Enhancing the Product Design Process: A Framework for Engineers Based on the Toyota Production System and the Psychology of Optimal Experience

by

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ABSTRACT

This study investigated the product design process using metrics formulated from the principles of a successful manufacturing system. The specific objective of this study is to measure the experience that engineers have during the product design process using principles of the Toyota Production System. Toyota Production System principles are mapped into a framework based on the psychology of optimal experience, which is also called flow. This mapping was enabled because of the strong parallels between the Toyota Production System and flow. The flow framework defines the Toyota Production System in terms that are not specific to automobiles, manufacturing, or product design. When conditions of flow are met, an engineer's ability to perform tasks related to product design is enhanced. The framework specifies conditions that increase the potential for optimal experience for an engineer involved with the product design process. The psychology of optimal experience, or flow, may also explain why the principles of the Toyota Production System are transferable outside of automobile manufacture.

A survey based on the principles of the Toyota Production System, the psychology of optimal experience, and the Experiential Sampling Method was used to measure the experience that engineers have during the product design process. Data was collected from over one hundred and seventy engineers at seventeen different companies.

The clearest result of this study is that the potential for flow is higher for engineers and designers with more diverse work descriptions. Secondary findings show that engineers and designers at large companies tend to have lower average potential for flow. High potential for flow for individuals was found in all types of organizations and work descriptions. Components of flow ratings for individual companies appeared to be influenced by internal organizational structures. When the results of the survey are broken down into the components of flow, it is possible to characterize an engineer's experience and suggest avenues for improvement. Lack of a common measure for creativity and success for all the companies in the survey impeded conclusive findings about the relationship with the measure of flow.

Thesis Supervisor: Woodie Flowers
Title: Pappalardo Professor of Mechanical Engineering

Biography of the Author

Seth Berman was born in New York City, where he attended public school through high school. After graduating from Cornell University in 1978, he worked as a civil/structural engineer, designing and analyzing wood, steel, and reinforced concrete building structures. He continued his work in sturctural analysis in the second half of his career performing, structural analysis of electronic and mechnical devices ranging from electronics packaging and flat cathode ray tubes to portable antennas and air born cameras. In September of 2000 his employer sponsored his full time graduate studies of manufacturing, mechanical design, and systems engineering.

Mr. Berman hopes to combine his experience and academic studies to improve the design and learning process.

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The many friends I made at school listened patiently as I asked for opinions on my evolving ideas in this study.

Over 170 engineers took the time to thoughtfully fill out the survey. Their contribution and the support of their employers is greatly appreciated.

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1.1 Scenarios

At a noisy party celebrating *(successful completion of a project)* the successful design, sale, and installation of a complex electro-mechanical product the following conversation among a group of engineers was overheard:

"It feels like yesterday *(feeling that the duration of time has been altered)* that we started this project. It's hard to believe that our customer is here celebrating the delivery of the first units."

"When I first heard about the project from Joe in strategic marketing, I jumped at the chance to get involved. I wanted to work on so many parts of it. Back then, the specification was pretty loose but before we knew it the input from everyone anxious to get to work turned the specification into a really useful design guide *(control over ones actions)*."

"Hey, you're making it sound so easy. A lot of us thought that some of the technical requirements were going to be impossible to meet *(a challenging activity that requires skill)*. It's a good thing that a physicist from the research division came down for a few months and taught us all some new tricks."

"The last project I worked on we were totally stuck on some really obscure parts of the specification. This time, we tailored the specification as we progressed from system goals at the beginning to customer requirements. Once I became familiar with the goals of the new system most of the tasks became solvable. There are still some details that need to be worked out, but we were able to defer those and still meet the customer's needs *(changing goals, flexibility built into design process)*".

"It's a good thing we prioritized a lot of the task. I got a lot of the easy stuff done early so I was left with plenty of time for the more important parts. Toward the end, each new task seemed more and more important to the overall success of the project. Sometimes I felt like the whole thing depended on me *(deep involvement)*".

"At first I thought each of my tasks was really important, but Joe and another guy from the manufacturing department showed me how the different parts fit into the system *(clear goals)* so I could gage their relative importance. It seemed like someone familiar with the new system was always around *(immediate feedback)* to help me *(loss of self-consciousness)* focus on the more important technical issues. Every time I got one part to work *(ability to concentrate on the task at hand)* it was easy to start work on the next because I could see how the whole project was fitting together (deep but effortless involvement). I'm looking forward to the next version because I've already figured out how to make those upgrades. Wait till those manufacturing guys see my ideas about how to reduce part count! Maybe next week I'll show my suggestions for some new features to the guys in marketing *(flow)*."

Across the street, at another company, an engineer was celebrating, too. Sitting alone in his office, he chatted quietly on the phone with his wife.

"Guess what? I just received a bonus check rewarding me for some of the projects I worked on last year (*feedback is not rapid*). The check came in the interoffice mail with a form letter and a printout of the list of projects that are being recognized."

"Some of these projects started so long ago the product lines I designed the parts for don't exist any more. There are even a few on the list that I can't even remember working on (*concentration on the task at hand is difficult*). Wait a minute; the W-29 low cost generic assembly is on the list, too. Remember me talking about that one? Even when I finished the project I couldn't tell the top from the bottom (*lack of deep involvement in project*)."

"Maybe I have solved so many of theses problems they are all beginning to look the same (*not a challenging activity*). I wonder what people would think if they knew I didn't understand exactly what these parts did even though I was responsible for making them work (*self-conscious about actions*). I certainly would feel better if I could find out how all those assemblies work (*lack of control over ones actions*). I guess I got the bonus for what I am best at; always meeting the specification (*rigid goals*) no matter what (*success defined externally rather than by customer*) and finishing on schedule (*duration of time is not altered based on project requirements*)."

1.2 Introduction

The search for methods of improving the product design process is continuous. Whether rapidly responding to customer needs or creating new products, companies want a process that can be tailored and optimized to their sector's requirements. This study investigates the principles that underlie the success of the Toyota Production System. Once the principles are defined they are mapped into a framework, based on flow. Flow is a technical term used in the field of intrinsic motivation to refer to an optimal state of experience. It was developed by the cognitive psychologist, Mihaly Csikszentmihalyi. A survey based on the flow framework is used to measure the degree to which engineers in different product design organizations adhere to these principles. The measurements from the survey are evaluated to establish connections between the principles related to an optimal work experience and factors in the product design process that influence these measurements.

1.3 Background

New technology has allowed rapid change in manufacturing and product design processes. CAD/CAM, CAE, CNC, MRP, and ERP are part of the alphabet soup of hardware and software revolutions that have improved many aspects of the manufacturing and design. Concurrent with improvements in individual manufacturing processes, detailed study of the way the processes interact have been carried out in many industries. Currently, the behavior of manufacturing systems is understood better than the behavior of the product design process. Progress in manufacturing has resulted in reduced costs and uniform high quality of manufactured products. As quality goods achieve commodity status, product design becomes a discipline that will be essential to provide the differentiation necessary for a company to achieve success.

This research project is aimed at providing a better understanding of the product design process through examining the factors that enhance a product designer's capabilities. This issue was studied by investigating the principles that provide the foundation for a successful manufacturing system, transferring the principles into a non-manufacturing specific framework, and then, using specific metrics from the framework for measuring the experiences that engineers have at different companies during the product design process.

The goal of this study is to determine the relation between the engineer's experience during the design process and the success of the product design organization he works in. Understanding these connections may reveal opportunities for enhancement of the engineer's experience first by identification and then modification of the important components of a product design system.

Over the last two decades the manufacturing sector of the world economy has distinguished itself as a model of achievement, able to rapidly incorporate the best of modern technological and intellectual developments. Reduced costs, uniform high quality and reliability, improved environmental records, and recognition of worker safety are among the measures of manufacturing achievements that have reached levels that are headed toward the final goal of perfection. As more and more companies approach perfection individual organizations will have to learn how to progress rapidly in other areas, including product design.

Manufacturing excellence was achieved in a variety of ways. In the United States, the emergence of a vibrant manufacturing sector after near extinction in the depths of the 1980's cannot be traced to a single factor. Improvement in the quality of manufactured goods has not only come to America. The goal of high quality and reduced costs has been obtained in some factories on all continents and for most types of goods. One thing is certain. The manufacturing sector has been, studied, measured, researched, and written about in great depth. This body of knowledge is organized in many useful formats and companies have been able to use this information to continuously and successfully improve their operations.

The fact that there has been so much progress and success in the manufacturing sector has been good for industry. Those making progress the fastest realized great benefits. Those who lagged during this period of rapid change either disappeared or lost market share. Virtually all serious participants in the manufacturing sector have dramatically modified their manufacturing capabilities and continue to do so as they pursue the ultimate goal of manufacturing perfection.

1.4 Motivation

Technology and other changes have affected other parts of industry besides manufacturing. For example, most companies have benefited greatly from improvements in information technology. Product design has also responded to changes in manufacturing processes and the higher expectations of customers. Many product design organizations have emerged in the last two decades that look nothing like their predecessors – and neither do their products.

But how different are today's product design organizations from the organizations of the past? Have they changed as much as the new manufacturing organizations have? Have they changed in the right ways? If perfection is the goal of a successful manufacturing system what is a similar goal of a product design organization? If it is true that some manufacturing systems are approaching perfection, how can understanding the principles that underlie a successful manufacturing system help a company to improve its product design capabilities?

Formal approaches to managing, improving, and attempting to design successful manufacturing systems include, Six Sigma (Pyzdek 2001), Lean Manufacturing (Womack 1996), Total Quality Management, and Statistical Process Control. These programs were developed and successfully implemented in the manufacturing environment and are now used in other parts of companies, including product design. Waste reduction, error elimination, productivity improvements, and product enhancements characterize the goal of these approaches.

Successful product design is carried out with careful consideration of the capabilities of the manufacturing system. This ever-deepening relationship requires that the product design organization understand and respond to manufacturing requirements during all phases of the product design process. Meeting these needs and making the relationship between these organizations strong may be accomplished by having both product design and manufacturing organizations follow the same rules. This has been done using a variety of methods. One way is to have the engineering organization adopt the same practices that have been successfully applied to manufacturing systems. This approach has proven successful. Companies such as General Electric lead the way in taking the principles of Six Sigma out of the factory and making it a required, integral part of the entire company's practices from sales to service.

So why do these approaches specifically designed for improving manufacturing systems help to improve the operations of other parts of a company? Are the techniques that were designed for manufacturing transferable to the product design process? If the techniques are transferable, will they reap the same benefits outside of the manufacturing domain?

Schemes to measure and manage improvements in the activities of knowledge workers are often met with skepticism. Problem solving that is rooted in the creative process does not appear to be easily organized and managed by a system originally set up to optimize a manufacturing system. The idiosyncratic nature of product design activities indicate that systems designed for measurement in factories are best left to high volume manufacturing operations. Criticisms of detailed management schemes also come from factories where the work is specialized and the volume of production is low. Workers often feel like the one of a kind nature of their efforts is not well managed or properly measured. Still, the experiences of companies that have rigorously implemented the principles of Six Sigma, Lean Manufacturing, and other approaches company-wide have found significant positive results that are related to the conscious design of the manufacturing system or product design system. That being said, there must be a reason why the good results are achieved.

