the next phase of their journey. This phase is the first of four that typically receive attention in design process characterizations. The four phases are: specification definition, concept generation, product development, and product support (see Figure 168, below). The last phase ends at the mountains.

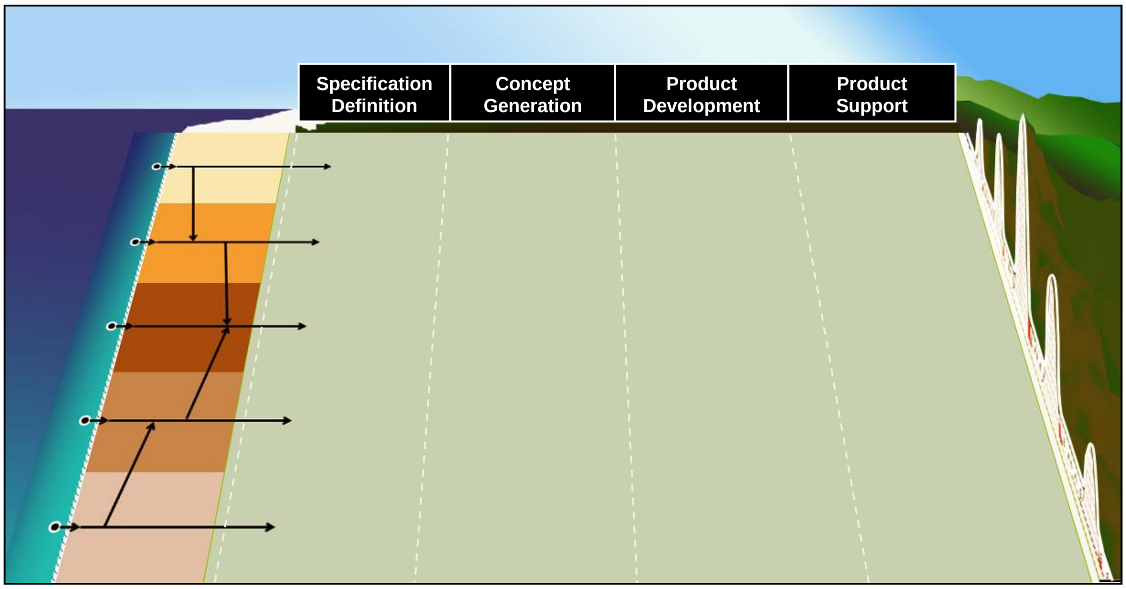


Figure 168: Four typically recognized phases of the design process

A key feature of the four phases is that the team is never certain where their efforts are leading them, other than in the general direction intended (i.e., the mountains). The vegetation and forest canopy prevent a good view of the mountains. Consequently, it is quite possible that a team on a path towards a smaller peripheral mountain might believe that they are headed towards the largest one. In an effort to increase the likelihood that the team is headed towards the central mountain, a thorough job of specification definition can be done. For those teams on non-central paths, this means taking an angled side-path that gets the team over to a more complete problem or opportunity understanding path (see Figure 169, on the next page). The most direct path through the phase is shorter and requires less effort. For those already on the central path, specification definition is still a necessity, but is also relatively straight forward.

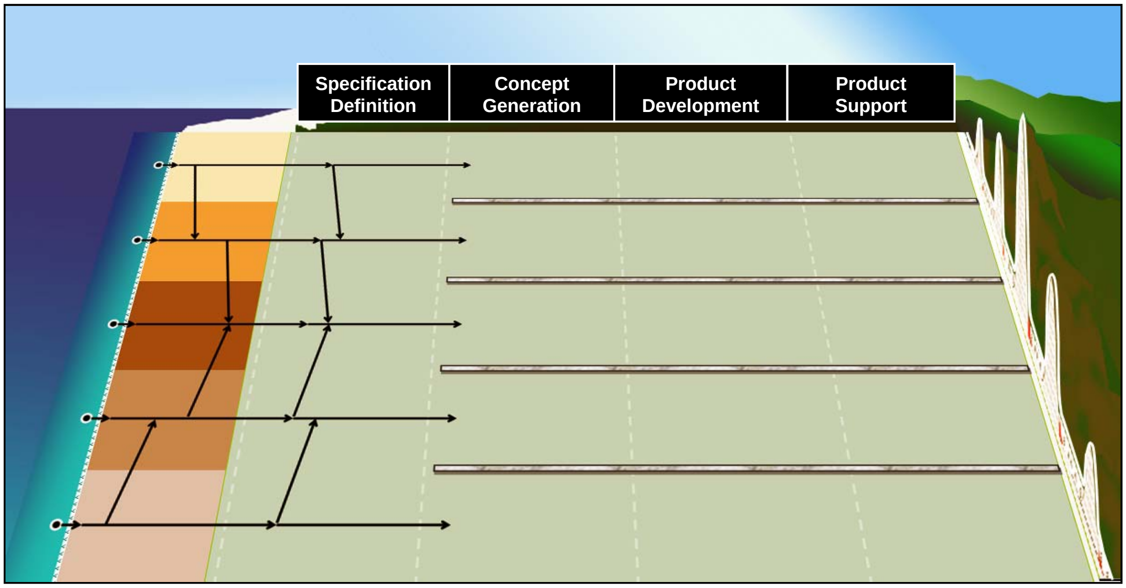


Figure 169: Design paths through specification definition, and path constraint once concept generation has begun

With the completion of specification definition and entrance into the concept generation phase, a design team becomes constrained to paths that can only lead to one response or product distribution (i.e., mountain). Paths leading towards other mountains are now on the other side of large parallel stone walls (see Figure 169, again). The paths through the remaining three phases will first be explained by focusing on a single process path subset leading towards one of the distribution mountains. Comparisons to other subsets will then be made.

The path the design team is on when it enters the concept generation phase widens during that phase, and members are free to search for and identify multiple potential paths forward. In Figure 170, on the next page, the diverging portion of the process is shown for the upper-most process path subset. Also shown are the beginnings of three identified paths forward. The design team has to pick. Often, they can pick only one.

After converging on the selected path, the team heads towards product development, usually believing that they are on the path most likely to get them to the most beneficial portion of the mountain. It is quite possible that their belief is inconsistent with where the path actually leads. This might be due, in large part, to the fact that none of the team has ever been here before. While some, perhaps all, of the team members have been in situations that are very similar, time-dependent phenomena, as well as unperceived situational differences, make each design effort unique. Consequently, multiple generated concept paths may unknowingly criss-cross on their way to product development (see Figure 171, also on the next page).

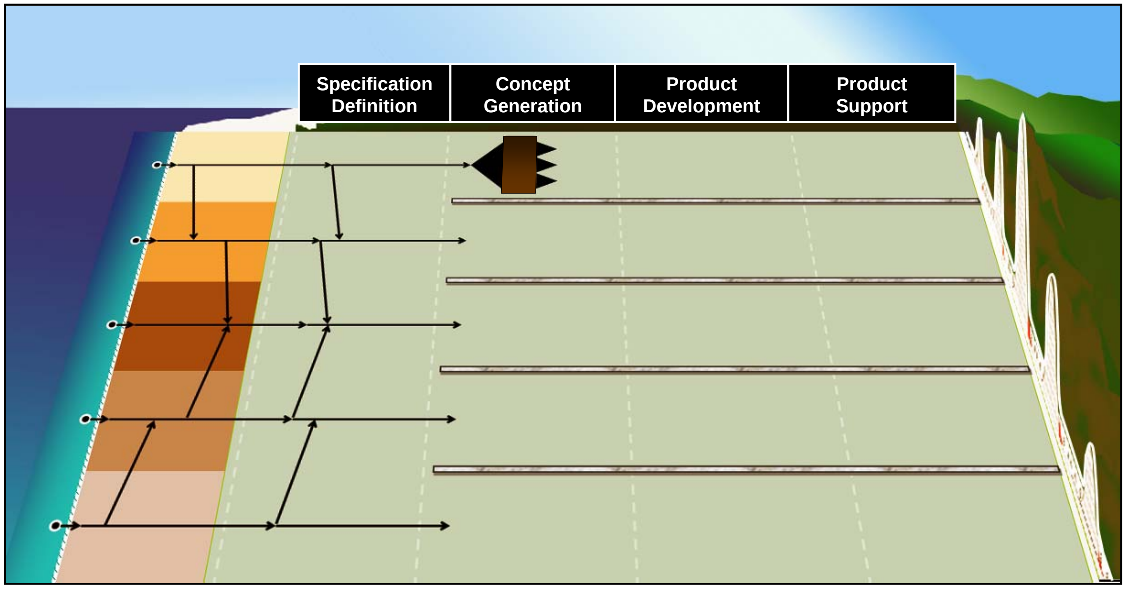


Figure 170: Divergence during concept generation and resulting path options

During product development, it might be determined that a particular concept actually cannot be developed into a viable product. A dead end is encountered (see Figure 172, on the next page). Backtracking is possible. However, the more time and effort a team has to spend doing so, the more likely they never make it to their goal.

Other concept ideas might have two (or more) potential variations that are identified

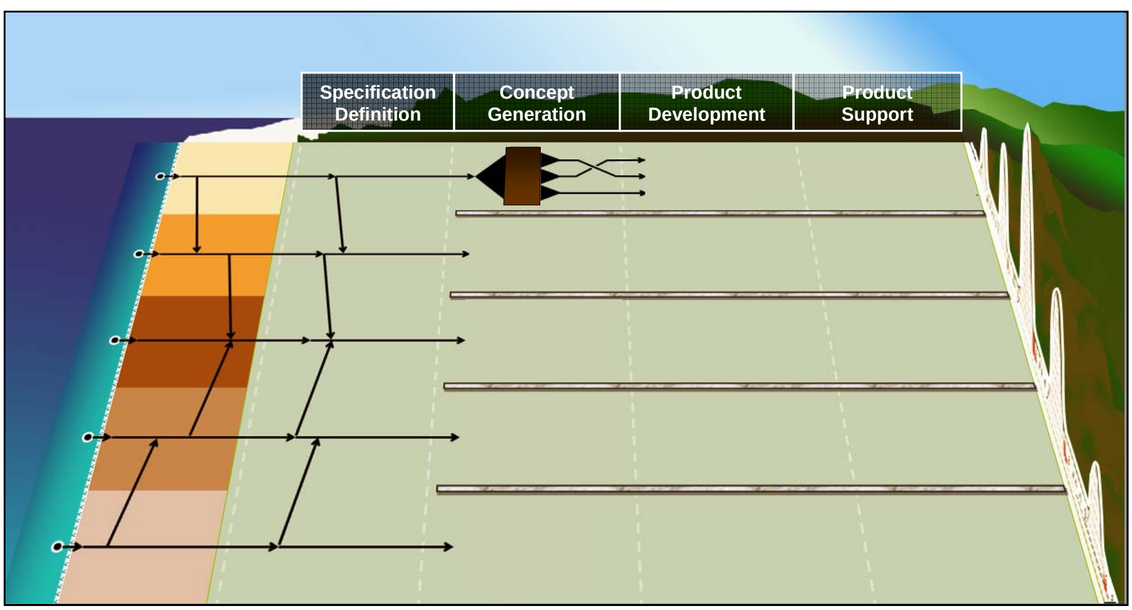


Figure 171: Design paths after concept generation, and the uncertainty of where they lead

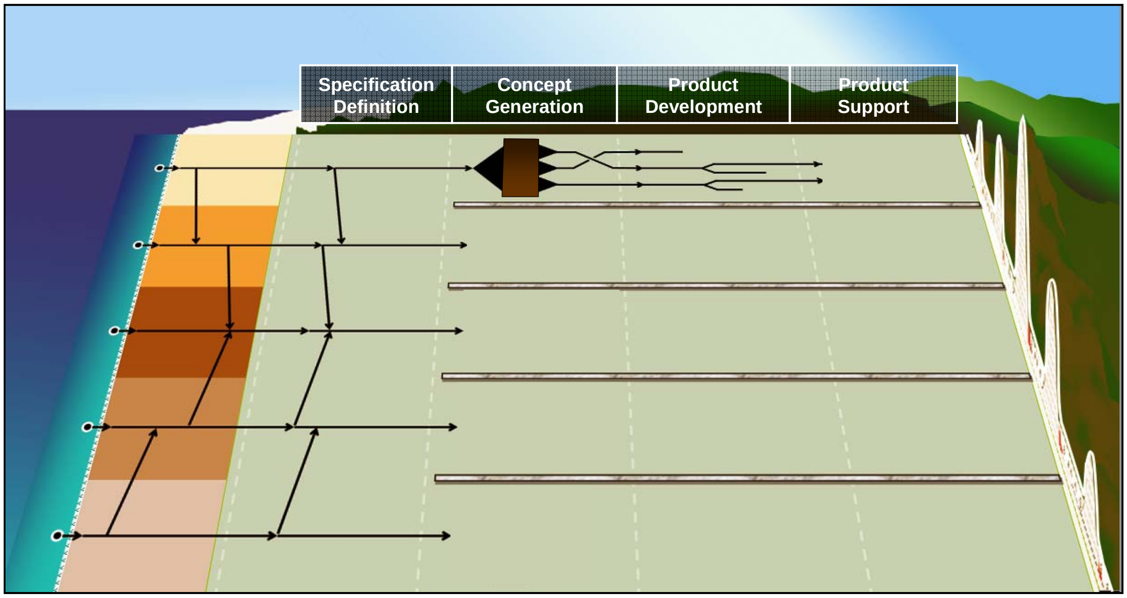


Figure 172: The design path dead-ends and forks during product development

during product development. Some of these variations can lead to products and some can lead to other dead-ends (see Figure 172, again). For the top process path subset, two viable product paths make it into the product support phase.