Measurement of manufacturing systems is usually based on one of the attributes of the final product. Examples of this are number of flaws, variation in geometry, quantity of waste, reduction in cycle time, etc. The goal is to attain a predetermined, desirable target for the product by improving the results of a variety of physical measurements. This is often done by adjusting the details of the design, material usage, and processing of the part that is being measured.

Product design is sometimes measured in the same way as a manufactured product. In large organizations drawing packages associated with a contract may be measured as one of the product designer's products; the drawing packages are passed along to his customer or the manufacturing organization. Measures such as number of errors per drawing and how long it takes to fix each error are used to determine how changes in the product design process are improving the quality of the product designer's work. In this kind of measurement scheme improvements focus on simplifying the drawing production process, defining new ways that drawings are made, redefined roles and responsibilities for the designers with respect to drawing errors, adding drawing automation tools, and training to improve drawing quality. These measurements and changes treat the product design process in a manner similar to error and waste reduction strategies used in manufacturing.

Another approach to addressing measurement in the product design process is to measure the product designer's experience during the design process. Rather than focus on error count, this approach tries to quantify a work environment that produces fewer errors. It is within this environment that the hard to define design process takes place. This is where concepts are developed, new features added and where the creative and innovative process takes place. It is also where errors and waste are incorporated into the details of a product and into the steps of the process.

"Precisely because creativity results in new, unexpected ideas, or products, its course cannot be strictly guided or planned" (Amablie 1987). However, it still may be possible to consciously form the structure of the environment where the design process takes place best. Optimization of an environment for the design process used by a modern product design company may require that large numbers of people in the organization follow a similar set of rules.

Because modern products are produced by a large number of people within an organization, the design process may be helped by guidelines, adhered to be all those involved, for optimization to occur. Rather than address the mechanics of the individual components of change in a product design organization, this study investigates a definable system that encourages the rapid adoption of processes that minimize errors and fosters an environment that optimizes many of the core aspects of the product design process.

Many companies have already implemented changes that result in consistent improvements in both manufacturing and product development organizations. This indicates that implementation of improvement schemes are working in both settings. The Toyota Motor Company is an example of implementation of similar guidelines in both the manufacturing and product development organizations. For their employees to be creative, the Toyota Production System acknowledges the need, for – **flexibility within** – a stable and predictable organization.

1.5 Goals

The overall goal of this thesis is to measure the experiences that engineers have during the design process and relate the measurements to characteristics of their organizations and products. The measurements quantify an engineer's experience according to a set of categories that define a broad range of experiences that occur during the design process. This picture is meant to identify the details that are part of an enhanced product design process and the categories of experience that should be modified to improve the overall experience of the engineers in the system. A product design system that is adjusted to optimize an engineer's experience by encouraging flow during the product design process will enable the engineer to operate at a significantly higher level. An enhanced product design experience is expected to be reflected in the final product. The potential for enhancements span the traditional measures of improvement and also include increased rate of creative contributions to the design, products that more closely reflect customer needs, fewer errors, and closer relationships with other parts of the organization. This approach is intended to expand the number of engineers involved in the product design process who are able to contribute creative and innovative attributes to the product by helping to understand the environment that encourages these activities and provide insight into how to design an organization that maximizes the opportunity for enhanced product design.

Some traditional measures of the engineering design process parallel the measurement process used in the manufacturing environment. These schemes usually deal with individual processes. Examples of traditional measures are: number of hours or dollars to complete a task, number of errors detected on a drawing, and percentage of budget spent compared to percentage of project completed. Traditional measures identify the state of a task or the state of a project.

The approach used in this study measures the engineer's perception of his involvement in the design process. These measures summarize the state of the individual working in the system and compare it to an event called flow. The product design process is not properly measured in only dollars and hours because of the vagaries of a complex design and the unknown challenges of implementing new ideas. Flow recognizes the influence of ambiguity in the design process but does not discard all traditional measures. Since it is hard to measure ambiguity an alternate approach is taken -- that of measuring how the engineers are responding to ambiguous problems. Rather than measure and try to control the variation and ambiguity in the design process, the measurement scheme developed in this project measures how well the engineer deals with variation and ambiguity in the design process within his organization and individual style. The flow rating that is discussed later is partly a measure of the strength of an individual engineer or organization to work effectively in the presence of the ambiguity that is always part of the design process.

A final goal of this study is to provide insight into how a product design system might be adjusted to improve the experience that an engineer has during the design process. This will be done by studying the categories that contribute to the flow rating that influence the differences between organization's scores. The expectation is that the improved experience will enhance the overall product design. This step can be thought of as a possible piece of an overall system design process for a product design organization. These measurements can be used to understand how business, technical, and especially organizational matters are connected to product design.

1.6 Definitions

Throughout this document the language common to different areas of academia, business, and engineering practice are used. To prevent misunderstanding of the jargon used in this document, a set of definitions is supplied to clarify the intended interpretation of a particular word or phrase.

Autonomation – built-in mechanism to prevent mass production of defective work in machines or product lines. Autonomous machines at Toyota have built in stopping devices (Monden 1998).

Creativity – a process resulting in a product; it is the production of a novel and appropriate response to an open ended task. The response must be new but it must also be appropriate to the task that must be completed or problem to be solved. The tasks must be open ended rather than having a single obvious solution.

Enhance - increase or improve in value, quality, desirability, or attractiveness (Webster 1981).

Process - a series of actions or operations conducing to an end, a continuous operation or treatment especially in manufacture (Webster 1981).

Manufacturing System – Definition 1. a collection or arrangement of operations and processes used to make a desired product or component. The manufacturing system includes the actual equipment composing the processes and the arrangement of those processes [and people]. (Black 1991)

Manufacturing System – Definition 2. an objective oriented network of people, entities, and processes that transform inputs into desired products and other outputs; all managed under an operating policy (Salzman 2002).

Manufacturing System Design – Definition 1. includes not only physical hardware but also people who mange and operate this hardware and who must communicate information within the manufacturing system (Cochran 2000).

Manufacturing System Design – Definition 2. The job of a manufacturing system designer includes decisions about equipment selection, physical arrangement of equipment, work design (manual and automatic), standardization, and design of material and manufacturing systems (Salzman 2002).

Manufacturing Control – the decisions that deal with the who, what, when, where, and sometimes why aspects of manufacturing coordination (McKay 2001).

MRP – Manufacturing Resource Planning.

ERP – Enterprise Resource Planning.

Intrinsic – belonging to the essential nature or constitution of a thing (Webster 1981).

Extrinsic – originating outside a part and acting upon the part as a whole (Webster 1981).

Transfer Machine – A multi-head automatic machine [tool] which performs a sequence of operations simultaneously on a series of product-units which are automatically indexed forward from one machine station to the next (Hounshell 1996).

Chapter 2 BRIEF HISTORY OF THE EVOLUTION OF MANUFACTURING SYSTEMS

This chapter will present a brief history of the evolution of manufacturing systems and set the stage for establishing useful parallels and connections with product design.

2.1 Historical Perspective for Manufacturing

A variety of events propel the evolution of a system. A manufacturing system evolves following market demands, changes in technology, assorted business factors, and, in some cases, by design. The evolutionary steps sometimes result in a successful organization; sometimes they lead to the demise of the company. Part of the reason to study the evolution of manufacturing systems is to identify and better understand the path that leads to the adoption of today's successful manufacturing systems. Identification of these factors may be useful in designing a new organization or modifying an existing one. Rather than follow an unknown evolutionary path, use of identified principles may turn the random evolution of manufacturing and product design systems into a rational design process.

Over a period of time longer than most companies have existed, it is possible to observe the evolution of manufacturing through studying the historical record of both individual organizations and the products they produced. The record yields much more detailed information about events related to manufacturing than it does about the history of the product design process. There are several reasons why. Both the machines in the factory and the products that were made leave behind a physical record. Manufacturing evolution impacted political and social history in terms of the scale of wars and the type of life workers experienced. Evidence of a factory remains long after production has ceased. This physical evidence often evokes strong memories of a more prosperous time or perhaps a period of sickening pollution. Although some information is available, knowledge of the process by which product designs developed is less detailed. New technology and design are an important part of history but the implementation is in many ways a more dominant part of the record because of the greater number of people involved, the amount of money spent on a factory, and the permanence of the physical attributes.

The ability to measure is also more easily implemented when physical features such as production numbers per unit of time or quality as measured by a specific physical parameter such as dimensions are available. Even more obvious is the factory itself. Huge factories have been built as monuments to people with a vision of being able to efficiently transform complex ideas into their physical embodiments. From clear-cut forests and surface mines to the places where the raw materials are converted into products essential to our daily lives, the manufacturing process now makes goods used by all and has made fortunes for the people involved. Productivity of these great factories has been part of the ever-improving standard of living that more and more people around the world take part in.

To understand why a particular manufacturing system was selected requires some understanding of the product itself. Some products are made in factories using mature processes that change only in small increments over many years. Other products may be the results of fads that last a short period of time. The manufacturing processes that make these may be short lived and never get the chance to evolve before production ceases.

Another influence over the manufacturing process is available technology. As new techniques become available, they are incorporated into the process. The rate at which these changes take place is influenced by the many factors such as competition, cost, and availability. Technology may also disrupt existing manufacturing systems by making completely new processes available.

2.2 Brief History of Manufacturing Systems

This summarizes three of phases of production systems. These phases were chosen to capture the broad historical shifts, or disruptions, in what were once considered fundamental manufacturing principles. The three phases discussed in this section span roughly the same time frame in the later discussion of the evolution of production control. These phases are more generally known and documented because they describe the production systems that are understood by a broad cross section of society.

A historical perspective is considered to be important in this study because of the potential for strong links -- or at least clear influence -- over the product design process used during the evolution of the production control or manufacturing process. This review of manufacturing history sets the stage for the hypothesis that methods that are successful in the manufacturing domain can be successfully transferred to a system outside manufacturing.

2.2.1 The American System of Production

Specialized machinery and interchangeable parts characterized the goals of manufacturing systems in the new era of manufacturing which began in the United States in about 1800. Without full incorporation of these attributes, final assembly of a product required special attention and craftsmanship to fit each part together. Parts from the same product could not be interchanged with parts from another of the same type. Each item was basically one of a kind. It was built in a manner that required a skilled workman to follow a procedure that was customized to the requirements of each assembly.

This changed in 1815. The system of interchangeable parts proposed for the United States military that year started out as an effort to improve uniformity of production between armories at different locations. The effort evolved to incorporate interchangeable parts when the systemized use of gages for checking dimensions on critical parts came into widespread use. Armory workers did not fully appreciate the long-term results that would occur upon successful implementation of uniform gaging techniques. Concurrent with efforts to improve uniformity, specialized production machinery was developed. An example of this is the machinery developed by Thomas Blanchard for the manufacture of gunstocks. By 1826 Blanchard's machines had eliminated the requirement for skilled labor for musket production. By 1850, virtually all fabrication of the muskets was carried out by a combination of flexible machines, (milling machines), and specialized machines (gun barrel and gunstock making machines) (Hounshell 1984).

By the time of the Civil War, interchangeability of parts between Springfield rifles had been accomplished. While uniformity and interchangeability were pursued in other industries in this time period, the extent to which the goals of interchangeability were achieved varied. In the sewing machine industry, for example, uniformity of parts had been achieved but not perfect interchangeability. Achieving interchangeability of parts brought the manufacturing sector to the doorstep of the era of mass production.

2.2.2 Mass Production

Mass production is the most widely known and best understood production technique. Its adoption at the Ford Motor Company was rapid. The early Ford factories established between 1903 and 1907 were basically job shops. During this time men from outside the automotive industry influenced the way the Ford factories evolved. Walter Flanders, whose experience was in the machine tool industry, had witnessed both quantity manufacture and precision grinding techniques at Singer (sewing machine) Manufacturing Company and while a salesman for a variety of machine tool makers. Flanders recommended the additional outside expertise of Max F. Wollering, a tool builder and gas engine production superintendent with experience gained at International Harvester. He, too, came to Ford. (Hounshell 1984)

Although Henry Ford understood the concept of interchangeability, he left its implementation to Flanders and Wollering. Flanders and Wollering stayed at Ford about two years, but it was time enough to teach Henry Ford's staff of young mechanics an updated version of armory practice. By 1908, production of large quantities of interchangeable parts became so great that assembly of these parts emerged as the new bottleneck. In 1913 the moving assembly line eased this congestion and heralded the era of mass production. (Hounshell 1984) Mass production system combined the use of interchangeable parts with the moving assembly line in order to maximize production while minimizing costs.

Year	Model T Production
1909	13,840
1910	20,727
1911	53,488
1912	82,388
1913	189,088
1914	230,788
1915	394,788
1916	585,388

Figure 1. Manufacturing of Model T Fords (Hounshell 1984)

Figure 1. shows the dramatic increase in the number of Model Ts that were produced after implementation of the assembly line. The success of the system used for model T manufacturing raised the question of whether mass production principles could be applied to other industries besides high volume automobile manufacturing. Housing construction, furniture making, and farming were obvious domains where the benefits of investing in mass production techniques might return rich rewards. The outcome of experiments in these categories can at least partially explain the fate of the Ford style of mass production.

Concurrent with the success of the Model T, consumption of a range of other products was growing, too. Consumers preferred a new style of automobile with a variety of features and frequent style changes. The Ford method of mass production proved too inflexible; it could not meet consumer demands. A great deal of highly specialized machinery developed specifically for the production of the Model T formed an efficient system for producing only one product. Inherent in Ford style mass production was the inability to respond rapidly to changes in consumer's tastes. Perhaps this is the explanation why the mass production system did not take hold in the furniture or construction markets. In these sectors the life cycle of a style was not long enough and the volume of goods sold not great enough to justify the investment.

While evolution of the mass production process drove sales volumes higher and production costs lower, its extraordinary success opened the door to other forms of competition. General Motors introduced choices in colors and other comforts. Though these features added cost, buyers were determined to have them despite the higher price. Henry Ford ignored the early signs of change in consumer taste, but even if he had tried to adjust to the trend his now mature and highly specialized production system could not have been easily adjusted, even with an earlier start.

The Ford style mass production was abandoned by 1926. It could not make changes in its operations without serious disruptions in the production schedule. The era initiated by General Motors was one in which "change had to be planned and carefully executed on a regular basis" (Hounshell 1984). This new era required that mass production also be flexible.

As part of the effort to become more flexible, industry responded by adopting successive generations of new machines. The goal of this machinery was both to automate the production process wherever possible and to provide a flexible upgrade path when changes in the production process were required by market forces.

Transfer machines symbolized this effort. The automobile companies invested heavily in this strategy but problems with predictable up time, tool change times, and standardization of equipment cut into the expected efficiencies of these systems. As difficulties arose, the transfer lines were segmented and inventory was banked between the segments to insure that operations could continue even if a segment was shut down. Trouble were evident when it was found that while direct labor costs were decreasing, there were equal increases in the indirect cost involved with the expensive labor of fixing and maintaining the new machines. (Hounshell 1996)

Even though the transfer machine concept was introduced to address the flexibility problems that brought down inflexible mass production, the machinery was not capable of making the changes required when the engine horsepower competition began between the automakers. The transfer machine manufacturers responded by developing machines that could be interchanged with the transfer machines made by other manufactures. Although this effort proved successful for increasing the flexibility of engine block manufacturing it was too late. By the time the new transfer machines were perfected, the engine horsepower race was over. The need for very rapid change in engine block production had passed. Ironically, to this day, transfer machines remain part of flexible mass production systems of some automotive engine manufacturing plants even though they have not proven to be particularly flexible.

2.2.3 Toyota Production System

During the post-World War II era another form of manufacturing system was evolving in Japan. Lacking the capitol necessary to copy the machines that were being purchased to address the flexibility problems in mass production in the United States, and, realizing that craft production "seemed to lead nowhere for a company intent on producing mass-market items" Taiichi Ohno, Toyota's chief production engineer, embarked on developing a new approach (Womack 1990). The need for flexibility in manufacturing processes in Japan was not driven by changes in consumer tastes as it was in the United States but rather by domestic issues specific to the post WWII Japanese economy. The volume of vehicles in demand in Japan was very small by American standards and the mix of vehicles that had to be produced was large because of the need to produce for the commercial and domestic markets. In addition, there was not enough capitol to purchase much of the latest high volume mass production equipment, especially expensive transfer machines being adopted in the United States. A production system evolved specifically around these constraints. Elements of the system that developed in Japan in the 1950's, such as just-in-time delivery, had appeared earlier in the history of manufacturing. This time the system became more widely adopted, the successes more dramatic and it influenced manufacturing systems around the world in a manner similar to the way mass production influenced the manufacturing world when it was first implemented.

The system that evolved became known as the Toyota Production System. Its operations around the world have been studied extensively. One study found that the Toyota Production System has five guidelines that govern "the design, operation, and improvement of *activities* done by individuals and machines to transform material, energy, or information from an input into an output; *connections* between adjacent activities through which material, energy, and information are transferred, and *flow-paths* – systems of connected activities—over which goods, services and information take form as they are delivered (Spear 1999)." The rules follow:

1. Design every activity so that it is structured and self diagnostic.
2. Design and operate the connection between every person who or every machine that supplies a good, service, or information and the customer that receives the specific item so that the connection is *direct, 'binary, and self-diagnostic'*.
3. Each good, service, and piece of information must have a *simple, pre-specified, self-diagnostic* flow-path over which it will travel as it takes form.
4. Improve activity-improvement in the work-content of each supplier.
5. Resolve <u>connection</u> and <u>flow-path</u> problems that affect a customer-supplier pair in the smallest group that includes the affected individuals.

Simple die change techniques for the sheet metal stamping process are examples that are often cited to explain many of the basic principles of the Toyota Production System. This example also serves to highlight the differences between Ford-style mass production and GM-style mass production, characterized by transfer machines.

When Taiichi Ohno, a production engineer from Toyota, came to the Ford River Rouge Plant after WWII, he observed large stamping machines dedicated to making single parts in large production runs. The large runs were required because a long period of the time was necessary to change the dies and get them aligned. Ohno could not afford large numbers of these stamping machines and knew that his initial production runs would be small. His solution was to develop a method that would allow dies to be changed rapidly by production workers. The numerous benefits to this process summarize many of the principles essential to the success of the Toyota Production System.

Rapid exchange of dies addressed the flexibility problem that plagued the increasingly automated form of manufacturing system that was evolving in the United States. The Toyota Production System was evolving into a flexible system capable of making and assembling a broad mix of parts in small production runs. Other surprising additional benefits to the small production lots also became apparent.

The small lots were installed in vehicles almost immediately. Mistakes in the stamping process were detected, and the problem fixed before large numbers of stamped parts with mistakes could be produced. Another benefit was reduced inventory cost. The parts from the small batches were consumed immediately so inventory did not accumulate. But small batches also had a downside. In order for this approach to work, it was necessary to minimize the amount of time consumed by correcting problems. With only small batches being produced and all the parts being consumed immediately, the system might be disrupted if the stamping process was not predictable. This style of production system required deep involvement of the production workers in anticipating and solving problems on a continuous basis to provide an uninterrupted supply of parts to the linked parts of the manufacturing process. Workers had to be highly skilled to make this system work. (Womack 1990)

Even with such a built-in requirement for enormous flexibility, the Toyota Production System is stable and predictable. The work itself is highly specified, by well defined content, sequence, timing, and output. There is also direct and unambiguous communication between the customer and suppliers through simple channels of communications. This is implemented with Kanban cards or other easily visible means of communications.

Rigid guidelines may at first seem like they create another form of an inflexible manufacturing system. The key rule that prevents this from happening is the recognition that changes in the process are part of the process itself. Rather than trying to meet production goals using a flawed, existing process through rework and temporary workarounds when problems are detected by tests built into the manufacturing process itself, the workers embark on an effort to correct or improve the process. The effort is viewed as a science project and as such is approached with the appropriate rigor. Improvements to any process are continuous and are made according to the scientific method by the workers involved in the process. Even with strict adherence to the process the system remains flexible by allowing change through use of the scientific method. All the participants in the production process accept change as an important part of their work.

Initially the success of the Toyota Production System was viewed as a cultural anomaly that could not be reproduced. This idea has been disproved. Toyota operates factories in the U.S. that achieve a measure of success similar to the factories in Japan. Industries that are trying to adopt the principles in their factories as well as their entire enterprises are numerous and cover the entire range of industry from autos and aircraft to furniture and the service sector. (Womack 1996)

While the Toyota Production System is mostly known for its manufacturing successes, the philosophy is carried through the entire Toyota enterprise. While most of the worldwide effort to obtain the benefits of this system for individual companies focuses on manufacturing, there is significant effort that involves trying to incorporate the philosophy into other aspects of an enterprise. Frequently the first step in trying to widen the application of the Toyota Production System in a company is to encourage or require first tier vendors to adopt the system. To achieve many of the goals of the Toyota Production System, the adoption of the principles has to reach as many of the vendors and their suppliers as possible.

The Toyota Motor Company is the best example of how a large organization continues to learn from its experiences and retain this knowledge for the purpose of reaching its goals. Researchers from many fields benchmark their own manufacturing processes using Toyota Production System. In this study the principles of the Toyota Production System are used to establish a measurement scheme for quantifying the experience that engineers have as they carry out their product design responsibilities.