Product support multiplies the possible responses or products that can be realized at the end by impacting the delivered utility level (see Figure 173, below). Further, a potentially

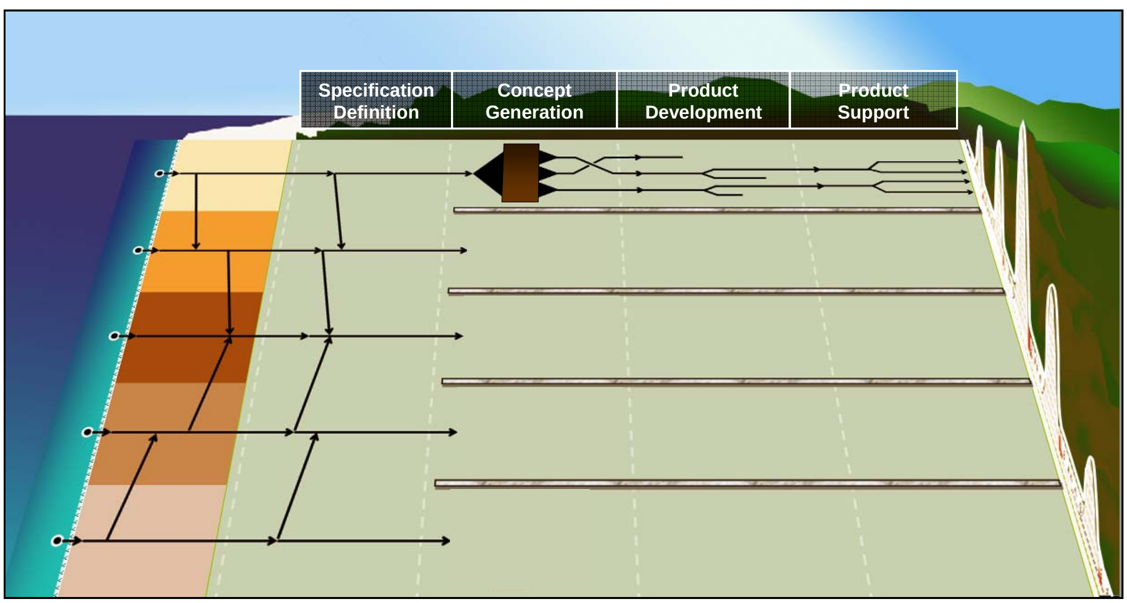


Figure 173: The multiple potential design paths during product support at the end of the design process

harmful product can also have a parallel path as an appropriately safe product made possible by a correctly implemented recall and engineering change.

The central and intermediary path subsets will now be compared to the path subset just defined. It is assumed that the performance level of concept generation, product development, and product support is equal across all path subsets. For example, the same number of concepts is generated for each subset. In turn, any differences amongst the subsets is reflective of a different level of problem or opportunity understanding going into concept generation.

Figure 174, below, shows the three process path subsets. Each has three generated concepts. However, by the end of the process, the central path subset has the highest number of possible responses or products, the intermediary subset has fewer, and the outlying subset has the least. The end-of-the-process arrow density differences reflect the sizes of the respective distribution mountains.

The reason for the greater number of potential products for the central process path

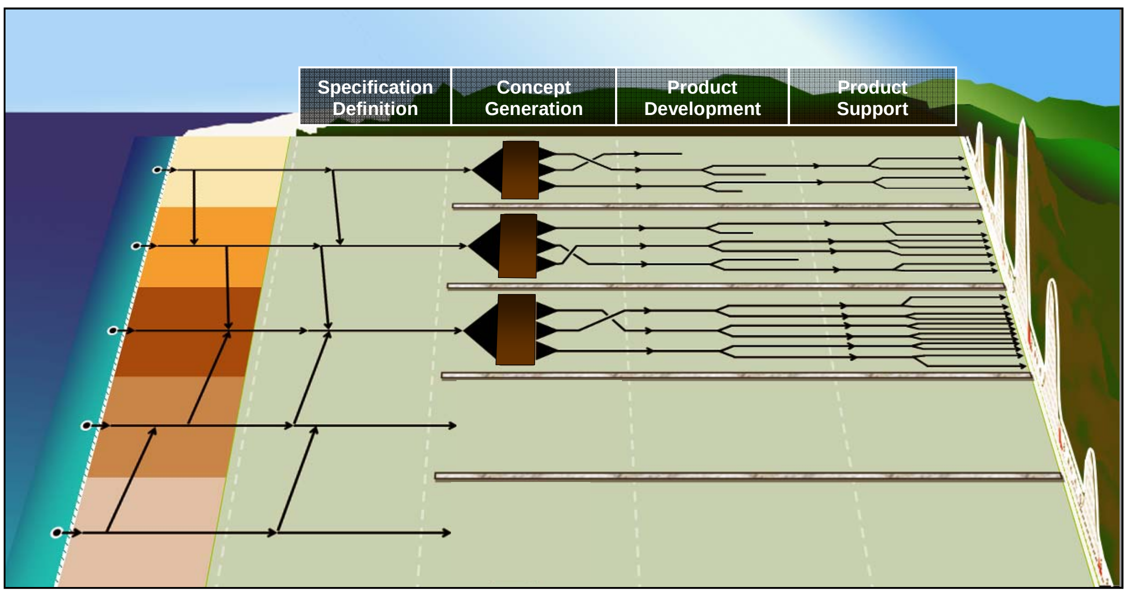


Figure 174: The complete central, intermediate, and most outlying (top) path subsets

subset is that, during product development, the probability that a concept can be developed into a viable product is greater. For graphical simplicity, that probability for the central path subset is approximated as 100-percent in Figure 174. The probability for the intermediate process path subset is lower, and is depicted as 67-percent. For the most outlying path subset (i.e., at the top of the figure), the probability drops further, and is shown as 33-percent.

During product development, the consequences of an incomplete understanding of the problem or opportunity become apparent. Assumptions are often necessary to act as a substitute for clarifying data that is not gathered or examined. Difficulties arise as differences between the true nature of a problem or opportunity and incorrect assumptions start showing up during concept modeling, prototyping, or testing. During evaluations by potential customers, including end-users, aspects of the problem or opportunity previously unknown to the design team are provided as feedback about what is insufficient, missing, or plain wrong with the product. Basically, the worse the problem or opportunity understanding is going into concept generation, the less likely that a viable product or response will be realized at the end.

Figure 175, below, presents the last two process path subsets. There is some symmetry. While concepts and paths are likely different, because of different initial perceptions, the probabilities of viable products are symmetrical for the last two path subsets with those on the other side of the central subset.

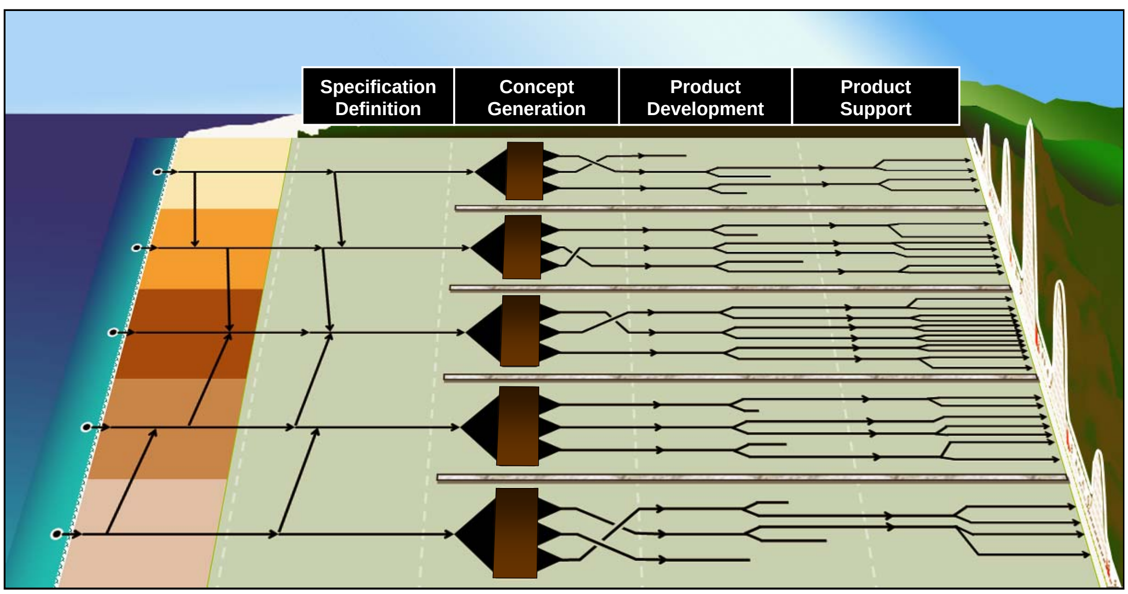


Figure 175: All five complete design path subsets

A shortcoming of the design process characterizations that minimize the significance of problem or opportunity clarification is that reliance solely on a thorough specification definition can improve understanding only so much. Beginning at a fairly poor understanding of a problematic opportunity, and doing an excellent specification definition still falls short of reaching the central process path subset. The large dot and yellow arrows on the top left of Figure 176, below, show this limitation.

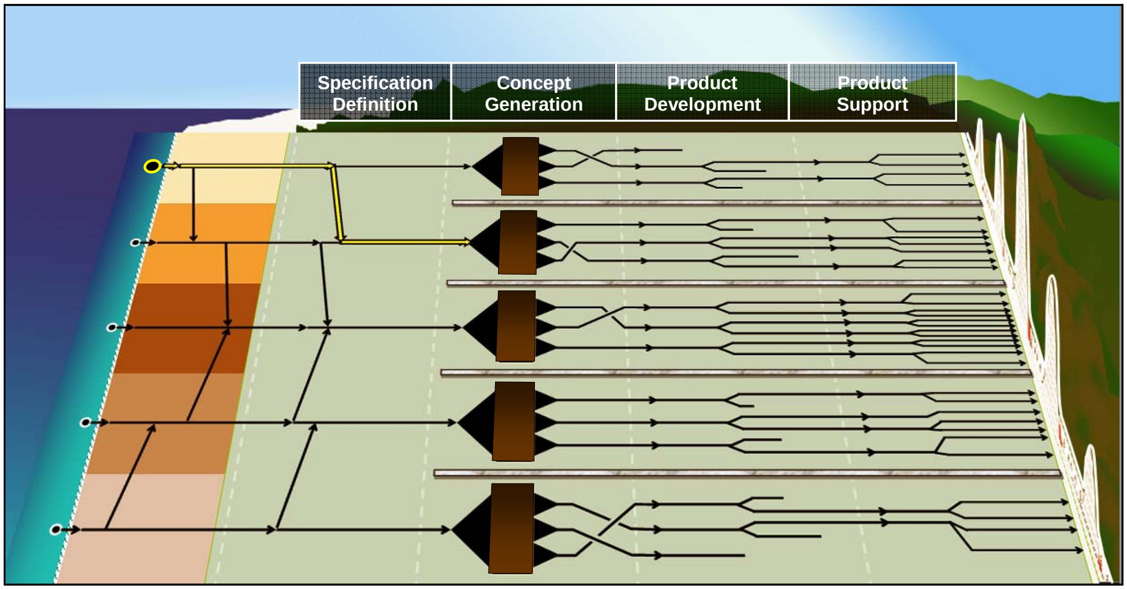


Figure 176: The limitation of relying solely on thorough specification definition in improving understanding of a problem or opportunity

In Figure 177, on the next page, the new design process path model is combined with the top two-thirds of Figure 149. This combined figure represents a model of current multi-disciplinary design teams, and the high procedural uncertainty that they encounter, as well as the impact of initial problem or opportunity understanding on the probability of realizing a viable product. This is the status quo that the engineering design and problem solving process overview document is intended to alter in positive ways. Figure 178, on page 134, shows the addition of the overview document to the model. It also shows the effects on procedural knowledge due to use of the document during the design process. The design engineer's procedural knowledge, which is considerable to begin with, becomes even greater. Further, each of the other team members' procedural knowledge increases significantly.