The principles of the Toyota Production System appear to underlie the production system as well as the other components of the entire Toyota enterprise. Many texts and scholarly papers have examined these principles (Speare 1999, Fujimoto 1999). There is general consensus that these principles, implemented so well in the manufacturing operations of Toyota, are what make the results of the operation successful.

2.3 Evolution of Manufacturing Control Observed in Industry

In this section the evolution of the methods of manufacturing control are summarized. Manufacturing control is considered an important component of a manufacturing system. Although the requirements for inventory control, resource utilization, and ensuring customer delivery remain constant, the methods of managing these problems change. This section will summarize a theory of manufacturing evolution that explains the stages of evolution of manufacturing control observed in history. This study of the evolution of manufacturing control presents a sequence of events different from the progression described in the previous three sections.

Modern manufacturing traces its roots to the late 1800's when systemization, standardization and scientific analysis began to be applied. Although the basic concepts had been documented earlier, "it was not until the late1800's that the topic of factory management gained a wide audience and its proponents started to influence practice (McKay 2001)". Since that time manufacturing control has passed through two similar evolutionary cycles of approximately fifty years that can be characterized by six similar phases of evolution of manufacturing control practice. The first started in 1890 and ended in approximately 1940 and the second started in 1950 and continued to 2000. See Figure 2.

McKay calls the first stage the pioneering stage. During this period demand is such that everything that is made can be sold with little regard to efficiency and inventory control. The introduction of electrical power and the post World War II boom were the catalysts for the start of these phases. Startups or companies based on new inventions are also present in this phase. For some companies the introduction of electrical power radically changed their ability to manufacture the product they were already making.

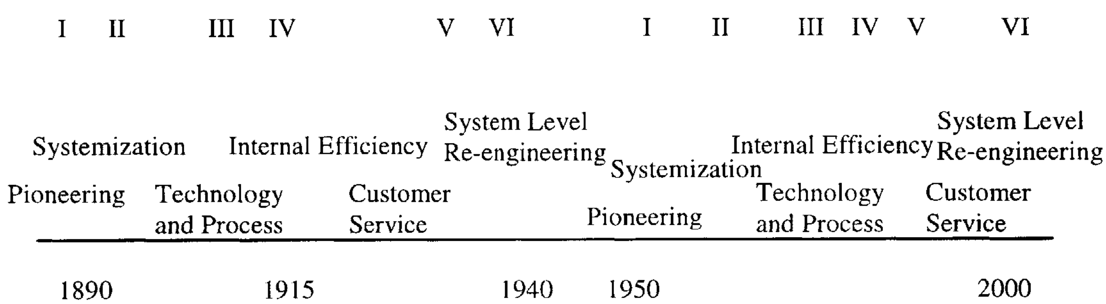

Figure 2. Timeline of Evolutionary Cycles of Manufacturing Control (McKay 2001)

The second phase of the evolution is characterized by systemization. Rapid growth and increasing complexity drove the requirement system for standardization and control. Only gross inefficiencies were addressed during the second phase because profit margins remained high and sales determined the company's success.

In the third stage (1910-1920, 1970-1980), McKay found evidence of the first quality circles continuous improvement and focus on waste in the plant. Margins were beginning to drop in this phase, and workers were becoming more specialized and rigid in carrying out their responsibilities. Competition was mostly friendly since there was still enough demand for what the factories produced. The goal of manufacturing control in this phase was to keep costs within a range that was similar to the others in the same business. More and more features were being added to the product as competition began to heat up.

In the fourth phase (1920-1930, 1980-1990) just-in-time practices, listening to the customer, and supply chain management methods began to be seen. Rapid change characterizes this period. During this phase firms no longer depended on product features for success but instead used techniques such as outsourcing, concurrent engineering, and design for manufacturing to improve internal efficiencies. The secret to success was now seen as cost control from within the factory and demanding help in inventory control from suppliers through just in time delivery.

By the fifth stage "the competitors are on almost equal footing when it comes to the basic technology and material….." "The key to success is what you do and how you use what you have (McKay 2000)". Core competency, responsiveness, and reducing lead-times were some of the challenges of this phase. Workers were encouraged to be more pro-active and general skills training was provided to help workers become part of the efficiency movement. (McKay 2000)

The fifth stage is where the product design process emerges as a system to be used for cost control and competition for market share. The factories are now on equal footing so the focus of the competition has to shift. This is the phase that many companies in the United States find themselves in today or should prepare themselves for in the near future.

By the sixth stage manufacturing control improvements yield little return. System level re-engineering efforts at the corporate level are required to address direct and overhead costs. Connections to the customers are strengthened through mass customization programs and supply chain management.

The cycles of manufacturing control evolution outlined by McKay provide insight into where we have come from and where we might be going in the area of manufacturing control. As the phases evolve, different activities are required to capitalize on the current state. Although these phases outline historical trends the state of an individual company or technology may not fit into the exact patterns summarized. Still, understanding these possible paths helps in anticipating and preparing for the future.

2.4 Manufacturing Summary

In the preceding sections three eras in the evolution of manufacturing were discussed; the American System (Armory Practice), Mass Production, and the Toyota Production System. Each era possesses certain developments that characterize that phase. The American System of manufacturing was strongly associated with the development of specialized manufacturing equipment and the use of interchangeable parts in complex assemblies. Ford style mass production built on the previous phase and added the moving assembly line, which dramatically increased assembly rates and decreased costs.

While mass production systems evolved in the U.S. to address flexibility issues, another approach to handling flexibility evolved in Japan. In addition to addressing flexibility, the Toyota Production System also incorporated the workers as a critical part of the system by linking the manufacturing processes tightly with the operators themselves. One of the main philosophical differences dividing the American System of Production and the Ford Mass Production System from the Toyota Production System is that the Toyota Production System relies on the increasing capability and involvement of its people while the American System of Manufacturing and various mass production schemes relied on the increasing capabilities of machines.

The 1980's "witnessed significant progress in robotization of final assembly lines in some Western assembly plants (Fujimoto 1999)." Although high tech assembly plants demonstrated progress in automobile process technologies, their overall productivity turned out to be lower than the best practice assembly plants in Japan where the assembly automation ratio was much lower (Womack 1990). Still Toyota modified its assembly processes by adding automation equipment. While Toyota followed the trend toward automation in automobile factories around the world, there were big differences in the reasons for change and how the new machines were incorporated in the factory. In the west the goal was to decrease the number of factory workers and improve quality by designing the machines to perform the tasks that required skill and training. Driven more by a fear of a labor shortage than the desire to reduce the number of workers in the factory, Toyota designed its more automated assembly process around improved working conditions so they could attract and retain good young workers. Young Japanese workers were less willing to work in the final assembly process which they associated with the 3-D's (dirty, demanding, and dangerous). The new automation equipment at Toyota made factory work more attractive (e.g. ergonomic designs) and was designed to assemble the new, leaner product designs of the early 1990's.

A summary of the key points of the manufacturing eras is shown in Figure 3.

Era of manufacturing	Approximate Dates	Key Attributes	Example
American System	1800- 1913	Specialized production machines, interchangeable parts for assembly.	Blanchard's Gunstockmaking machine, Armory Practice. (Hounshell 1984)
Ford Mass Production and flexible mass production	1913 – 1932 1932 – present	Moving assembly line, workers have one or two specialized jobs, high volume production for the general population. Specialized automated machines.	Low cost car, 500,000 built in 1916, Flexible Manufacturing Systems
Toyota Production System	Post WWII – present	Manufacturing cells, small lot size, autonomation, emphasis on human resources. (Monden 1985)	Flexible system, mass customization, very high quality, intense socialization of workers (Sobek 1998)

Figure 3. Summary of Eras of Manufacturing

Chapter 3 CONNECTIONS BETWEEN MANUFACTURING AND PRODUCT DESIGN

In the previous chapter the evolution of manufacturing systems was summarized. The era of manufacturing, embodied by the Toyota Production System, is characterized partly by its emphasis on human resources and flexibility. In this chapter, the product design process will be examined in terms of its connections to the principles of a successful manufacturing system. Emphasis on human resources and flexibility is an important part of this connection.

Specifically, the relation between the Toyota Production System and product development at Toyota will be examined. Principles that are common to both systems will be enumerated. Following the establishment of the common principles is a discussion of how the principles of the Toyota Production System can be used to measure the experience that engineers have during the product design process. The measurement system will be established using the principles of the Toyota Production System and the psychology of optimal experience.

In the histories of manufacturing the strength of the connection between the manufacturing process and the product design process varies. The type of product and the stage of technology development may result in highly dependent or independent efforts. The current business environment of short product lifecycles, rapidly changing consumer tastes, and the expectation of high quality, make a close relationship between the product design process and manufacturing process essential. The Toyota Production System, which is built on strong connections between manufacturing and design, is used in this study for examining these relationships. Studying how Toyota makes these connections uncovers some of the principles of what makes the Toyota Production System successful.

3.1 Why Production Principles Are Adopted Outside of Manufacturing

In the 1850's many individuals outside the American armories gradually recognized the benefits of the use of specialized production machinery and the use of gages to obtain full uniformity of parts. Although the benefits differed from product to product efforts were made to incorporate theses procedures into other businesses. Examples of this can be seen in woodworking, sewing machine manufacturing, and bicycle manufacturing. (Hounshell 1984) For some, adoption of the process was a necessity to survive while for others implementation of portions of the new system was all they could manage.

Full adoption of mass production principles -- especially the moving assembly line -- by other automakers was almost immediate. Manufacturers of other consumer products soon followed. Experiments were conducted in the use of mass production principles in the housing, furniture and farming industries with varying degrees of success. Many believed that the principles of mass production could be applied in all types of production. Even today, mass production, the idea of producing large quantities at low cost, still has currency in the American consciousness. (Hounshell 1984) The principles appear to be applied in many facets of the American culture from manufacturing to the schooling of children. The attraction of the productive efficiency of the system appears to be universally understood and applied in the daily lives of many citizens. Mass production and assembly line concepts of manufacturing are understood by a broad range of individuals in many societies around the world. The success of mass production and near universal understanding of how it works makes it an obvious choice for addressing production problems outside manufacturing. This partly explains why elements of a mass production system are applied in product design systems as well.

3.1.1 Similarities Between Production and Product Design at Toyota

The principles of the Toyota Productions System are probably not as universally understood and accepted as the principles of mass production. However, the employees of Toyota and other companies that are part of the Toyota enterprise deeply understand the principles. Although specific protocols tie Toyota's production and product design systems together this study is more concerned with the underlying principles that are the basis of their similarities.

In one summary of the Toyota Production System the author states that people are made more capable and responsible for doing and improving their work by "standardizing connections between individual customers and suppliers and by pushing the resolution of connection and flow problems to the lowest possible levels (Spear 1999)". Standardized connections are the foundation of a close relationship between the production system and the design process.