The two primary intended effects of the overview document are highlighted in Figure 179 (on page 135). First, with each design team member having increased procedural knowledge, procedural uncertainty drops to a low level – which is good. Second, the document reinforces the idea that the first phase in the design process involves efforts to define the

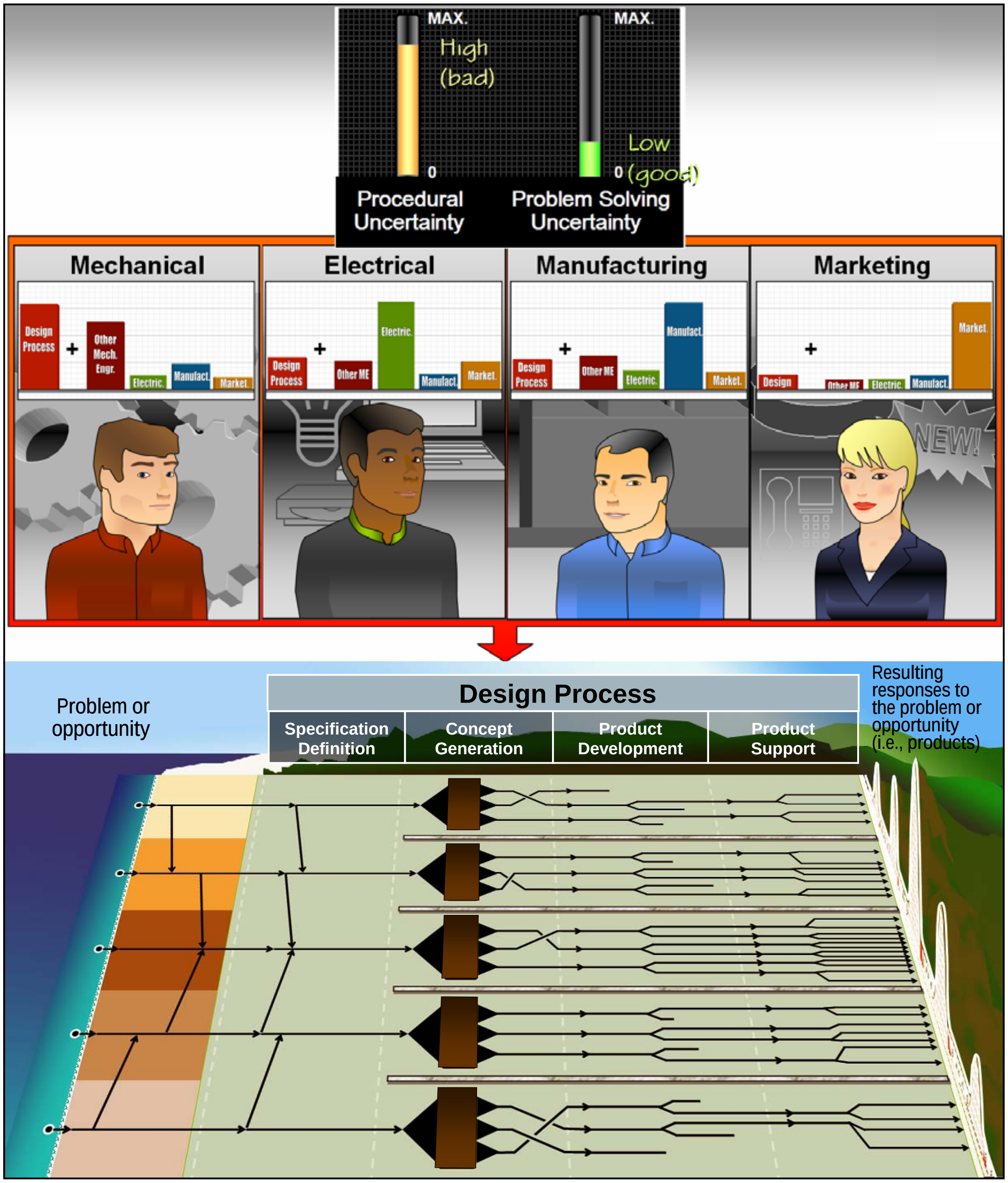


Figure 177: Combining the multi-disciplinary design team and the design process path model

problem or opportunity that supersede the initiation of specification definition techniques such as a QFD House of Quality.

Greater efforts to increase problem or opportunity understanding earlier in the process increase the likelihood of having a viable product at the end. When beginning at the same fairly incomplete understanding of the problematic opportunity as back in Figure 176, and

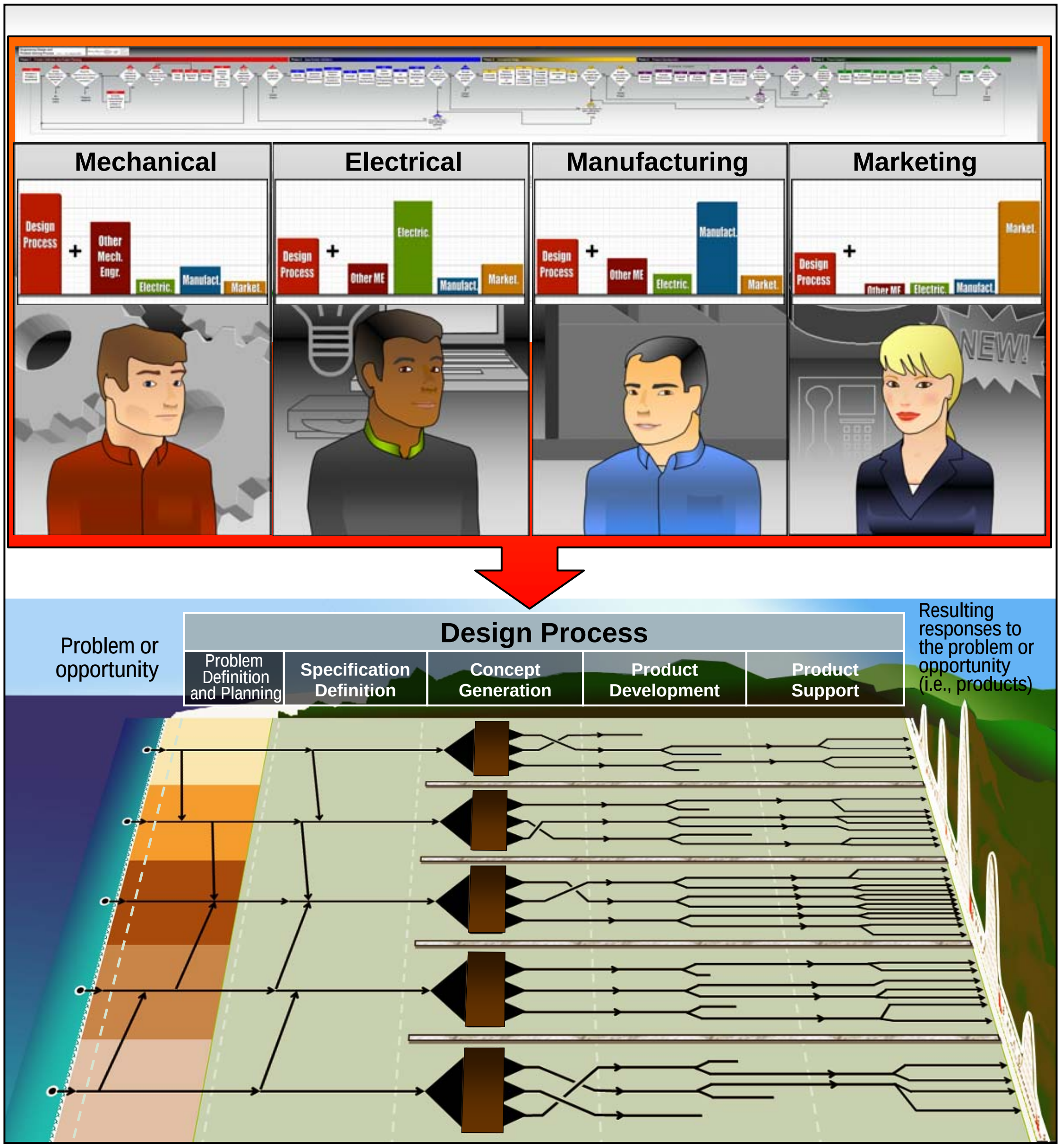


Figure 178: Addition of the overview document to the design team's efforts and the resulting increases in individual procedural knowledge

immediately pursuing greater problem or opportunity understanding, a team puts itself on a path that provides them two opportunities to get to the preferred central process path subset (see the dot and orange arrows in Figure 179, on the next page). The first of the two path opportunities involves a doubling of the efforts so far during problem definition. Alternatively, a second path is available in specification definition. This time, extra effort during specification definition can get the design team onto the path towards the largest distribution of potential products.

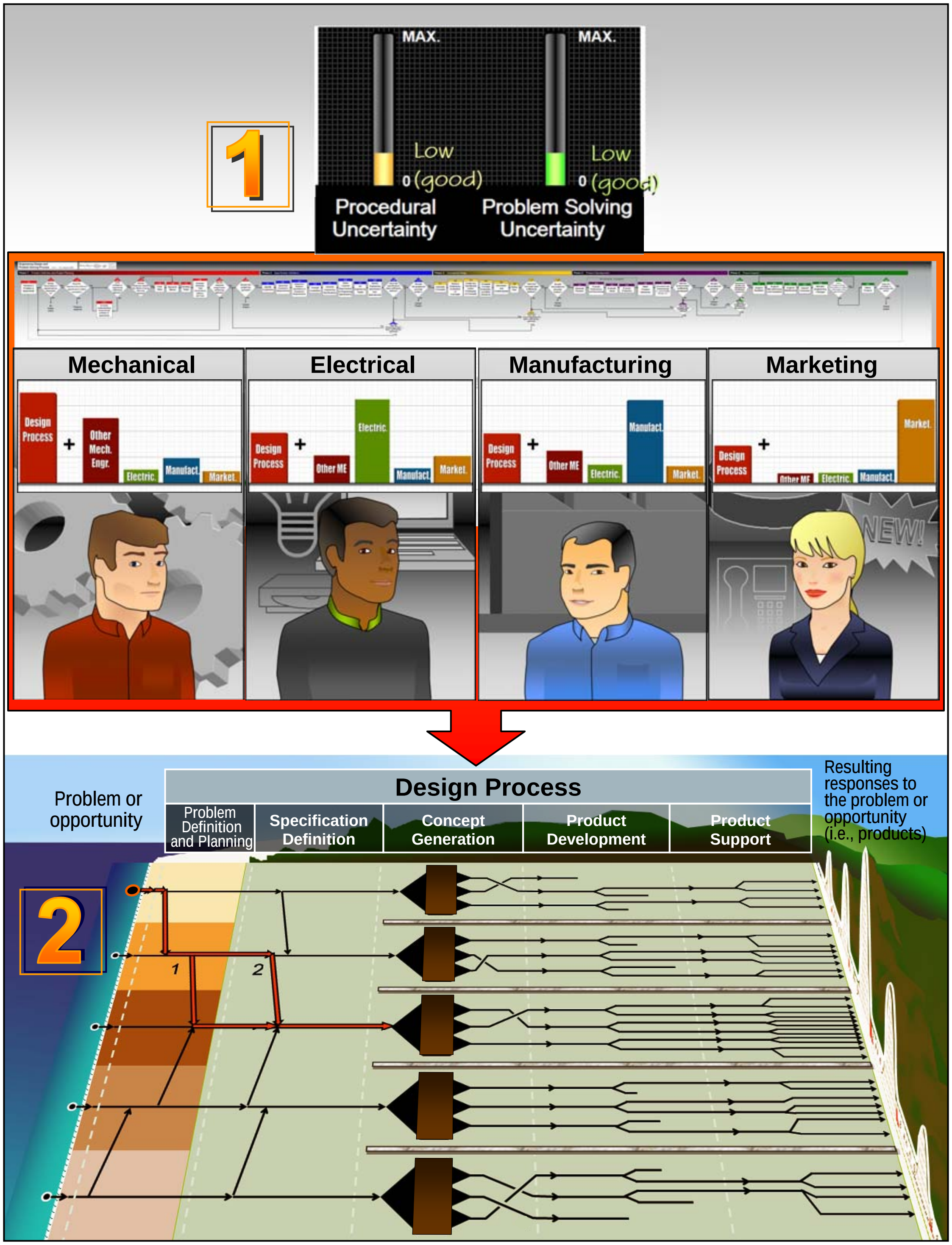


Figure 179: A representation of the hypothetical improvements to both the design team procedural uncertainty and initial problem definition efforts that are the intended contributions of the process overview document

[Disclaimer: The people and situation described here are hypothetical. If someone finds himself or herself washed up on a real island, the preceding model description should not be taken as literal island survival advice.]

Chapter 6 ─ Conclusion

It seems possible. Members of a design team stand before a large flat display screen as wide as the room itself. Displayed in front of them is their design project, clearly laid-out and updated in real-time. Evidence of the design work so far is a hyperlink or two away. Also readily available are all of the following: process clarifying information, company standards, CAD models, parts lists, and contact information. Other design team members, half-the-planet away, join them via a video-conference. Any needed language translation and unit conversion occurs automatically and instantaneously. A supplier has also video-linked in from the other coast. The team reviews the results of process model simulations done to examine the potential impact of possible fluctuations in a needed production resource. A contingency plan is developed; and a note linked to the schedule is added, so that the issue is revisited next time. Members are focused on contributing their expertise and solving the problem, and not on wondering how they fit in to what is going on.

If the process overview document is found to contribute to improved design, perhaps other applications of the idea are possible. Response projects to natural disasters may, as a result, become more successful. Teams of medical experts might more easily tackle widespread health issues, or save a specific patient. If used in training, with a task scheduling chart incremented in minutes, if not seconds, emergency responders might develop a mutually shared and internally accessible process description that they can refer to and more efficiently deal with dynamic crisis situations.

The utility of the engineering design and problem solving process overview document needs further assessment. Evidence of utility is necessary for actual design teams to adopt such an innovation in knowledge management and capture. While the experiment conducted does not provide generalizable evidence, its goal was more modest – establishment of an experimental model. In the effort to do so, however, an initial version of the process overview document had to first be created. To explain the document's intended benefits, a second design process model was developed. Perhaps, amongst the three main products of this thesis, some positive contribution to engineering design, and to problem solving in general, will result.