The Toyota Corporation uses the principles associated with the Toyota Production System in many parts of the company. The principles can be found in the way their product development process works. Toyota's managerial practices are "grouped into six organizational mechanisms. Three of them are primarily social processes: mutual adjustment, close supervision and integrative leadership from product heads. The other three are forms of standardization: standard skills, standard work processes, and design standards (Sobek 1998)". While the product of the product development system at Toyota and the Toyota Production System differ, the principles that underlie both systems have many similarities.

Mutual adjustment refers to an iterative process that gives engineers working on related parts of a project rapid feed back. An example of the way this is done is the sequence of short, focused memos that are written between parties as they adjust their design until the disciplines are in agreement on the details.

When talking about standardization in a design process the question of what the effect on creativity will be must be addressed. Standardization of a manufacturing process is desirable because of the requirement for a highly reproducible product. However, as discussed earlier, the goal is not to standardize the method that creates the process. The method that creates the manufacturing process should be highly flexible.

In Toyota's product development process, the process for changing work standards is encouraged and is flexible. Engineers working on product development at Toyota have a standard set of skills. Rather than rely on universities or specialized training consultants, Toyota engineers receive most of their training from intensive mentoring and direct supervision. (Sobek 1998) The engineers rotate within their functions and develop a deep understanding of their technical field and are able to concentrate on their specialty. To avoid the chimney effect, the more senior managers rotate between functions to develop a broad range of experience and contacts. Like the factory, each design group knows what to expect from another with a minimum of communication. This is because the process follows a standard procedure that does not differ much from product model to model. When implemented at other companies this approach sometimes leads to either an inflexible system or standards that engineers do not follow. These problems are avoided at Toyota by keeping the details of the process to a minimum but having the concept of the standard described and well understood by the engineers. This allows the implementation to be tailored from product to product but the results to be predictable.

Design standards are constantly updated and are used by the practicing engineers. The design standards serve as one of the foundations for a learning organization. Even on new projects the standards serve as a starting point. Another part of standardization is the style of communication. The need for frequent iteration is recognized and compromise in this system is based on the scientific method.

Product development at Toyota is a "a routinized learning capability, which consists of various individual routines that bring about better management of problem-solving cycles as well as information flows between them (Fujimoto 1999)." Similar routines and standards are used to create a new set of information assets for the production of each new product. Studies of twenty major automobile manufacturing companies comparing product development performance factors such as lead times, development productivity, and total product quality identified some routines that the best performers tended to adopt. The following list summarizes the pattern of problem solving and information transmission in seven categories of activities (Fujimoto 1999):

1. Direct and continual flow of information from market to concept generation units, which creates product concepts proactively, rather than reactively.
2. Continual and cumulative elaboration of product concept information throughout the project period for flexible adaptation of the concepts to changing market needs.
3. Direct and continual internal flows of information among the concept generation units, and product engineering units throughout product development. Since the product concepts cannot be fully articulated by product plans or other documents, direct interaction between concepts and designs is of particular importance.
4. Early information exchange to bring downstream experience upstream effectively and to reveal conflicts during the early stages.
5. Early information exchange between automakers and suppliers. Many of the first tier suppliers, with detailed engineering capabilities, work closely with automakers by maintaining frequent communication of component design information.
6. Overlapping problem solving. Downstream problem-solving cycles start before upstream cycles are completed in order to shorten lead time. To do this effectively, upstream and downstream have to be integrated through early release of preliminary information in both directions.

7. Fast problem-solving cycles within each stage in order to respond quickly to continuously changing inputs. This includes speeding up individual activities such as searching and simulation. As well as reducing iteration of cycles needed for reaching the final solution.

"The above routines can be seen as the factors that enhance the success ratio of individual projects. This pattern of information creation and transmission leads to a higher success ratio of products, which many observers believe was the case at Toyota during the 1980's" (Fujimoto 1999). Figure 3. summarizes the striking similarities between the basic pattern of routinized capabilities in production and product development… (Fujimoto 1999)". Figure 4. is a detailed compilation of similarities between the Toyota Production System and product development at Toyota.

Toyota Production System	Product Development at Toyota
Frequent setup changes.	Frequent product renewals.
Short production throughput time.	Short development lead-time.
Reduction in work-in-process inventory between production steps.	Reduction of information inventory between product development steps.
Piece-by piece transfer (not in batch) of parts from upstream to downstream. (Single piece flow)	Frequent transmission (not in batch) of preliminary information from upstream to downstream.
Quick feedback of information on downstream problems.	Early feedback of information on potential downstream problems.
Quick problem solving in manufacturing.	Quick problem solving in engineering.
Upstream activities are triggered by real-time demand of downstream (pull system).	Upstream activities are motivated by market introduction date in downstream.
Simultaneous improvement in quality, delivery, and productivity.	Simultaneous improvement in quality, lead- time, and development productivity.
Capability of the upstream process to produce saleable products in the first place.	Capability of development (upstream) to produce manufacturable product in the first place.
Flexibility to changes in volume, product mix, product design, etc.	Flexibility to changes in product design, schedule, cost target, etc.
Broad task assignment of workers for higher productivity.	Broad task assignment of engineers for higher productivity.
Attitude and capability for continuous improvement and quick problem solving.	Attitude and capability for frequent innovations.
Reduction of inventory (slack resources) forces more information flows for problem solving and improvements.	Reduction of lead time (slack resources) forces more information flows across stages for integral problem solving.

Figure 4. Similarity of Patterns of Production and Product Developemnt Capabilities (Fujimoto 1999, Clark and Fujimoto 1991)

3.2 Flow: A Framework for the Principles of the Toyota Production System

In the preceding section a set of principles common to both production and product development at Toyota were identified. The similarities between the principles of the two successful systems indicate that there are underlying reasons for the relationship and that the similarities are not specific to either manufacturing or product design. The success of both systems is partially explained by the uniform application of the principles of a successful system, the Toyota Production System, to both a manufacturing system and a product development system. The reason the principles work outside of the domain where they were initially developed is the subject of this section.

Similar principles found to underlie production and product development at Toyota can be linked using a framework called flow. Flow is a set of conditions an individual experiences that allow him to perform at an enhanced level. The categories that are used to define the flow experience closely resemble the categories used to define the principles of the Toyota Production system and the system used for product development at Toyota. The flow framework describes a set of experiences that an individual can have during work or leisure. The parallels are between the experiences of the worker -- the human component -- within the Toyota Production system.

3.2.1 What is Flow?

"Flow occurs when a person's body or mind is stretched to it limits in a voluntary effort to accomplish something difficult and worthwhile" (Csikszentmihalyi 1975). For an individual to reach a flow condition he must seek rewards that are under his own power. "In fact, many, perhaps most occupations can be made to have intrinsic rewards if the activity is restructured, either from above or by the person himself, so that it can produce the flow experience." (Csikszentmihalyi, M., 1975) This intrinsic system of reward and control make up the fundamentals of the flow condition that leads to optimal experience.

Examples of flow are usually given for people who are having peak experiences and who are intrinsically motivated. Early studies of chess players, rock climbers and surgeons detected similarities in their experience and motivation. However, case studies of individuals involved in more ordinary tasks related to farm work, factory work and computer usage, found that the flow experience could be attained under a wide range of activities. The extent to which occupational activities conform to the flow model depends on whether the structure of the task "allows a person to match his skills with demands in the environment, to center his attention, to receive clear feedback, to be in control of his actions, and to lose self-consciousness" (Csikszentmihalyi 1975).

Human events are defined as "comprising a type of activity, e.g. sport, art, intellectual activity, and work; levels of performance, from personal best to failure and feeling, from highest happiness to misery; and behavioral, neurophysiological, environmental, personality, and experiential correlates" (Privette 1987). In this study the *activity* is broadly described as product design. The levels of performance can range from design of an innovative and popular product to design of a product that doesn't even meet basic functional requirements. The product design engineer may experience intense pride and deep satisfaction or sickening anxiety, boredom, or feelings of failure.

Flow contains elements of peak performance and peak experience. Peak performance "is a high level rather than type of functioning that may occur as creative expression, physical strength, athletic prowess, intellectual mastery or rich human relatedness" (Privette 1987). It may also be described as "an episode of superior functioning (Privette 1987)". Peak experience is a highly valued moment that surpasses usual levels of intensity, meaning and richness and is often associated with loss of self. (Privette 1987) Flow contains elements of peak performance and peak experience. To achieve flow an individual must want the outcome of his own work and the final product to be positive.

One of the aspects of flow that makes it a desirable event is that flow is associated with creativity. An example of this is the link between flow and exploratory use behavior that was established in Human-Computer Interaction studies. (Ghani 1993)

Engineers' ability to perform product design may be enhanced when experiences related to the following nine categories are optimized: concentration, challenging work, ability to succeed, rapid feedback, control, loss of self-consciousness, flexible time, and deep involvement. The conditions for reaching the flow condition may be provided or encouraged by a good manager or a well designed organization that recognizes the benefit of similar conditions. Often, it is the individual himself that is able to set up the conditions to achieve these goals.

A person who is never bored, seldom anxious, involved in what goes on, and in flow most of the time is said to be autotelic. Autotelic behavior is driven by self-contained goals and it reflects the idea that such an individual has relatively few goals that do not originate from within himself. This type of individual translates potential threats into enjoyable challenges. An autotelic personality does not require a structure for each problem but is able to set the appropriate goals for his individual task and attain the flow condition. "For most people, goals are shaped by biological needs and social conventions, and therefore their origin is outside the self. For an autotelic person, the primary goals emerge from experience evaluated in consciousness, and therefore from the self proper. (Csikszentmihalyi, M., 1990)"

3.2.2 Difference Between Measurements Based On Flow and Traditional Business Measurements

A measurement scheme based on flow concentrates on measuring the experiences of an individual. In this study, the flow framework measures the experience an engineer has during the design process. The results may be viewed as a percent of maximum, or total score, as well as with other statistical measures. The measured results are referred to as the flow rating. A high score, for example, indicates that the engineer is either experiencing flow or is approaching the condition. The ultimate goal for the use of the information is to understand how an organization influences the potential for optimal experience.

Traditional measurements survey worker satisfaction, adequacy of compensation, career development, corporate leadership, effectiveness of quality programs, corporate vision, and many other facets of company life. This type of survey measures how well the company is doing at keeping their workers happy. The survey developed for this study is more narrowly focused. It specifically targets engineers involved in the product design process and whether there is potential for them to do their best work.

3.2.3 Similar Surveys and Measurement Schemes

The Gallup organization discovered that measuring the strength of an organization could be simplified to twelve questions. Strength of an organization was defined to be when an organization could attract, focus, and keep the most talented employees. From their vast data banks spanning twenty-five years and a hundred million questions, twelve questions emerged as the ones that measure the most important information. (Buckingham 1999) The questions are listed in Figure 5.

1. Do I know what is expected of me at work?
2. Do I have the materials and equipment I need to do my work right?
3. At work, do I have the opportunity to do what I do best everyday?
4. In the last seven days, have I received recognition or praise for doing good work?
5. Does my supervisor or someone at work, seem to care about me as a person?
6. Is there someone at work who encourages my development?
7. At work, do my opinions seem to count?
8. Does the mission/purpose of my company make me feel my job is important?
9. Are my co-workers committed to doing quality work?
10. Do I have a best friend at work?
11. In the last six months, has someone at work talked to me about my progress?
12. This last year, have I had the opportunity to learn and grow?

Figure 5. Core Elements Needed to Attract, Focus, and Keep the Most Talented Employees (Buckingham 1999)

"Measuring productivity and managing to achieve an increase are an interesting challenge for a research and development organization (Lund 1996)". Mr. Lund's goal in developing a survey was to measure the impact company productivity programs had on the health of the work climate and to provide clues about what could be done to improve the climate. Mr. Lund developed a twenty seven question survey, shown in Figure 6., that permitted either total agreement or total disagreement. This forced an "emotional commitment to either liking an aspect of the climate or disliking it." (Lund 1996).

Conditions of Excellence:

1. I am fully utilizing my skills to benefit my company.
2. I am growing in my job.
3. I am challenged by my work.

Work Valued:

4. My creativity is valued.
5. My work is respected by my management.

Stress Manageable:

6. I am not stressed excessively.
7. My job does not interfere with my home life.
8. I am not overworked.
9. I am "in control" of my work situation.

Partnership:

10. I feel in contact with the organizations that use my work.

11. The organizations that use my work value my contributions highly.
12. I feel personal "ownership" for insuring the success of the organizations that use my work.

Resource Availability:

13. I have the information I need to fulfill my responsibilities.
14. I have the resources (e.g. hardware, software, and lab) to fulfill my responsibilities.
15. I know how to use my role in the company to fulfill my responsibilities.

Motivation:

16. My bias is toward "making it happen" in spite of obstacles.
17. My work is important.
18. My work is important to me personally.
19. I am committed to helping the teammates with whom I work excel.

Pride:

20. I am proud to work for my company.
21. I am proud of my professional contributions.
22. My work will help make a difference in our customer's lives.
23. The people I work with are excellent.

General:

24. I look forward to coming to work each day
25. I am tempted by the job opportunities I know about at other companies.
26. I am comfortable with where I am in my career.
27. There are enough people to help me fulfill my responsibilities.

Figure 6. Work Climate Survey (Lund 1996)

The twelve important questions identified by the Gallup organization, not surprisingly, share many themes consistent with those identified with flow. In the Lund survey the first three questions are three of the conditions that partly define the flow state. A high value for the Conditions of Excellence section of the Lund survey "should be associated with a great deal of productivity bang and worker satisfaction for the salary buck (Lund 1996)."

However, a flow measurement is not meant to measure talent, management style or corporate climate. This study focuses on the components of an experience that encourage an engineer to perform at an enhanced level. Rather than measure the specifics of the way he does his work, e.g. computer power available, number of iterations to resolve problems, number of drawings produced, or error rates in design work, flow addresses the way an engineer involved in the product design process relates to his organization and the product that is being designed. When these connections are right, the engineer's experiences will be enhanced and his work will be surprisingly creative, innovative, and free of errors.

3.2.4 Connection Between Flow, the Toyota Production System, and Product Development at Toyota

Elements of flow are found in both the Toyota Production System and product development at Toyota. In this section the similarities are mapped into the categories of flow. First, the history that lead to the adoption of the principles of the Toyota Production System will be reviewed and then detailed, category by category, connections will be made between flow and the principles of the Toyota Production System.

3.2.4.1 Historical Path to the Toyota Production System

Henry Ford-style mass production made automobiles affordable to the workers who built them. Increased wages and reduced cost of the product were the main reasons for this. The factory workers paid for an improved standard of living with a severely decreased quality of work environment caused by the introduction of the moving assembly line. Factory work became monotonous and humiliating by minimizing intellectual requirements. Productivity increases required specialization and repetition of each worker's tasks. To counter high turnover rates caused by the intolerable working conditions, dramatically higher wages were required to keep people on the assembly line. The mass production system was unattractive to people, especially when they were asked to repeat tasks that were difficult to perform properly for an indefinite period of time. Henry Ford-style mass production did not recognize the critical nature of the human component.

At first glance the problem seems the same for the style of factory work fundamental to the Toyota Production System. High quality and productivity are maintained by following a rigid set of rules. Slack is continuously taken out of the system. The buffering effect of piles of inventory at workstations and frequent work stoppages due to broken machines is reduced by ever improving work processes. Do these improvements result in ever more demanding worker requirements that cause the same unattractive humanly unsustainable work environment that characterized Henry Ford's moving assembly line?

No. Part of the explanation of the difference between the two systems may be seen in a comparison between the pressure a worker feels on an assembly line when he is required to meet externally set production goals and the creative tension that a worker in the Toyota Production System feels when he is asked to solve a production problem related to increased production goals. On an old style assembly line the worker may not be given the opportunity to make changes that effect how the work is done. Even if he was, he might not have the skills or tools necessary to solve the problem. Extrinsic requirements are likely to result in a work environment characterized by either the worker being underutilized or asked to perform a task he is not equipped to perform adequately.

One of the major principles of the Toyota Production System is the recognition that problems always exist. Continuous anticipation and solution of problems is a standard part of a worker's responsibilities. To assist in the problem solving process workers are encouraged to build their skills for the purpose of implementing changes that improve their work.

The flow framework specifically recognizes the need for involvement of the worker in many aspects of the work. Boredom caused by a repetitive task or the anxiety of working in an environment where a flawed process results in difficulty meeting the production requirements is addressed. The flow framework and the principles of the Toyota Production System outline a series of conditions that represent a continuously evolving environment that enhances the worker's performance. Optimal experience occurs in response to the creative tension introduced when a problem is recognized and the worker or group of workers exercise control by making changes that take into account the need to balance both the requirements of the production process as well as the extent of the worker's current capability.

Achieving the right balance is a building block of an optimal experience. "The creative tension involved in solving complex problems is precisely what has separated professional "think" work from work in the age of mass production (Womack 1990)". In traditional mass production the think work was left to the white collar workers and the factory workers are required to execute their ideas. The twist in this study is to transfer the routines of a successful manufacturing system that relies on "think" to the white collar domain of product design. "It is the way that Toyota designs its systems and the principles that guide the systems that are the true innovation (Spear 1999)". "The principles may generalize to the effective design and management of any large scale organizational system. Furthermore, the principles seem actionable, suggesting that these principles may make the Toyota Production System transferable across organizational boundaries and even across diverse sectors."(Sobek 2001) The categories of flow are used to explain why it is transferable.

3.2.5 Flow Categories

Figure 7. summarizes the connections between the principles of the Toyota Production System and product development at Toyota to nine categories that define flow. Many of the connections are quite strong. In the following nine sections each flow category will be defined and the connection to the appropriate principle of the Toyota Production System will be explained.

3.2.5.1 A Successful Outcome Can be Achieved

An individual must believe that he can reach his goal in order to achieve the flow condition. For example, a chess player believes he can win his match, a rock climber believes he can reach the top without falling, a factory worker believes he can meet his production goals, and a product designer believes he can come up with a clever solution for a new design problem. Belief in future success is an essential component of the flow condition. The absence of the belief leaves the participant either anxious about an ambiguous outcome or depressed about expected failure.

In the Toyota Production System the path to successful outcomes is designed by the workers. An example of this is how the manufacturing cell is designed. The workers know what their production goals are and are given the responsibility to influence the design of the machines and work processes for the manufacturing cell that can meet the goals. The workers can change this system to ensure a successful outcome.

Engineers involved in product development at Toyota are highly trained and within their specialty, have a standard set of skills. The training process is highly specified and includes intensive mentoring and high quality in-house training. Therefore, when a task is undertaken the parties know what to expect with a minimum of coordination. (Sobek 1998) The extensive training gives the engineers involved with product design the tools to bring about a successful outcome to their design responsibilities. Although conflict between product design disciplines is intense and encouraged, the participants expect a successful outcome since the resolution of conflict is a built in, incremental, systematized process.

3.2.5.2 Ability to Concentrate on the Task at Hand

When an individual achieves flow "the clearly structured demands of the activity impose order and exclude the interference of disorder in consciousness (Csikszentmihalyi 1990)." Concentration on the task at hand means freedom from the pressure of irrelevant information and unrelated interruptions. Some people can achieve flow in a work environment in the presence of distractions because of their autotelic nature. Others are helped by the structure of an organization that minimizes disruptions.

The Toyota Production System encourages a factory worker to concentrate on the task at hand using a work process called Single-Piece-Flow. Using this approach, a factory worker completes one step at a time, for a length of time that allows him to complete the task without it feeling repetitive and boring. The task is designed to require the workers attention and is highly specified. When he finishes one task he moves on to the next manufacturing step. A sequence of these steps is assigned to each worker in a manner that assures that connected processes are provided with the products they need. When the last step is complete he can start the sequence again. (Spear 1990) The workers are freed from worry about the disruption of not having enough product to work on by a predictable system that times deliveries of product as signaled by actual use. The system is designed around letting the worker focus on his task by eliminating distractions.

Concentration on the task at hand is encouraged in many ways during product development at Toyota. Focused meetings are an example. Short, disciplined meetings are designed to keep different issues on the same project separate to avoid confusion. Participants are expected to prepare ahead for the meeting so that they "understand the key issues, are all working from a common set of data, and have thought about and prepared proposals and responses. (Sobek 1998)" This keeps the focus on the task at hand. Reports are mostly limited to one page. In this concise, standardized format the important issues are clearly stated, allowing rapid iterations and interactions.

3.2.5.3 Goals

Clear goals are necessary to achieve the flow experience. The path that an individual follows to select these goals varies with his skills and the forces that shape his environment. A strong autotelic personality is able to select appropriate goals under the widest range of conditions. Others may be helped by an environment that provides guidance concerning the immediate goals of the work and the important goals of the organization. For goals to be chosen to allow the opportunity for flow, the engineer must have the feeling of ownership of the decisions concerning the selection of the goals. This insures a strong dedication to the goals. In addition, internally controlled goals can be more easily modified when the reason for preserving them no longer makes sense. An engineer that sets his goals in this manner is more consistent and more flexible.

The Toyota Production System defines clear goals based on visibility. Large electronic signs, filled and stacked shipping containers, marked racks, and Kanban card are examples of how goals are made clearly visible to the responsible workers. They can observe their progress toward meeting their goals and modify their pace accordingly. This allows the individual to define his actions to meet his daily requirements and provide the flexibility to make the adjustments on a continuous basis. The visibility also allows others to easily see into the system and offer help when required.

An engineer involved in the product development process is highly trained in understanding what is expected of him during the design process. These expectations allow him to set goals that meet these expectations in a step by step way an carry out his work in a way tailored to his own skills and talents.