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Appendix

Oregon State University OSU | Institutional Review Board
Office of Sponsored Programs and Research Compliance

Initial Application

*Please read through the entire application before beginning. Requested information must be typed and submitted to the Human Protections Administrator, Office of Sponsored Programs and Research Compliance, 312 Kerr Administration Bldg. **Be sure to allow adequate time for review and comments. Incomplete requests will delay the review process.** Applications will be returned without review if the application involves technical language without common explanations or if the application is poorly constructed grammatically. Send an email to IRB@oregonstate.edu or call (541) 737-8008 with any questions.*

Project Title: Engineering Design Knowledge Management and Capture Using a Process Overview Document			**IRB Application #:** Assigned by IRB Office
Principal Investigator: Paasch, Robert K. ; Ph.d		**Department:** Mechanical Engineering	
PI Email: paasch@engr.orst.edu			**PI Telephone:** (541) 737-7019
Student Researcher: Zarins, Andis M.		**Class or Degree Program (if requirement for student):** Masters of Science	
Primary Contact Person: Zarins, Andis M.	**Email:** zarinsa@onid.orst.edu		**Telephone:** [redacted]
Campus or US Mail Address (to send correspondence): [redacted]			**Date:** 11/20/2006

1. **Level of Review Requested:**

☐ Exempt from Full Board — Allow a ***minimum of two weeks for the initial review*** and additional time for modifications, if required for approval.

☒ Expedited — Allow a ***minimum of one month for the initial review*** and additional time for modifications, if required for approval.

☐ Full Board — A schedule of upcoming Full Board meetings and submission deadlines can be found at: http://oregonstate.edu/research/osprc/rc/humansubjects.htm

2. **Method of Submission:**

☐ Via campus/US mail — Hard copy of application and appropriate materials (e.g., recruitment materials, informed consent document) sent in mail. ***For Exempt from Full Board applications submit 1 copy, for Expedited and Full Board applications submit 3 copies.***

☒ Via email — Submit application and appropriate materials as email attachments. ***The signature page (page 4) must be mailed or faxed to complete the application.***

3. **External Funding** (present or proposed):

☐ **Yes** Contract or grant title: _____
Funding source: _____
If funded by NIH, DHHS, PHS (including subcontracts), submit a copy of the grant.

☒ **No**

4. Certification of Education:

All research staff involved in this project must receive training in the ethical use of human participants in research. To document this training, the **Certification of Education form** must be submitted (available at: http://oregonstate.edu/research/osprc/rc/humansubjects.htm) . The Certification of Education form is **NOT** the confirmation issued by the educational tutorial. The Certification of Education form needs to be submitted only once for each researcher. ***Submission of all necessary certificates is a prerequisite to review.**

Research Staff Name	Role in Project	Certification of Education Submitted
Paasch, Robert K.; Ph.d	Principal Investigator	☒ Yes ☐ No*
Zarins, Andis M.	Student Researcher	☒ Yes ☐ No*
Ge, Ping (Christine); Ph.d	Co-Advising Professor	☒ Yes ☐ No*
		☐ Yes ☐ No*
		☐ Yes ☐ No*
		☐ Yes ☐ No*
		☐ Yes ☐ No*
		☐ Yes ☐ No*
		☐ Yes ☐ No*

Attach additional sheet if necessary.

5. Project Start Date (i.e., recruitment of human participants): 1/2/2007

6. Expected Duration of the Study: 12 weeks

7. Does this study only involve de-identified data or samples?*

☐ **Yes** If "yes", then skip to Question 10.

☒ **No**

*Research involving the collection or study of existing data, documents, records, tissue culture cells, or pathological/diagnostic specimens, if these sources are publicly available or if the information is recorded by investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to subjects.

8. Risk/Benefit Assessment:

☒ Minimal risk

☐ Greater than minimal risk, but holds prospect of direct benefit to subjects

☐ Greater than minimal risk, no prospect of direct benefit to subjects but likely to yield generalizable knowledge about the subject's disorder or condition

☐ Research not otherwise approvable but presents an opportunity to understand, prevent, or alleviate a serious problem affecting the health or welfare of the subjects.

9. Subject Population:

Number of subjects that will be enrolled over the life of the study: six
In order to enroll more than the number specified, a Project Revision request must be approved.

Participant age range (check all that apply):
Populations designated with an asterisk (*) are vulnerable populations and ineligible for exempt review.

- ☐ *0-7: Youth (include parental consent form)
- ☐ *8-17: Youth (include assent and parental consent)
- ☒ 18-65
- ☐ 65 and older

Populations targeted in this research (check all that apply):
Populations designated with an asterisk (*) are vulnerable populations and ineligible for exempt review.

- ☐ *Persons with mental/emotional/developmental disabilities
- ☐ Gender imbalances – all or more of one gender
- ☐ *Minority group(s) and non-English speakers
- ☐ *Pregnant women/fetuses/IVF
- ☐ *Prisoners
- ☐ Elderly subjects

10. If the research involves any of the following, check the appropriate box:

- ☐ Audio or videotaping
  Ineligible for Exempt review
- ☐ Deception
  Requires review at Full Board level
- ☐ Radiation
  Complete and submit Attachment A
- ☐ Human materials (i.e., blood or other bodily secretions)
  Complete and submit Attachment B
- ☒ Survey/questionnaire
- ☐ Behavioral observation
- ☐ Study of existing data
- ☐ Microorganisms or recombinant DNA
- ☐ Waiver of documentation (signature) of informed consent
  Include justification in the protocol
- ☐ Waiver of informed consent
  Include justification in the protocol
- ☐ Consent material in another language
  Include consent material in other language and an English translation; provide details regarding qualifications of translator and of research staff obtaining consent in other language
- ☐ Other research site (i.e. school, tribal reservation, etc)
  Provide documentation of the approval of the relevant IRB, school principal, tribal office, etc.
  Name of other research site(s):
- ☐ International research site
  Provide documentation of the approval of the relevant IRB, community leader, FWA, etc.
  Name of international research site(s):
- ☐ Submitted to another institution's IRB for review
  Name of institution:

11. Attachments (check all that apply):

- ☒ Protocol *(required)*
- ☒ Consent Document
- ☐ Assent Document
- ☐ Attachment A: Radiation
- ☐ Attachment B: Human Materials
- ☐ Grant (required for NIH, DHHS, PHS funded projects)
- ☒ Recruiting tools (scripts for recruitment/screening)
- ☒ Test instruments (e.g., questionnaires, surveys)
- ☐ Material in other languages
- ☒ Additional information (e.g., debriefing materials)
- ☐ Approvals from other research sites (other IRB, school principal, tribal office, etc)

12. Will the study need to be registered with ClinicalTrials.gov?

☐ **Yes** For more information: http://www.oregonstate.edu/research/osprc/rc/humansubjects.htm

☒ **No**

13. Conflict of Interest:

Federal Guidelines require assurances that there are no conflicts of interest in research projects that could affect the welfare of human subjects. If this study presents a potential conflict of interest, additional information will need to be provided to the IRB. Examples of potential conflicts of interest may include, but are not limited to:

- A researcher or family member participating in research on a technology, process or product owned by a business in which the faculty member holds a financial interest
- A researcher participating in research on a technology, process or product developed by that researcher
- A researcher or family member assuming an executive position in a business engaged in commercial or research activities related to the researchers University responsibilities
- A researcher or family member serving on the Board of Directors of a business from which that member receives University-supervised Sponsored Research Support

For more information: http://oregonstate.edu/research/osprc/rc/conflictofinterest.htm

Conflict of Interest Statement:

Could the results of the study provide a potential financial gain to you, a member of your family, or any of the co-investigators that may give the appearance of a potential conflict of interest?

☐ **Yes** Please describe any potential conflicts of interest in a cover letter and disclose in the informed consent document.

Has this potential conflict been disclosed and managed? ☐ **Yes*** ☐ **No**

☒ **No**

IRB will confirm with Conflict of Interest Officer that potential conflicts of interest have been managed. Final IRB approval cannot be granted until all potential conflict matters are settled. The full IRB committee grants final approval regarding the disclosure of conflict statement in the consent form.

By signing below, I certify that the above information is accurate and complete. I understand that research involving human participants, **including recruitment**, may not begin until full approval has been granted by the IRB.

Signature____ Date_________________________________
Principal Investigator (required) *

***If submitting Initial Application via email, mail or fax this page with the PI's signature to the Human Protections Administrator.**

Protocol

for Thesis Experimental Project Entitled

Engineering Design Knowledge Management and Capture Using a Process Overview Document

1. Brief Description

The experimental project has two goals:

1) Understanding how the use of a process overview document impacts knowledge management and capture in engineering design.
2) Establishing an experimental model for examining the process overview document's effectiveness in helping manage and capture knowledge in a multi-disciplinary design team.

Experimental results are to be used in a Mechanical Engineering graduate student thesis that will be presented in a defense and available in written form in the library.

Hypotheses

This experiment has two hypotheses:

H₁: Groups that use the process overview document to manage and capture knowledge will generate higher numbers of communicative acts to orient the group and establish procedures than those groups that do not use the process overview document.

H₂: Groups that use the process overview document to manage and capture knowledge will generate higher numbers of communicative acts to analyze the problem or task than those groups that do not use the process overview document.

2. Background and Significance

Engineering can be generally defined as the application of science and mathematics to useful purpose in the form of machines, structures, and/or systems (Merriam-Webster, 2004). Three types of particular knowledge needed in engineering are *general* knowledge, *domain-specific* knowledge and *procedural* knowledge (Ullman, 2003, 43-44). An engineer has two places to which to turn for this knowledge: 1) the engineer's own mind and memory, or 2) some external information source.

Engineering design and problem solving most often involves more than one person. The involvement of multi-disciplinary experts, or use of a concurrent design team, significantly increases the domain-specific specialty knowledge being applied throughout the process. General knowledge also increases, as does specialty procedural knowledge. However, the *average* overall design process knowledge of team members decreases with concurrent engineering. This decline, of course, is based upon the assumption that design engineers have a greater understanding of the design and problem solving process than specialty engineers or others (i.e., marketing, etc.). The realized benefits of concurrent engineering are likely reduced due to the lower average overall process understanding.

A document that provides a process overview, brief clarifying information, and worksheets is intended to help both manage existing engineering knowledge and capture the knowledge created during design. Use of such a document might lead to communication that maximizes the benefits versus costs of the solutions generated by small group problem solving (Propp and Nelson, 1996).

SOURCES: Merriam-Webster Online Dictionary (2005).
Propp, K. M., & Nelson, D. (1996). Problem-solving performance in naturalistic groups, *Communication Studies*, 47, 1, 35-45.
Ullman, D. (2003). *The mechanical design process* (3rd Edition). Boston, MA: McGraw-Hill.

3. Methods and Procedures

January 30, 2007 Recruitment of subjects begins.

February 7, 2007 A recruitment meeting is held in a Mechanical Engineering Department building. Approximately 60 minutes in length and occurring sometime between 7:00 and 10:00 pm, the meeting has four parts: 1) Welcome and the excusing of those in the wrong place, 2) Informed consent, 3) Pre-experiment questionnaire, and 4) Clarification of the next step.

February 8, 2007 The potential subjects' status as enrolled students in their claimed majors is confirmed. Two people from each of three majors are selected (for a total of six people) and divided into two design teams that have one member from each of the three majors. A coin toss decides which group is the control and which is experimental. Selected and not-selected potential subjects are informed by 6:00 pm via email.

February 12, 2007 [Note: All of the following is true for both the control and experimental group, except for what is in **bold**. The items in **bold** identify how the experimental group differs from the control group.]

Each team meets at the site of their designated project team room. Meetings are to be about 30-60 minutes in length. The rooms are likely in Rogers or Dearborn Hall, or the Kelley Engineering Center. **The starts of the two meetings are staggered by one hour, with the experimental group meeting occurring second. (The control group meeting is expected to be shorter and less likely to run-over.)**

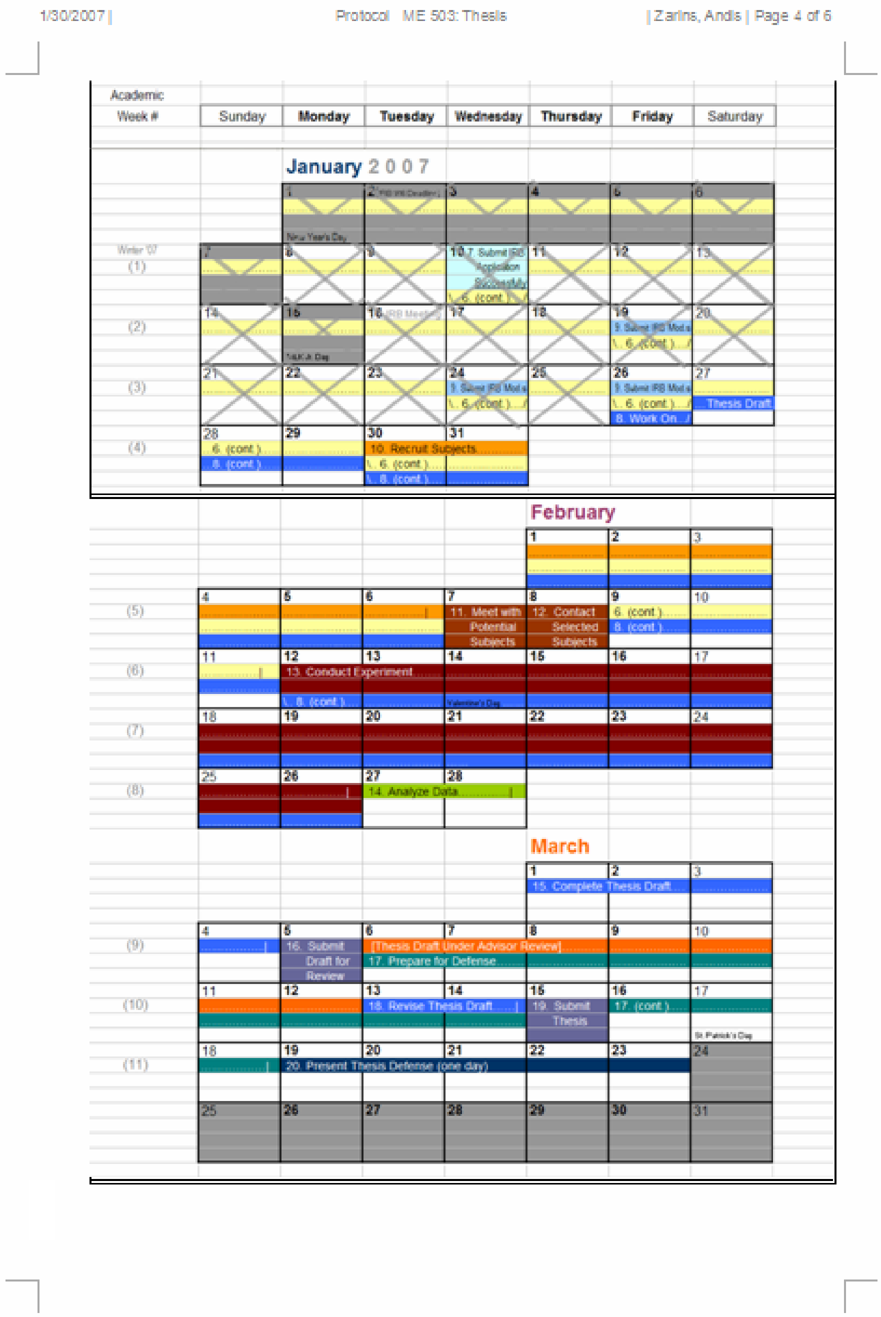
The project rooms include: one table, three chairs, three pads of paper, four new mechanical pencils, one clock, one reference set, and one computer (i.e., a PC) with Microsoft Office and a calculator, but no internet connection or other software. **Included in the experimental group room is an engineering design and problem solving process overview document set, made up of: 1) two Excel files (one blank, and one an example), 2) a three-ring notebook, and 3) a wall-sized poster.**

During the initial group meetings, each group is instructed that they are a new product design team at an aircraft interior product company. Each group's attention is directed towards a folder that is described as having a print-out of an email from their boss and other information. That other information includes four news articles, some federal regulations, and a diagram of an airplane interior with dimensions.

The group members are further instructed that they are to work together a total of 20 hours in the project room over the next two weeks to reach a consensus solution that they will submit, in person, in their project rooms at the same time of day as this initial meeting. They are provided forms and asked to maintain daily journals

(continued)

February 12, 2007 (continued)	documenting their work. **The experimental group has journal items referring to the overview document, while the control does not.** Also, the groups are provided the code for a key box on their project room door. They are told to use the room during regular business hours (i.e., likely 7:00 am to 12:00 midnight). Further, they are told to keep the project to themselves, and they are instructed to use any of the reference materials provided in the project room. **For the experimental group, the reference set includes the overview document set, which is described and demonstrated to them for about 15 minutes.**
Next Two Weeks	Groups work by themselves to accomplish task.
February 26, 2007	Groups meet in their respective project rooms and submit the results of their efforts, including journals. Subjects are then asked to complete a post-experiment survey for the next 20 minutes. The survey requests responses for 25 statements. **Some of the statements on the experimental group survey refer to the overview document, while the control group's does not.** After answering any questions, the subjects are reminded of payment arrangements, reminded not to talk about the experiment to other students for the next 24 hours (so as to avoid 'contaminating' other subjects who have yet to complete their participation), thanked, and released.
February 27, 2007	Concept scoring and data analysis begin. Identification of the 'best concept' is to be based on scored evaluations of: 1) information provided necessary for making the concept a reality, 2) concept characteristics related to the diffusion of innovations, and 3) captured design knowledge. Subjects were provided general criteria for 'best concept' determination in the Informed Consent Document (under the "What will happen…?" section). Specifically, "[s]coring of the concepts to find the 'best' will consider concept characteristics and supporting information.
March 2, 2007	'Best concept' determination is complete.
March 5, 2007	Subjects can pick-up payment at Mechanical Engineering Department Office in Rogers 204 during regular office hours (i.e., 8:00 am to 12:00 noon, and 1:00 pm to 5:00 pm). The total time required of subjects is estimated at 23 hours.
March 6, 2007 to March 23, 2007	Data analysis is completed. Thesis is finished, submitted, presented, and defended.


1/30/2007 | Protocol ME 503: Thesis | Zarins, Andis | Page 4 of 6
Academic Week #
Sunday
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
January 2007
New Year's Day
Winter '07
(1)
(2)
(3)
(4)
7. Submit IRB Application Successfully
6. (cont.)
9. Submit IRB Mod.s
Thesis Draft
8. Work On...
10. Recruit Subjects
8. (cont.)
February
(5)
(6)
(7)
(8)
11. Meet with Potential Subjects
12. Contact Selected Subjects
13. Conduct Experiment
Valentine's Day
14. Analyze Data
March
(9)
(10)
(11)
15. Complete Thesis Draft
16. Submit Draft for Review
[Thesis Draft Under Advisor Review]
17. Prepare for Defense
18. Revise Thesis Draft
19. Submit Thesis
17. (cont.)
St. Patrick's Day
20. Present Thesis Defense (one day)

4. Risks/Benefit Assessment

Risks

There is minimal risk to subjects; that is, risk associated with participation is comparable to the level of risk associated with typical educational and examination situations.

Benefits

There are no direct benefits to subjects. The benefit of an experience as a member of a multi-disciplinary engineering design team is an indirect benefit to subjects. Society benefits indirectly from the establishment of an experimental model framework that can be used to conduct more extensive research that might be generalizable.

Conclusion

Subjects encounter minimal risk while benefiting from a multi-disciplinary design team experience that also provides society a model for future experiments.

5. Participant Population

About 12-20 senior level undergraduate Oregon State University students are to be recruited for the experiment. A maximum number of 20 participants will be involved in the experiment. More specifically, the students will have majors that might be represented on a non-academic multi-disciplinary engineering design team. A minimum of six subjects are needed to participate in the three person control group and the three person experimental group. Four majors are recruited: 1) Mechanical Engineering (ME), 2) Industrial and Manufacturing Engineering (IME), 3) Design and Human Environment (DHE), and 4) Exercise and Sports Science (EXSS).

At the recruitment meeting, potential subjects fill-out pre-experiment surveys. In the case that more than 20 potential subjects show up for the recruitment meeting, 60 sets of Informed Consent Documents and 60 pre-experiment surveys will be available (i.e., a set of the consent document includes one copy to sign and one copy for the subjects to keep). If additional copies are needed, a copier will be available during the meeting (in the next room) to make more. Further, if more than 50 people show up (the meeting room capacity is 50), a backup room has been reserved that will seat 94 just down the hall. A sign will be posted on the outside of the initial room indicating any room change. Further, the maximum number of participants is 94. When the maximum has been reached – that is, all the chairs appear to be full – the room doors will be closed with signs posted on the outside of the doors stating that the meeting is in progress. Additionally, the sign will request that no one more enters, and the sign would thank anyone turned away for their interest. The same sign will be posted on the door(s) of either meeting room just prior to the start of recruiting meeting script being read. Posting of the signs is to ensure that everyone is there from the start of the meeting, and to limit the number of disruptions.

Two people from each of three majors are selected (for a total of six people) and divided into two design teams that have one member from each of the three majors. To help insure that at least two appropriately qualified subjects from at least one non-engineering major show up to participate in an engineering department experiment, two non-engineering majors are recruited (i.e., DHE and EXSS). Priority for major selection is (from highest to lowest): 1) ME, 2) IME, 3) DHE, and 4) EXSS. GPAs and project team experience is balanced. Researchers will verify subjects' majors by requesting that major departments confirm that the names and levels provided by subjects on pre-experiment surveys are correct based on departmental lists of students.

6. Subject Identification and Recruitment

Recruitment involves posters and emailed notices. Letter-sized recruiting advertisements are to be posted, beginning January 30, 2007, in equal numbers in department buildings for Mechanical Engineering (ME), Industrial and Manufacturing Engineering (IME), Design and Human Environment (DHE), and Exercise and Sports Science (EXSS). On or after January 31st, recruitment notices are emailed to students in the above majors as part of weekly department e-bulletins or separately, if necessary. The emailed notices are sent only during the week beginning January 30th.

7. Compensation

Subject compensation is $10.00 an hour for a total of 20 hours; so that each participant receives $200.00. Participants that do not participate for the entire 20 hours receive payment based on the hours actually involved. The hours are to be determined using work log entries cross-checked against other group members' entries. Additionally, a $100.00 bonus is to be given to each member of the group that generates 'the best design'. Determination of the best design will be made by the averaging the evaluation scores (from provided Excel scoring forms) of the Principal Investigator, the faculty co-advising professor, and the graduate student researcher (see application for names).

8. Informed Consent Process

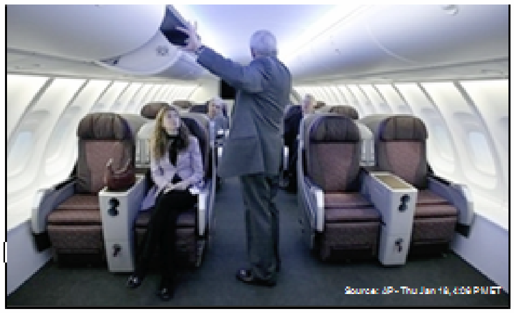
At the subject recruiting meeting, potential subjects will be provided copies of an informed consent document. The document is based on an informed consent document template provided on the Oregon State University IRB website. At the recruiting meeting, the consent document will be read out loud, any questions answered, and copies given to potential subjects who submit signed forms.

9. Anonymity or Confidentiality

Completed forms and documents will be placed in a lockable document carrier and kept with an investigator during transport to a secure location. Data in electronic files will be password protected.

ME, IME, DHE, and EXSS Seniors

Do Design



and Make up to $300

Be a member of a design team that develops ideas to enhance the experience of airline travel. If you are a senior ME, IME, DHE, or EXSS student, you could earn up to $300 by doing design. During a two week experiment conducted through OSU's Mechanical Engineering Department, students are to spend 20 hours working as members of a design team. For those interested, please attend the recruiting meeting on Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

If you have questions, please contact:

Robert K. Paasch; Ph.D
Associate Professor
Mechanical Engineering
414 Rogers Hall
541-737-7019
paasch@engr.orst.edu

Oregon State UNIVERSITY OSU

Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

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Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

Design Experiment Meeting
Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

Design Experiment Subject Recruiting

Senior ME, IME, DHE and EXSS students can earn up to $300 by doing design. During a two week experiment conducted through OSU's Mechanical Engineering Department, students are to spend 20 hours working as members of a design team. For those interested, please attend the recruiting meeting on Wednesday, February 7th, at 7:00 pm in Rogers Hall 226.

If you have questions, please contact:

Robert K. Paasch; Ph.D
Associate Professor
Mechanical Engineering
414 Rogers Hall
541-737-7019
paasch@engr.orst.edu

Student Researcher: I would like to welcome to the recruiting meeting for a design experiment that is being conducted through the Oregon State University Mechanical Engineering Department. If any of you are here for some other reason, would you please excuse yourselves. [Wait for anyone who begins to leave to finish doing so.] Thanks.

My name is Andis Zarins, and I am a graduate student in Mechanical Engineering. I am also a student researcher on this experiment.

The rest of this meeting should take about fifty-five minutes, and has three parts. First, you will be provided with copies of an Informed Consent Document, that will we go over together. All of you who are here when we go over the Consent Document need to sign the form, even if you choose not to continue your participation after reading the Consent Document. Also, everyone will be provided a blank copy of the Consent Document for your records. Those who decide not to continue, you will be asked to hand in your signed Consent Document, and excused from the rest of the meeting. Second, those continuing will be asked to complete a brief pre-experiment questionnaire. Lastly, I will describe the next step in the process. Feel free to raise your hand and ask questions at any time. [Pause a moment to find out if any potential subjects have questions.]

[Hand-out Informed Consent Document.]

Everybody has one?

[Read the document out loud; and answer questions, as necessary.]

Once you are done with the document, please give it to me. [Pick-up documents, check for signatures, and hand blank copies back.] If you chose not to continue, please leave now, and thanks for your interest.

Do I have everybody's?

Next, please take a few minutes to complete this brief pre-experiment questionnaire. When you are done with it, please place the completed form in this folder. [Hand-out questionnaire. Answer any questions. Wait. When potential subjects appear done, walk around with folder to receive completed forms.]

Finally, as noted previously, all of you will be notified via email, by 6:00 pm tomorrow, if you have been selected or not selected to participate in the study. Those of you who are selected will be informed of when and where you need to report. Do you have any more questions?

Thanks for your time and interest. You are excused.

Mechanical Engineering Department
Oregon State University, 204 Rogers Hall, Corvallis, Oregon 97331
Tel 541-737-3441 | Fax 541-737-2600 | http://me.oregonstate.edu/

INFORMED CONSENT DOCUMENT

Project Title:	**Engineering Design Knowledge Management and Capture Using a Process Overview Document**
Principal Investigator:	Dr. Robert K. Paasch, Associate Professor, Mechanical Engineering Department
Co-Investigator(s):	Dr. Ping (Christine) Ge, Assistant Professor, Mechanical Engineering Department; Andis Zarins, Graduate Student, Mechanical Engineering Department

WHAT IS THE PURPOSE OF THIS STUDY?

You are being invited to take part in a research study designed to investigate engineering design teams. More specifically, teams that consist of members who are experts in different areas are to use various ways to do design. We are trying to find out how the teams design differently depending on the approach taken. We are studying this because previous research indicates that how small problem solving groups function influences the benefits and costs resulting from their problem solution. Experimental results are to be used in a Mechanical Engineering graduate student thesis that will be presented in a defense and available in written form in the library.