3.2.5.4 Immediate Feedback

Rapid feedback maintains the involvement necessary for flow. Feedback also encourages adjustment of goals. The format of the feedback is not what is important. "What makes this information valuable is the symbolic message it contains: that I have succeeded in my goal. Such knowledge creates order in consciousness.....(Csikszentmihalyi 1990)"

Immediate feedback is part of the foundation of the Toyota Production System. Just-in Time, autonomation, Kanban, and other visual control systems all contribute to the feedback so important to the flexibility of the Toyota Production System. Digital display panels are visible to everyone on the production line. If production is going too slowly workers can see where the problem is and work together to keep production on schedule. Andon lights of various colors are another form of feedback. The color of a light associated with a machine indicates various conditions, such as machine trouble, satisfactory end of production run, shortage of materials, defective unit, or setup required. The lights indicate a response is required. (Monden 1997) Another form of feedback is from the customer. Each worker understands his customer supplier connections. Unambiguous signals from his customers through direct paths of communication let a worker know immediately whether he has produced the right product. (Spear 1999)

One of the ways rapid feedback is implemented during product development at Toyota is in the way memos are written. As discussed in the earlier section on concentration, engineers are trained to write one page reports that summarize key information. Recipients are expected to study the report and offer feedback. There is recognition that several iterations are likely before satisfactory resolution is achieved. The written format is designed for rapid response. In this manner the concerned parties are able to work from a common set of data. A similar approach is applied to meetings. Attendees are expected to have read all the reports and come to the meeting with prepared proposals and responses. Short, focused meetings are designed to keep the subject and outcome clear. The nature of the of the brief iterative report and focused meeting are key elements to rapid feedback during product development at Toyota. (Sobek 1998)

3.2.5.5 Control Over One's Actions

"The flow experience is typically described as a sense of control-or, more precisely, as lacking the sense of worry about losing control... (Csikszentmihalyi 1990)". People generally realize that they can not control all the variables of their environment. However, they feel in control when they influence factors important to them.

In the Toyota Production system there is an emphasis on self-direction and self-control. Job design does not assume stability in organizational goals or processes. Upgrading and broadening skills is encouraged. This growth is viewed as a capitol investment that leads to improved performance and flexibility. This model reflects the acceptance and encouragement of change. The skills required to control one's activities in one situation are at least partially transferable to new circumstances. Confidence gained through successful self direction is a pre-requisite to the acceptance of new challenges. The Toyota Production System gives the workers the tools they need to control their job related activities. (Monden 1985, Hackman 1975)

Living design standards are used as a guide for existing products and new models during product development at Toyota. Unlike the frequently ignored, archaic standards at other companies, the design standards are actively updated and applied across the company. The engineers are trained in the process of abstracting their experience into their own work standards. Use of fresh standards allows the designer to draw on the various experiences of engineers throughout the company.

3.2.5.6 Deep but Effortless Involvement

This category of flow is easily observed during sports events. A strong example is an athlete participating in an important competition who is making consistently miraculous plays in the presence of flashing camera lights and the deafening noise of a hostile crowd. At the same time he appears to be relaxed and enjoying himself, oblivious to the surrounding tumult, with his main focus on creating unexpected positive outcomes for his team. His goals are clear and the requirements of the game are balanced perfectly against what he believes his capabilities are, leaving him to immerse himself in the activity.

While not as dramatic, the Toyota Production System has features that encourage deep involvement. A properly working manufacturing cell is designed to challenge the skills of the operator. With production goals clear he must use his skills to operate a variety of machines in a rhythm that produce the right amount of product. The goal of a properly designed manufacturing cell demands that the worker be deeply involved in the work. At the same time the worker believes that the cell was designed so that he can meet these goals without suffering physical injuries. When a manufacturing cell is designed and operated properly the operator's physical motions appear to have a rhythm. This is an indication of deep involvement.

There is no physical activity visible in the product design process. In the product development system at Toyota deep involvement by a designer is encouraged through long term associations with their functional group. "Toyota believes that deep expertise in engineering specialties is essential to its product development system" (Sobek 1998).

3.2.5.7 Loss of Self-Consciousness

During flow, a person is challenged to do his best and must constantly improve his skills. At the time he becomes absorbed in the activity rather than his own self. This is unusual because normal activities include a great deal of self awareness.

In the Toyota Production System a connection to the category of loss of self-consciousness may be seen in the way the production processes are linked together. For the system to work properly, each worker must complete his part properly and pass it on to the next step in a predictable manner. This rigid requirement demands the full involvement of the worker with little room for self centered concerns.

Conflict is encouraged during the product development process at Toyota. The engineers are aware that a systematized process acts to incrementally resolve design conflicts. This knowledge frees the engineer from personal concerns about how his ideas will be received.

3.2.5.8 A Challenging Activity That Requires Skill

To achieve the flow condition an individual must be challenged. This often requires the engagement of his physical, technical or social skills. As an individual resolves the complexity of an activity, the magnitude of the challenge diminishes. To maintain flow the individual must seek new challenges or change the way he participates in the activity. The result is a continuously evolving "game" of keeping the activity at a level that contributes to flow.

The desire to maintain an optimal ratio between challenges and skills does not only hold for human adults. The most culturally widespread game of human children, escape and pursuit, is also performed by a dog and his master. The dog "would run circles around me at top speed, with his tongue hanging out and his eyes warily watching every move I made, daring me to catch him. Occasionally I would take a lunge and if I was lucky I got to touch him. Now the interesting part is that whenever I was tired and moved halfheartedly, the dog would run much tighter circles, making it relatively easy for me to catch him; on the other hand if I was in good shape and willing to extend myself, he would enlarge the diameter of the circle. In this way the difficulty of the game was kept constant (Csikszentmihalyi 1990)."

Continuous improvement is one of the most widely known principles of the Toyota Production System. This activity has obvious business benefits in waste reduction and product refinement. Continuous improvement is also an activity that helps to maintain the challenge of the work. It is part of each workers job to participate in continuously changing the production system. A worker seeking flow will help to design a system that provides machines and production schedules that are balanced to create the proper challenge.

In the product development system at Toyota the engineers continuously adjust their challenge. They do this through frequent and incremental innovations in their products.

3.2.5.9 Alteration of Time

"One of the most common descriptions of optimal experience is that time no longer seems to pass in the way it ordinarily does (Csikszentmihalyi 1975)." The ordinary extrinsic measure of time, the clock, is rendered irrelevant by the rhythms dictated by the activity. (Csikszentmihalyi 1975). When people experience flow they generally report that time passes faster than they expect. This condition allows people to proceed at their own pace. This category is not considered to be one of the more essential categories that make up the flow condition.

A parallel in the Toyota Production System comes from activities associated with a manufacturing cell. When a cell is operating properly the workers do not watch the clock.

Instead they focus on the activity, perhaps rhythmically moving from machine to machine, and regulating their pace according to their customer's requirements.

The parallel in the product development system at Toyota is the way schedules, milestones and final deadlines are adhered to. From model to model the company enforces hard deadlines for certain well understood milestones but simplified work plans offer time flexibility between deadlines so the engineers are not stifled by arbitrary time constraints.

Flow Categories (Csikszentmihalyi 1990).	Toyota Production System (Womack 1996)	Product Development at Toyota (Sobek 1998)(Fujimoto 1999)
There is an opportunity for successful completion of a task.	The length and complexity of a task is designed so production goals and perfect quality can be achieved.	Adjust skills through training to meet the requirements of a task.
Ability to concentrate on the task at hand.	Single piece flow, length and complexity of task match workers optimal attention span.	Separate meetings for different issues, narrowly focused short memos, short development lead time.
Clear goals.	Production goals are clearly defined for everyone.	Training to understand expectations of every step in the design process so that goals can be set.
Immediate feedback.	Continuous visual feedback on progress toward production goals, inventory management through kanban or other visual means.	Iterative one-page reports. After one or two cycles a face-to-face meeting is held to hammer out specific details.
Control over one's actions.	Work processes designed with strong input from workers in cell.	Work standards are designed and maintained by those that use them.
Deep but effortless involvement.	Cell has rhythm designed for the operator's capabilities.	Product designers develop deep specialized knowledge and experience through long-term association with a specific function. Intense socialization through on-the-job training.
Loss of self-consciousness.	Dedication to responding to connected processes in a predictable manner.	Conflict between functional departments is encouraged. Conflict is managed in a predictable manner.
A challenging activity that requires skill. Balance between boredom and anxiety.	Continuous improvement. Requirements of workers are constantly adjusted to the right level.	Attitude and capability for frequent, incremental innovations.
Feeling that duration of time is altered.	Workers report this condition when a cell is operating properly.	Standard, broadly defined milestones allow flexible schedules tailored to the special requirements of each project.

Figure 7. Examples of Common Principles of Optimal Experience and the Toyota Production System

3.2.6 Can Flow Be Measured?

In this study the notion of "psychological aspects" which are normally observed and empirically studied are not the ones used. Instead, inner processes, which cannot be observed, are of interest. Self-reporting is the method chosen to collect this data. It is assumed that experiential phenomena may be measured by surveying appropriate groups of individuals. Flow and similar events have been measured for a wide variety of activities such as computer use, leisure activities, surgery, work in a research and development environment, and other pursuits. Both white and blue-collar workers have been measured. Studies worldwide have determined that the flow experience is the same for people from diverse societies, over a broad range of age groups and for farmers and factory workers. (Amablie 1987,Csikszentmihalyi 1975, Lund 1996)

In this study, flow is measured using a survey of individual engineers. A high total score reported in each flow category is taken to mean that the conditions for flow are being met. The survey and its sixty-one statements associated with flow will be described in detail in Chapter 5.

Although the conditions related to flow can be measured, the point value required for each flow category to ignite the flow event is not specified. If all answers on a survey are in strong agreement with the conditions of flow it is likely that the individual is experiencing flow. Less than a perfect score does not mean that the individual can not have the experience. A high score in a single category indicates that the potential for the flow condition exists.

Instead of attempting to determine who is in flow and who is not, the numbers from the survey will be used understand the relationship between external factors and the experience that an engineer has during the design process. Examples of these factors include the number of people in his organization, the type of organization, and work responsibilities. It is not known whether simply attaining a high score on the survey is beneficial to the design process or that for benefits to accrue, an engineer must be in flow. Since the flow condition itself represents a discontinuous jump in experience, the data will be analyzed to see if it can identify this event.

Chapter 4 HYPOTHESES AND FLOW MEASUREMENT

The Toyota Motor Company is considered to be a successful company by many measures. Its foundation, the Toyota Production System, defines how the entire company works. Product development at Toyota follows the same principles that define the Toyota Production System. It appears that adherence to these principles around the company result in similar types of success.

In the previous chapters, principles of a successful manufacturing system and the principles of a successful product design system are enumerated and mapped into a non-domain specific framework called flow. Adherence by individuals to the categories of flow is associated with optimal experience. This chapter will outline hypotheses for the relationship between flow measurements of engineers and designers involved with the product design process and various attributes of the organizations they are associated with.