WHAT IS THE PURPOSE OF THIS FORM?

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a senior level undergraduate student with a major that might be represented on a non-academic multi-disciplinary design team.

WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?

On the next page is brief chronological overview of will happen during the study.

(continued)

February 7, 2007	A recruitment meeting is held in a Mechanical Engineering Department building. Approximately 60 minutes in length, the meeting has four parts: 1) Welcome and the excusing of those in the wrong place, 2) Informed consent, 3) Pre-experiment questionnaire, and 4) Clarification of the next step.
February 8, 2007	Selected and not-selected potential subjects are informed by 6:00 pm by email. Teams are to consist of engineering and non-engineering majors. Four majors are recruited: 1) Mechanical Engineering (ME), 2) Industrial and Manufacturing Engineering (IME), 3) Design and Human Environment (DHE), and 4) Exercise and Sports Science (EXSS). Priority for major selection is (from highest to lowest): 1) ME, 2) IME, 3) DHE, and 4) EXSS. Selection will attempt to balance GPAs and project team experience, while having the same three majors represented on each team.
February 12, 2007	Each team meets at the site of their designated project team room. Meetings are to be about 45-60 minutes in length. The rooms are likely in Dearborn Hall. During the initial group meetings, each group is instructed that they are a new product design team. Information clarifying their task is provided. The group members are further instructed that they are to work together a total of 20 hours in the project room over the next two weeks to reach a consensus solution. Further, the teams are asked to keep their involvement in the study confidential until February 28, 2007. The teams are told that their solutions are to be submitted, in person, in the project rooms at the same time of day as the initial meeting. Groups are provided forms and asked to maintain brief daily journals documenting their work.
Next Two Weeks	Groups work by themselves to accomplish task.
February 26, 2007	Groups meet in their respective project rooms and submit the results of their efforts, including journals. Subjects are then asked to complete a post-experiment survey. After any questions, the subjects are reminded of payment arrangements, reminded not to talk about the experiment to other students, thanked, and released.
February 27, 2007	Concept scoring begins. Scoring of the concepts to find the 'best' will consider concept characteristics and supporting information.
March 2, 2007	'Best concept' determination is complete.
March 5, 2007	Subjects can pick-up payment at Mechanical Engineering Department Office in Rogers 204 during regular office hours (i.e., 8:00 am to 12:00 noon, and 1:00 pm to 5:00 pm). The total time required of subjects is estimated at 23 hours.

Again, if you agree to take part in this study, your involvement will last for about 23 hours.

WHAT ARE THE RISKS OF THIS STUDY?

The possible risks and/or discomforts associated with the procedures described in this study are minimal; that is, the risk associated with participation is comparable to the level of risk associated with typical educational and examination situations.

Notification regarding your selection or non-selection will be made by email. Email transmission cannot be guaranteed to be secure or error-free as information could be intercepted, corrupted, lost, destroyed, arrive late or incomplete, or contain viruses.

WHAT ARE THE BENEFITS OF THIS STUDY?

There are no direct benefits to subjects. The benefit of an experience as a member of a multi-disciplinary engineering design team is an indirect benefit to subjects. Society benefits indirectly from the establishment of an experimental model framework that can be used to conduct more extensive research that might be generalizable.

WILL I BE PAID FOR PARTICIPATING?

You will be paid for being in this research study. Subject compensation is $10.00 an hour for a total of 20 hours; so that each participant receives $200.00. Participants that do not participate for the entire 20 hours receive payment based on the hours actually involved. Pro-rated compensation will be determined using work log entries cross-checked against other group members' entries. Additionally, a $100.00 bonus is to be given to each member of the group that generates the 'best design'. Identification of the 'best design' is to be based on scored evaluations of: 1) information provided necessary for making the concept a reality, 2) concept characteristics related to the diffusion of innovations, and 3) captured design knowledge.

WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, completed forms and documents will be placed in a lockable document carrier and kept with an investigator during transport to a secure location. Data in electronic files will be password protected.

If the results of this project are published your identity will not be made public.

DO I HAVE A CHOICE TO BE IN THE STUDY?

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide to stop taking part in the study. Further, you are free to skip any questions on surveys, or questionnaires, that you would prefer not to answer. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

Termination of Study by Investigator/Sponsor

Under certain circumstances, your participation in this research study may be ended without your consent. This might happen because it is discovered that you are not a currently enrolled senior level undergraduate student in one of the majors being recruited.

WHAT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Principal Investigator:	Co-Investigator:	Co-Investigator:
Dr. Robert K. Paasch Associate Professor Mechanical Engineering 414 Rogers Hall 541-737-7019 paasch@engr.orst.edu	Dr. Ping (Christine) Ge Assistant Professor Mechanical Engineering 416 Rogers Hall 541-737-7713 christine.ping-ge@oregonstate.edu	Andis Zarins Graduate Student Mechanical Engineering 541-[redacted] zarinsa@onid.orst.edu

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Participant's Name (printed): ______________________________

______________________________ ______________________

(Signature of Participant) (Date)

Oregon State University - IRB Study #: 3499 Approval Date: 01/30/07 Expiration Date: 01/29/08

Pre-Experiment Survey

Directions: This survey has eight requests for a response and should take approximately five minutes to complete. Please follow the instructions on the survey, and indicate your responses according to the example items presented below.

EXAMPLES:

Requested Information	Response
1. Major:	Industrial and Manufacturing Engineering
2. Minor (if any):	(none)

3. Academic level:

Freshman	Sophomore	Junior	Senior	Graduate Student
○	○	●	○	○
		or		
○	○	✓	○	○
		or		
○	○	☒	○	○

Requested Information	Response
1. Major:	______________________
2. Minor (if any):	______________________

3. Academic level:

Freshman	Sophomore	Junior	Senior	Graduate Student
○	○	○	○	○

4. Overall university grade point average (GPA):

Less than 2.00	2.00 to 2.49	2.50 to 3.00	2.99 to 3.50	3.49 to 4.00
○	○	○	○	○

5. Total number of project teams you have been a member of, in school or elsewhere:

None	One to Five	Six to Ten	Eleven to Fifteen	Sixteen or More
○	○	○	○	○

6. **Name:** **Last:**__________________________**First:**________________________

7. **Email Address:** ____

Dear Potential Design Experiment Participant,

This email is to inform you that you have been selected to participate in the experiment. Please report to Rogers Hall/Dearborn Hall/Kelley Engineering Center [room number] on February 12th at [sometime between 7:00 pm and 10:00 pm.]

Sincerely,
Andis Zarins
Graduate Student
Mechanical Engineering

Dear Potential Design Experiment Participant,

This email is to inform you that you have not been selected to participate in the experiment. Thank you again for your time and interest.

Sincerely,
Andis Zarins
Graduate Student
Mechanical Engineering

2/12/2007 Design Log and Journal Day 1 of 15

1. Log of Time Worked (please enter times):

Started	Finished

☐ Non-Working Day

2. Survey of Activity (please mark one response for each question):

Question	0 (i.e. zero) times	1 or 3 times	4 to 6 times	7 to 9 times	10 or more times
1. How many times did you individually refer to some reference material?	○	○	○	○	○
2. How many times did you individually refer to some reference material to help clarify procedures?	○	○	○	○	○
3. How many times did you individually refer to some reference material to help analyze the problem or task?	○	○	○	○	○
4. How many times did you as a group refer to some reference material?	○	○	○	○	○
5. How many times did you as a group refer to some reference material to help clarify procedures?	○	○	○	○	○
6. How many times did you as a group refer to some reference material to help analyze the problem or task?	○	○	○	○	○

1. **Log of Time Worked (please enter times):**

Started	Finished

☐ Non-Working Day

2. **Survey of Activity (please mark one response for each question):**

Question	0 (i.e. zero) times	1 or 3 times	4 to 6 times	7 to 9 times	10 or more times
1. How many times did you individually refer to some reference material?	○	○	○	○	○
2. How many times did you individually refer to some reference material to help clarify procedures?	○	○	○	○	○
3. How many times did you individually refer to some reference material to help analyze the problem or task?	○	○	○	○	○
4. How many times did you individually refer to the process overview document (Excel file, notebook, or poster)?	○	○	○	○	○
5. How many times did you individually refer to the process overview document (Excel file, notebook, or poster) to help clarify procedures?	○	○	○	○	○
6. How many times did you individually refer to the process overview document (Excel file, notebook, or poster) to help help analyze the problem or task?	○	○	○	○	○

INBOX: Product Opportunity (3 of 58)

Date: Tue, 30 Jan 2007 2:46:33 PM
From: "Smith, J.M." <smithjm@osubeve_aircraft_systems_inc.com>
To: Design Team
Subject: Product Opportunity

Dear Design Team,

Our market research and customer service departments have brought to my attention an opportunity, and I would like you to do some work on developing a product in response. More specifically, legal use of cell phones during entire commercial passenger airline flights might soon become a reality. However, there might be problems associated with this change. To help clarify the opportunity/problem(s), please refer to the additional background information on the topic in the project file folder. Also included is a drawing with some relevant aircraft interior dimensions, and some regulations.

Please come up with a response by working together in your assigned project room a total of 20 hours over the next two weeks. Further, KEEP YOUR PROJECT CONFIDENTIAL. On Monday, February 26th, and by the same time of day as this meeting, have a 'paper' concept ready for review. Provide any documentation of your efforts. The concept and documentation can be on paper and/or in an electronic file (or files) saved on your project room computer.

Finally, the business case appears solid for developing some sort of response, so do not concern yourselves with that aspect of the project. Also, remember that the design team with the best concept earns a bonus. Good luck.

Best regards,
J. M. Smith
Engineering Manager
Osubeve Aircraft Systems Inc.

abc NEWS

Emirates Airline to Debut Cell Phone Calls

The 37,000-Foot-High Sanctuary From Cell Phones Has Crumbled

By LAURA WESTMACOTT

Nov. 10, 2006 — - Dubai-based Emirates Airline announced that it would become the world's first airline to introduce in-flight mobile phone use across its fleet. It has beat rivals Ryan Air and Air France to the post.

Phones are currently banned on all flights as soon as the engines start because they can cause signal surges that can interfere with navigation and communication systems of the cockpit.

The airline has invested $27 million to fit the fleet with equipment supplied by AeroMobile, which will allow passengers' cell phones to operate at their minimum power setting, thereby allowing their safe use.

It will be celebrated by workaholics, who suffer withdrawal symptoms when that all-important umbilical cord is severed between them and their phones.

But what about the millions of customers who found flying light relief from the office or family calls, and now have to contend with the in-flight chorus of "Hi Mom, I'm over Greenland," on top of the wailing babies and constant drone of the engines?

Steve Double, associate director of AeroMobile, told ABC News there is considerable demand for the service, as there are currently 6,000 calls a month placed from the in-seat phones. Double also divulged his company is currently in talks with Qantas, as well as European and U.S. airlines. And he vehemently denied the service would become an annoyance to other passengers.

"A phone etiquette will be put in operation, in much the same way as a restaurant and cinema," Double said. "Passengers will be requested to switch their phones to silent or vibrate mode, and the phone service would be switched off for night flights. The cabin crew will have ultimate control of the system."

There are limitations to the service; it can't be used on takeoff and landing, and during climbs or descents. And only five passengers will be able to make voice calls at the same time.

David Learmount, safety editor of Flight International magazine, said that "most passengers don't want the service; they won't observe phone etiquette and silent cabins will have to be offered."

Some have even voiced safety fears about phones being used to trigger bombs onboard, but Emirates' spokesman, Charlie Hampton, said, "Emirates, in conjunction with AeroMobile, have carried out numerous security evaluations and we have had clearance to operate on 32 of our routes."

Emirates says the phone technology will be rolled out in January 2007, and GPRS (General Packet Radio Service) data and Internet capability will be added as soon as the necessary communications systems are upgraded next year.

So, you'll be able to use your whole office in the skies.

USA TODAY

Cell phone use coming for Airbus fliers

GENEVA (AP) — Passengers will soon be able to use their own cell phones on commercial airliners, under a deal signed Tuesday by European aeronautics giant Airbus and a Geneva-based technology firm.

OnAir's voice and data systems will be a standard option on all new Airbus superjumbo A380 planes from 2006, giving passengers on short- and long-haul flights the chance make calls using their own phones, Chief Executive George Cooper said.

The technology could also be fitted to Boeing jets, and will be used to give passengers Internet access using their own laptops, he said.

"It is going to rapidly become something that people are going to be very upset if they don't have," Cooper told The Associated Press in an interview. "It's not many years ago when most of us had phones that didn't work everywhere, now we expect them to work anywhere."

Users of mobile phones with roaming capability will be able to make and receive calls using a base station within the airplane, which will use GSM technology, the main European system.

Most users will not be able to connect to U.S. or Asian networks, but Cooper said OnAir had "focused on the mobile phone side on GSM, because that is the dominant standard and will be for years."

The company is banking on a large increase in GSM-compatible phones being sold in North America and Asia, he said. But "the main market for voice is short-haul," as business travelers within a connected Europe will increasingly see such a service as a necessity.

"Short-haul journeys tend to be part of a business day, they tend to be in daylight and the person you are calling is quite likely to be in the same time zone as you," Cooper said.

"We think it's likely that the day will come when, if you don't have this, you may actually not get some of those passengers."

OnAir estimates the global market for airliner Internet access at about $400 million annually. For mobile telephone service, revenues could be four times as high.

That would make the combined market worth some $2 billion, catering to more than 700 million people.