4.1 Measuring Flow

Flow is measured using a web-based survey administered to individuals at a variety of companies. Flow ratings are based on the flow categories and are sorted by job responsibilities, company size, and other factors.

4.2 Product Design Attributes Measured by Flow

The following hypotheses will be evaluated using the results of the survey:

1) High flow rating is related to whether the organization is a desirable place to work.
2) Low flow rating is associated with a large number of employees in a company.
3) High flow rating is associated with small group size.
4) High flow rating is related to faster product design cycle time.
5) High flow rating is associated with popular products.
6) High flow rating is associated with new companies.
7) High flow rating is related to the creative process.

4.3 Survey Format

The statements in the survey were chosen to determine how well an engineer's experience matched the experiences associated with flow. General information about the respondent was collected with a fill in the blank type form. Experience data related to flow was collected through Likert scale responses to sixty one questions that ranged from strongly agree to strongly disagree. Respondents received a request to fill out the survey through e-mail, usually through a company representative with authority to approve an outside survey activity. Access to the survey was through the Internet. The results were transmitted back through email and compiled in a spreadsheet. A copy of the survey is provided in Appendix A.

4.4 Survey Structure

The statements in the survey are based on the categories of flow listed in Figure 7. The questions address the most important issues related to product design in each flow category. Most of the important issues were covered in seven questions; while, one category had five, one had six, and one category had eight questions. The length of the survey was guided by the conflicting requirements of keeping it short but collecting enough data to satisfy requirements for statistical significance. Seven is considered to be the minimum number of statements necessary to conduct statistical validity checks.

4.5 How Engineers Were Chosen for the Survey

The survey is designed to measure the experience an individual engineer has during the design process. Responses can be combined to examine the relationship between an engineer's experience and organizational factors such as size of company, size of group that he works in, job description and other factors. To get this kind of information, engineers from a variety of companies were chosen. The main requirement is that their responsibilities contribute directly to the product design.

The size of the companies sampled ranged from a one-man consulting firm to companies that are among the largest in the world. The companies were selected to obtain a sample engineers from a range of product design experiences. For example, some of the engineers work at companies that produce products that take more than ten years from the time a specification is written to the time the product is delivered to a customer. At other firms sampled in the survey, engineers complete their design work in a matter of weeks, often well before any formal specification is complete and production starts within months of the start of the project.

4.6 Explanation of Statements In Each Category

This section contains a discussion of the background for each statement in the survey. The scores range from 0 to 6 with a value of 6 indicating that the engineer's experience closely adheres to the definition of flow and a value of zero indicating that his experience was very different from the definition of flow.

One of the goals of the survey is to have the engineer provide an answer that best describes how he works within his organization. For example, complex projects are often held together with a system specification describing many requirements ranging from material selection to testing requirements. An engineer may feel that this is the most important influence on how he conducts himself in the design process. His goals may be set by the narrow requirements of the specification document because of his belief in the importance of this document or because of the organizations emphasis on compliance. On the other hand another engineer, who is also subject to the requirements of a system specification, may not use it as his priority for setting goals. His priorities may come from other influences such as his immediate customer, marketing whims or his own superior technical knowledge. This engineer may know how to arrange for changes in the specification to give him additional flexibility during implementation of its requirements. For some engineers involved in the product design process there may be no formal specification when the project begins. This does not mean he will not meet the system requirements when the project is complete. Instead the engineer may start from a reference point that he defines on the ultimate path to meeting the requirement of the system specification.

This survey is designed to measure experiences that are specific to the product design process. The statements in the survey are associated with a particular category. The magnitude of the selection on the Likert scale is an indication of the potential to experience the flow condition. Some of the statements are similar to those found in surveys used to measure other conditions in organizations. Figure 8. contains all the statements in the survey sorted by flow category. The following sections provide detailed rationale for the selection of each item in the survey.

Flow Category	Survey Statements
Success	*I know when a task is successful.* *Tasks are complete when my immediate customer is satisfied.* *A task begins when I receive requests for help on a new problem.* *Over the last 12 months all of my tasks were successful.* *Tasks are complete when the budget is exhausted.* *I influence whether a task is successful.* *Tasks begin when the specification is complete.*
Concentration	*The number of tasks I work on is just right.* *I work on a task from beginning to end.* *Distractions prevent me from doing my best work.* *Changes in customer requirements affect the quality of my final product.* *Specifications I am given clarify the task requirements* *I am able to concentrate on my tasks.* *Tasks take so long it is hard to remember all of the details*
Goals	*I set personal goals for each task.* *My immediate customer influences the project's goals.* *I use specifications to define task goals.* *Mangers define goals for each task.* *My goals are the same for each task.* *Everyone involved with a task has the same goals.* *Goals change during a task.*
Feedback	*I work alone.* *Design reviews are the main form of feedback.* *Co-worker feedback influences my work.* *There is continuous feedback on my work.* *The amount of feedback on my work is just right.* *I use customer feedback during the design process.* *My feedback educates the customer.*
Control	*I have control over important design decisions.* *I influence marketing decisions.* *There are many opportunities for my design inputs.* *I interact with the sales department* *Most of my time is spent responding to special requests.* *Suggested changes to the product specification are easily incorporated.* *My work is visible in the final product.*
Involvement	*My projects reflect my skills and interests.* *My contributions to a design are meaningful.* *I feel personally involved with a project.* *Sometimes my work feels like an exciting adventure.* *Solutions to problems often come to me when I am not at work.* *My work is part of my personal identity.*
Self Consciousness	*I often seek help from my peers.* *I work with engineers on projects other than my own.* *I do not hesitate to ask for help.* *I frequently present new ideas to my co-workers.* *I share my special knowledge and expertise with other group members.* *I frequently challenge the work of others.* *My designs incorporate ideas that have some risk.*
Time	*There is enough time to finish a project.* *Needs of design determine how much time I spend on a task.* *Contract schedule determines how I budget my time.* *I sometimes lose track of time when I am working.* *I am often surprised by how much I have accomplished*
Challenging	*My work is a challenging activity that requires skill.* *My workday is devoted technical tasks that directly affect the product.* *My work adds to future opportunities of the company.* *Most of my tasks require concentration.* *I am satisfied when a task is complete.* *Each new project is a little more challenging than the previous one.* *To perform my job I must frequently learn new things.* *Solutions are obvious at the beginning the task.*

Figure 8. Summary of Survey Statements Sorted by Flow Category

4.6.1 Category 1. Opportunity for Successful Completion of a Task

Some of the experiences that influence the potential for flow affect the opportunity for successful completion of a task. "Do I have the right materials and equipment I need to do my work?" (Buckingham 1999), is the way a similar question in a Gallup survey was phrased. A variety of factors are associated with successful completion of a task. For this survey, common and important statements concerning successful task completion are included. The statements deal with beginning of a task, end of a task, definition of success, task definition, and outcome.

I know when a task is successful.
Over the last 12 months all of my tasks were successful.
I influence whether a task is successful.

Success has many definitions. There is no single measure or variable that covers all the factors. For example it is not practical for an engineer involved with product design to use return on investment or shareholder value as his own metric. He may use something better suited to a specific activity. In this survey the definition is left to the engineer. The survey deals with how he relates to his own definition. The first statement on the survey determines whether the engineer feels able to use a definition of success to assess the outcome of his work. The second statement determines how successful the engineer feels.

A task begins when I receive requests for help on a new problem.
Tasks are complete when my immediate customer is satisfied.
Tasks begin when the specification is complete.
Tasks are complete when the budget is exhausted.

The remaining four statements deal with how the engineer views the beginning and end of the task. The response of the engineer indicate whether he defines these events for himself or uses external queues. An example of an extrinsic definition is when the engineer feels that the end of the task comes when the budget is exhausted. Agreement with this definition indicates a weak connection between the definition of completion and the task itself. The other statements in this category follow a similar pattern. In the statements concerning beginning and end, cues such as contract signing, completed specification or scheduling are external to the design task while customer cues and component technical issues are internal to the design process. In these statements, as in others, the position of the engineer in the organization may influence his definition of whether the cue is internal or external. For example, in a product design organization where product design managers are the point of contact for the rest of the company, contract dates and schedule may be a more intrinsic measure of the starting and stopping of a task for the manger while a product design engineer in the same organization may be insulated from contract schedules and take his queues from technical issues. These influences will be addressed in the data analysis by looking at the relation ship between flow and job description.

4.6.2 Category 2. Ability to Concentrate on the Task at Hand

The ability of an engineer to concentrate on a task is influenced by many factors. The seven chosen for the survey were selected to try to capture the effect of a range of possible disruptions and distractions. To achieve a condition where an engineer can focus all his relevant skills on the task he must be able to work well in an environment with a lot of distractions or work in an environment that optimizes his ability to concentrate. For some engineers, distractions are viewed as part of the work, and they may not feel like their concentration is effected.

I am able to concentrate on my tasks.

This statement addresses concentration directly. Some engineers feel that concentrating is difficult in the work environment while an engineer experiencing the flow condition may be able to concentrate despite disruptions.

The number of tasks I work on is just right.
Tasks take so long it is hard to remember all of the details.
I work on a task from beginning to end.

The three survey statements above address how the tasks affect his ability to concentrate. The number of tasks that an engineer is comfortable working on differs for each individual. Some thrive on the challenge of juggling many projects. Others can't concentrate under the demands of constantly shifting gears. Number of tasks, length of project, and level of involvement may affect the ability to concentrate on the task. For each engineer there is an optimal length of time for a task that allows him to contribute and complete his work without losing interest in the content.

Distractions prevent me from doing my best work.
Changes in customer requirements affect the quality of my final product.
Specifications I am given clarify the task requirements.

In the above three statements the problem of whether distractions effect concentration is surveyed. For some engineer's distractions such as phone calls, meetings, or other activities are detrimental to the product design process. For others, the right amount of distractions is part of the inputs required to perform the product design optimally. The statement on specifications giving clarity gives an indication whether an external influence is helpful or a distraction. The definition of flow implies that use of an externally generated specification by an engineer to guide his work is an extrinsic influence and diminishes the flow experience.

4.6.3 Category 3. Clear Goals for Each Task

When working on a complex long-term project clear goals for each task are important for the engineer to maintain deep involvement. Goals provide the focus necessary for the ultimate success of the project. The Gallup survey asked the question "Do I know what is expected of me at work?" (Buckingham 1999). That question asked if the worker new the goals. The survey in this study examines the engineers experience with different aspects of the project's goals.

I set personal goals for each task.
My immediate customer influences the project's goals.
I use specifications to define task goals.
Mangers define goals for each task.

In this category of the survey the statements asks first about who sets the goals. Agreement with the first two statements indicates that the engineer sets goals consistent with the principles of flow. In other words, he uses intrinsic criteria to determine personal goals and the needs of the person that will be the recipient of his services. Agreement with the third and fourth statements indicates that the method of setting goals relies on extrinsic influences. When others set goals the potential for flow decreases.

My goals are the same for each task.
Goals change during a task.
Everyone involved with a task has the same goals.

Flexibility