The company — a joint venture of Airbus and Netherlands-based IT company SITA Information Networking Computing — is aiming to sell its services to airlines, which could then use the technology in other plane models.

European and Asian companies, as well as some American airlines, have already shown strong interest in fitting their planes with OnAir's technology, Cooper said, declining to name firms that have placed orders.

OnAir hopes that the surcharge for mobile phone use will be competitive, with international call rates at about $2 to $2.50 per minute. A text message should cost about 50 cents to send or receive.

Prices for Internet access will be higher, at about $15 per flight for basic services such as e-mail and $30 for a more comprehensive service, Cooper said.

Planes can be fitted with either wired or wireless connections, but so far airlines have been more keen to use wireless because it weighs less and is cheaper, Cooper said. To log on to the Internet, a user would then need a wireless-capable laptop.

"It is as if we are creating a new country in the sky," Cooper said, stressing that airlines will find ways to regulate the use of cell phones and laptops "so that it doesn't annoy everybody."

Crews will be able to switch the system off when the aircraft enters its local night and the blinds go down. Mobile service could be disconnected, while still allowing text services, he said.

Airlines may introduce new seating plans, to allow nonusers to avoid the noise and potential annoyance from mobile phone conversations, Cooper suggested.

Seattle-based Connexion, a rival provider backed by Boeing, offers a similar Internet service on all Lufthansa flights, allowing passengers to log on using their own laptops at comparable rates of $9.95 for 30 minutes to $29.95 flights longer than six hours.

Find this article at:
http://www.usatoday.com/travel/flights/2005-02-15-airbus-cell-phones_x.htm

☐ Check the box to include the list of links referenced in the article.

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Travel

Business travelers don't want cell phones on airplanes

Saturday, February 04, 2006

The Associated Press

MINNEAPOLIS -- A survey of business travelers around the world shows that most -- 61 percent -- would rather not see cell phone use permitted on airplanes.

Europeans -- 70 percent of them -- were most strongly opposed while North Americans were most amenable, with just 57 percent against cell-phone use during a flight.

Cell phone use is not now permitted on airborne planes for fear that it might interfere with navigation, but a new communications system designed to avoid that problem is scheduled to debut on a couple of European airlines later this year.

The survey of business travelers from 12 countries was commissioned by Minneapolis-based Carlson Wagonlit Travel, one of the world's largest travel firms.

The survey showed that pet peeves vary among business travelers by region. The top annoyance among business travelers in the Asia-Pacific region is crying babies; Europeans are bothered by travelers not checking bags when they should; Brazilians can't stand being disturbed by other passengers; and the No. 1 annoyance among North Americans is people stowing luggage far forward from their seat. All agreed that vacationing travelers are the least of their annoyances.

Those surveyed were less concerned about work-life balance issues and terrorism than in last year's poll.

Airport security lines topped the list of issues with the most negative impact on business travel, with flight delays coming in a close second.

Today:
Opinio
Maureen I
president
refresher
Busine

Fifty-eight percent of business travelers say they extend their business trip to include leisure or vacation time, at least once a year, either at the beginning or end of their trip. Of those, 47 percent said they occasionally or frequently have family or friends join them for the leisure portion of the trip.

The telephone survey randomly sampled the opinions of 2,100 business travelers and 650 travel managers, including customers of the company as well as non-customers, between Oct. 27 and Nov. 23.

Respondents were surveyed in Australia, China, India, and Japan; France, Germany, Italy, Spain and the United Kingdom; Brazil; the U.S. and Canada.

Posted 12/16/2004 11:15 PM Updated 12/22/2004 4:50 PM

Cell phones in the air: Convenience or curse?

By Rick Hampson, USA TODAY

Just when air travel seems to have become our national gripe, along comes a possibility to make us appreciate flight as we now know it: A cabin full of people talking, loudly and simultaneously, on their cell phones.

Hear the prayer of frequent flier Bill Kalmar of Lake Orion, Mich.: "There are so few places these days where we can escape cell phones, pagers, BlackBerrys and CNN. Please let my airline flight be the last comfortable, quiet cocoon that is left to me where I can get lost in my own thoughts."

Yet consider also the petition of Steven Silverman of Westfield, N.J.: "For the road warrior who calls his Samsonite his home, the use of cell phones on airplanes would be the first wish on the list for Santa Claus."

QUICK QUESTION

Should cell-phone use be allowed on airplanes?

◯ Yes

◯ No

Vote now

Latest results

TALK ABOUT IT

Have more to say? Share your opinions about cell phones in our message boards.

Silverman's wish is at least several years from being granted, because the movement to end the ban on airborne cell phones still faces several hurdles.

But the Federal Communications Commission's decision Wednesday to solicit public comment on the issue has ignited a debate. Would the electronically connected airline cabin feel like your den — or like the floor of the New York Stock Exchange? Is stratospheric cell phone service a nightmare or a dream?

It depends on the traveler.

Imagine you're in seat 33B. The person on your left extols the airliner as a sort of flying monastery — a place to read, contemplate, rest, and retreat from the world below. The one on the right laments hours of lost productivity, missed opportunities and work that must be made up on the ground — all for lack of connectivity.

Today's Top Travel Stories

- Maxim magazine to lend name to Vegas casino - 2:23 PM
- China Southern to join SkyTeam year - 12:57 PM
- 10 great places to remember D-D heroes - 10:58 AM
- The business traveler explained -
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Early opinion favors the monastery. The FCC has been barraged with hundreds of e-mails opposing phones on planes. Most of the e-mailers "believe that use of devices that don't involve talking are fine, but are not looking forward to the possibility of hearing more conversations than they do now," says Lauren Patrich, a spokeswoman for the FCC wireless bureau.

It's unclear when or even if cell service will come to airline cabins.

The FCC must be satisfied there's no interference with cell phone service on the ground.

The Federal Aviation Administration must be satisfied there's no interference with the airplane's navigation and electrical systems.

The airlines must be satisfied there's a profit.

The move being considered by the FCC is part of a broader trend to allow airline passengers the communication devices that surround (and sometimes annoy) them in their homes, offices and cars. A few airlines already offer moderately fast Internet connections, and the commission moved Wednesday to permit high-speed Internet connections. Air travelers could be routinely surfing the Web by 2006.

Passengers are now allowed to use electronic devices without radio transmitters — such as video games, CD players and laptops — above 10,000 feet. Some airlines also offer satellite TV. But things like cell phones and pagers are banned from takeoff to touchdown.

The only way passengers on domestic flights can communicate with the ground is on a type of phone found on about 1,500 jets, usually built into seat backs. The phones aren't very popular because of complaints about high cost and poor reception.

Cell phones usually don't work at high altitudes. When they do, they simultaneously communicate with hundreds of cell towers on the ground, clogging networks.

But it's now possible to place a small cell phone tower on each airplane to receive signals from passengers' cell phones and relay them, directly or by satellite, to designated towers on the ground.

And this can be done, according to manufacturers and airlines, without disrupting cell service below or the plane's own navigation or electrical systems.

The tab: $100,000 per plane

The new cell systems would cost about $100,000 per plane but might give the financially-pressed airlines a new source of revenue based on a per-call surcharge.

If the FCC eventually approves passenger use of cell phones, the FAA still must rule on their safety.

The issue of radio frequency interference has become more critical as jets rely increasingly on sophisticated computers and electronic devices. For example, many planes now use the Global Positioning Satellite system, and the weak signal from satellites in space is easily distorted by other radio broadcasts.

Also, studies show that, under some conditions, cell phone signals can interfere with a jet's electronics, primarily the delicate radio receivers that pilots use to navigate or to guide them to runways. Although the new cell system is designed to avoid that problem, an FAA panel is still investigating.

But there is no documented case of a problem caused by an electronic device in flight. The FAA, airlines and jet manufacturers say that they've investigated numerous complaints by pilots and others; in several cases, Boeing purchased from passengers the same devices suspected of causing problems and used them in tests.

"We have never ever been able to duplicate the interference," says David Carson, who co-chairs the FAA-sanctioned group studying whether cell phones and other electronic devices are safe on planes.

The cost of connectivity

So far, no airline has applied for permission to provide cell phone service. "We don't even know if we're going to do this yet," says Billy Sanez, a spokesman for American Airlines. He insists there's a demand, but only up to a point: "Our customers don't want to listen to 250 conversations at once."

The prospect of a flying chatterbox inspires even some of the most disenchanted air travelers to conclude that these are the good old days. "There goes my personal oasis in the sky," moans Richard Catalano, a Cleveland retail food sales rep who logs 250,000 air miles a year.

Randy Peterson, founder of the FlyerTalk Web site, used to agitate for cell calls in flight. But since the rules were loosened — to allow, for instance, phone use as planes taxi to the gate — what he's heard has convinced him it's a bad idea.

He estimates 60% of passengers get on their phones immediately upon landing and only 1% say anything worth saying: "If I hear one more woman calling someone to say, 'We got in three minutes late,' or 'It's raining here.' "

Those who liken an airline cabin to a library in Shangri-La find cell phone legalization troubling for at least three reasons:

•Noise from inside the cabin.

Welcome to frequent flier Bill Kalmar's nightmare: a three-hour flight to Florida on which he is seated between two characters he calls First Time Flier Freda and Very Important Business Person Bob.

"For three hours you will be subjected to Freda's recitation of her drive to the airport, her parking dilemma, being wanded in security, the price of airport food and the lack of space on the plane," he predicts. "This would be accompanied by Business Person Bob conducting a meeting with his staff detailing his strategy for a stock repurchase."

"I'm not a cranky guy," says Bernie Williams, a pharmaceuticals consultant who lives near Indianapolis and commutes to work weekly outside New York City. "But all those stupid rings make me want to reprogram people's phones for them."

•Intrusions from outside the cabin.

When the cabin door closes, it severs the traveler's electronic leash to the outside word.

Michael Loguercio of Ridge, N.Y., travels frequently to sell management software systems to insurance companies. "Sometimes the flight is the only time on a trip that I can truly relax without the annoyance of my cell phone. ... You're constantly in touch with the office, the kids, the wife. Sometimes you want to order a drink, sit back and say, 'You know what? You can't bother me for two hours.' "

•Cabin behavior.

"Passengers currently pay little or no attention to the flight attendants, and would pay less (if they had cell phones). This becomes a safety hazard," says Ira Dale, West Coast regional manager of LifeNet, which provides organs and issues for transplant operations.

Brad Thomas, who travels the western states on business for Kodak (averaging 2,700 cell phone minutes a month) agrees: "I can't imagine the trouble getting everyone seated, buckled in, and so forth. People don't listen to directions for stowing their bags as it is."

Richard Roeper, a Chicago *Sun-Times* columnist, predicts cell use disputes will escalate — from complaint to argument to fight to arrest.

'A happier place'

But the generation that wanted its MTV now demands cell phones in flight. "One of the things in being a successful road warrior is to multi-task at all times," says Silverman, a sales and marketing executive who flies about 80,000 miles a year.

"When you get on an airplane, it becomes somewhat frustrating that you are out of contact," he says. "People need to stay in touch. If airlines reversed the rule, the world might be a happier place — at least for some of us."

David Stempler, president of the Air Travelers Association, a passenger group, says audio and data links would "make business travelers more efficient, and wile away the time for a lot of other passengers. This is all the wave of the future."

Even critics of cell phones aloft admit they probably are inevitable. "People use their cell phones in a variety of inappropriate places. Why should aircraft by any different?" asks Richard Aboulafia, an airline industry analyst with the Teal Group in Fairfax, Va. "We've seen the erosion of civil society everywhere else."

The chatter might not be too bad. George Larson, editor of *Air & Space* magazine, says airline cabins are fairly good noise absorbers, and the engines and ventilation system provide a steady white noise that muffles individual sounds.

Some ideas to tame the airborne cell phone are being discussed:

•**Time limits**. Each cell phone user would be restricted to a certain number of calls or minutes. Williams sees a problem, however: "Short of posting snipers in front and in back, it's gonna be difficult to enforce." Peterson agrees: "Guys I know, they'll be calling from under the seats, in the bathrooms."

•**Calling hours**. Phones could be used only during certain periods, such as the first and last hour of a trans-continental flight. But, again, who would enforce it? "The crew is there to fly us from point A to point B," says Peterson.

•**Quiet sections**. Some Amtrak trains have "quiet cars." Airlines might similarly designate certain rows or sections of the cabin. But the sound of 100 people talking travels, and in this case it won't have far to go. As the Motley Fool Web site observed, "Not even that window seat in the back row will be able to save you now."

•**Phone booths**. They may be almost extinct down below, but soundproof compartments could be constructed in the back of planes — albeit at the cost of precious space.

•**Earphones.** Kalmar again: "On my last flight I wore a set of sound-deadening earphones, and turned off the sound around me, including the engines. Perhaps the airlines should give them to everyone sitting next to someone using a cell phone." But at $100 a set, that seems unlikely.

•**Cellular education**. Many people speak too loudly into their cell phones ("cell yell"), partly because users suspect something so small must lack amplification, and partly because the phones lack the aural feedback of land phones that let people know how loudly they're talking. Now imagine the caller who also feels a need to shout because the other party is 30,000 feet below.

Carol Page, founder of CellManners.com, says cell callers must learn they'll be more easily understood if they tone it down.

Finally, some people would try to escape the din by flying first class. That's where Michael Loguercio was sitting this week when he called to discuss the phone issue. "I'm hoping people up here will have more courtesy," he said. "In back, it'll be a free for all."

Further conversation would have to wait, he said: "They're about to close the door." But at least he was whispering.

Contributing: Alan Levin, Kitty Yancey, Paul Davidson, Barbara Hansen, Laura Bly, Dan Reed, wires.

Federal Aviation Regulation

Sec. 121.215

Part 121 OPERATING REQUIREMENTS: DOMESTIC, FLAG, AND SUPPLEMENTAL OPERATIONS	
Subpart J--Special Airworthiness Requirements	

Sec. 121.215

Cabin interiors.

(a) Except as provided in Sec. 121.312, each compartment used by the crew or passengers must meet the requirements of this section.
(b) Materials must be at least flash resistant.
(c) The wall and ceiling linings and the covering of upholstering, floors, and furnishings must be flame resistant.
(d) Each compartment where smoking is to be allowed must be equipped with self-contained ash trays that are completely removable and other compartments must be placarded against smoking.
(e) Each receptacle for used towels, papers, and wastes must be of fire-resistant material and must have a cover or other means of containing possible fires started in the receptacles.

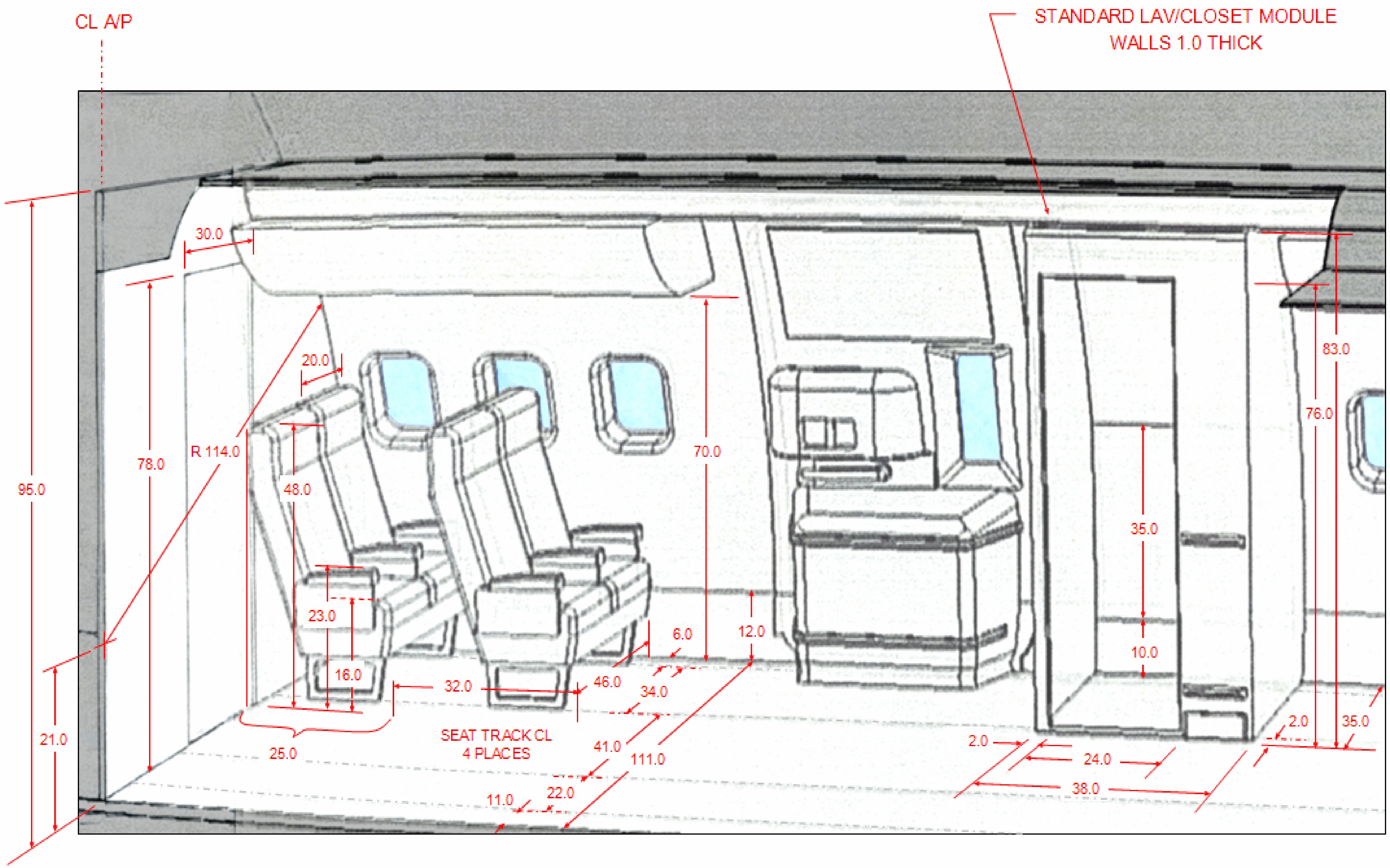
Amdt. 121-84, Eff. 5/1/72

Comments

Document History

Notice of Proposed Rulemaking Actions:

Final Rule Actions:



BXO7 INTERIOR SECTION

ALL DIMENSIONS IN INCHES

NOT TO SCALE

Post-Project Survey

Directions: This post design project survey has 25 requests for a response and should take approximately 15 minutes to complete. Please follow the instructions on the survey, and indicate your responses according to the example question presented below.

EXAMPLE:

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
2. The tools and equipment provided were useful.	○	●	○	○	○	○
or	○	✓	○	○	○	○
or	○	⊠	○	○	○	○

Section 1: Design Problem or Task (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
1. The problem or opportunity was ill-defined.	○	○	○	○	○	○
2. At the start of the project, there was uncertainty as to the eventual solution or response to the problem or opportunity.	○	○	○	○	○	○
3. The problem or opportunity had characteristics that related to course work in my major.	○	○	○	○	○	○
4. The expectation that the problem or opportunity would not be discussed outside the group was realistic.	○	○	○	○	○	○
5. There were identifiable constraints regarding potential solutions or responses.	○	○	○	○	○	○

Comments about the Design Problem or Task (optional)

Section 2: Solution or Response Developed (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
6. Customer requirements were met by the solution or response.	○	○	○	○	○	○
7. The solution or response maximizes utility.	○	○	○	○	○	○
8. I am satisfied with the solution or response that my group developed.	○	○	○	○	○	○
9. The solution or response fails to maximize benefits.	○	○	○	○	○	○
10. The solution or response minimizes costs.	○	○	○	○	○	○

Comments about the Solution or Response Developed (optional)

Section 3: Process (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
11. At the beginning, the process that the group would follow to develop a solution or response was not clear to me.	○	○	○	○	○	○
12. The provided reference materials were helpful.	○	○	○	○	○	○
13. The provided reference materials were sufficient.	○	○	○	○	○	○
14. Having the provided reference materials is better than having <u>only</u> one reference source.	○	○	○	○	○	○
15. The provided reference materials were consistent with the needs of the group.	○	○	○	○	○	○
16. The provided reference materials were complex to use.	○	○	○	○	○	○
17. Use of the provided reference materials could be tried without a significant commitment.	○	○	○	○	○	○
18. The results of other's use of the provided reference materials were readily observable.	○	○	○	○	○	○
19. Our group communicated well.	○	○	○	○	○	○
20. The journal was easy to keep.	○	○	○	○	○	○

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
21. Our group was stressed for time at the end.	O	O	O	O	O	O
22. Information was shared amongst group members.	O	O	O	O	O	O
23. Our group was constructive.	O	O	O	O	O	O
24. In the end, the process that the group followed to develop a solution or response was not clear to me.	O	O	O	O	O	O
25. I would be happy to work with my group again.	O	O	O	O	O	O

Comments about the Process (optional)

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2/26/2007 Post-Project Survey Page 1 of 4

Post-Project Survey

Directions: This post design project survey has 25 requests for a response and should take approximately 15 minutes to complete. Please follow the instructions on the survey, and indicate your responses according to the example question presented below.

EXAMPLE:

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
2. The tools and equipment provided were useful.	○	●	○	○	○	○
		or				
	○	✓	○	○	○	○
		or				
	○	☒	○	○	○	○

Section 1: Design Problem or Task (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
1. The problem or opportunity was ill-defined.	○	○	○	○	○	○
2. At the start of the project, there was uncertainty as to the eventual solution or response to the problem or opportunity.	○	○	○	○	○	○
3. The problem or opportunity had characteristics that related to course work in my major.	○	○	○	○	○	○
4. The expectation that the problem or opportunity would not be discussed outside the group was realistic.	○	○	○	○	○	○
5. There were identifiable constraints regarding potential solutions or responses.	○	○	○	○	○	○

Comments about the Design Problem or Task (optional)

Section 2: Solution or Response Developed (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
6. Customer requirements were met by the solution or response.	○	○	○	○	○	○
7. The solution or response maximizes utility.	○	○	○	○	○	○
8. I am satisfied with the solution or response that my group developed.	○	○	○	○	○	○
9. The solution or response fails to maximize benefits.	○	○	○	○	○	○
10. The solution or response minimizes costs.	○	○	○	○	○	○

Comments about the Solution or Response Developed (optional)

Section 3: Process (please mark one response for each statement):

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
11. At the beginning, the process that the group would follow to develop a solution or response was not clear to me.	○	○	○	○	○	○
12. The provided reference materials were helpful.	○	○	○	○	○	○
13. The process overview document was helpful.	○	○	○	○	○	○
14. Having the process overview document available as a reference is better than having <u>only</u> the standard reference materials available.	○	○	○	○	○	○
15. The process overview document was consistent with the needs of the group.	○	○	○	○	○	○
16. The process overview document was complex to use.	○	○	○	○	○	○
17. Use of the process overview document could be tried without a significant commitment.	○	○	○	○	○	○
18. The results of other's use of the process overview document were readily observable.	○	○	○	○	○	○
19. Our group communicated well.	○	○	○	○	○	○
20. The journal was easy to keep.	○	○	○	○	○	○

2/26/2007 Post-Project Survey Page 4 of 4

Statement	Strongly Agree	Agree	Not Sure	Disagree	Strongly Disagree	Not Applicable
21. Our group was stressed for time at the end.	○	○	○	○	○	○
22. Information was shared amongst group members.	○	○	○	○	○	○
23. Our group was constructive.	○	○	○	○	○	○
24. In the end, the process that the group followed to develop a solution or response was not clear to me.	○	○	○	○	○	○
25. I would be happy to work with my group again.	○	○	○	○	○	○

Comments about the Process (optional)

2/27/2007 Design Concept Scoring Sheet ME 503: Thesis Zarins, Andis | 1 of 2

Group ID: [ ]

Evaluator: [ ]

Directions: Type and enter a lower case x into one box below for each scoring category

Total Points Available: 100

A. Concept 55

1. Summary of Concept
   None 0 [ ] Yes 5 [ ] — Earned 0 / 5

2. Concept Drawing(s)/Schematics
   None 0 [ ] Yes, Poor 11 [ ] Yes, Fair 14 [ ] Yes, Good 17 [ ] Yes, Excellent 20 [ ] — Earned 0 / 20

3. Parts List
   None 0 [ ] Yes 3 [ ] — Earned 0 / 3

4. Specifications, Materials, and/or Dimensions (with Units) Included in Summary, Drawings, and/or Parts List
   None 0 [ ] Some 3 [ ] Many 5 [ ] — Earned 0 / 5

5. Mention of Manufacturing Process(es), Reliability, Maintenance, and Retirement/Recycling in Summary, Drawings, and/or Parts List
   None 0 1 2 3 4 — Earned 0 / 4

6. Relative Advantage (note: includes subjective component)
   None 0 1 2 3 4 5 Very High — Earned 0 / 5

7. Compatibility
   None 0 1 2 3 4 Complete — Earned 0 / 4

8. Complexity(note: reverse scoring scale)
   High 0 1 2 3 None — Earned 0 / 3

9. Trialability
   None 0 1 2 3 High — Earned 0 / 3

10. Observability
    None 0 1 2 3 High — Earned 0 / 3

Concept Points: 0 / 55

B. Evidence of Design Work 45

1. Concepts Generated
   None 0 [ ] 1 to 3 2 [ ] 4 or More 4 [ ] — Earned 0 / 4

2. Concepts Evaluated
None (0) ☐ Some (2) ☐ Thoroughly (4) ☐
Earned: 0 / 4

3. Concepts Modeled or Analyzed
None (0) ☐ Some (2) ☐ Extensively (4) ☐
Earned: 0 / 4

4. Number of Customers Identified as Part of Total Customer
None (0) ☐ 1-4 (2) ☐ 5 or more (4) ☐
Earned: 0 / 4

5. Number of Customer Requirements
None (0) ☐ 1-5 (2) ☐ 6 or more (4) ☐
Earned: 0 / 4

6. Relative Importance of Customer Requirements Determined
No (0) ☐ Yes (3) ☐
Earned: 0 / 3

7. Competition Evaluated
No (0) ☐ Yes (3) ☐
Earned: 0 / 3

8. Engineering Specifications Generated
No (0) ☐ Yes (3) ☐
Earned: 0 / 3

9. Engineering Specifications Related to Customer Requirements
No (0) ☐ Yes (2) ☐
Earned: 0 / 2

10. Engineering Targets Set
No (0) ☐ Yes (2) ☐
Earned: 0 / 2

11. Engineering Specification Interdependencies Identified
No (0) ☐ Yes (2) ☐
Earned: 0 / 2

12. Problem Definition Statement (including simplifying assumptions)
None (0) ☐ Yes, Partial (6) ☐ Yes, Thorough (10) ☐
Earned: 0 / 10

Evidence of Design Work Points: 0 / 45

Total Points Earned: 0 / 100

0.0%

Notes: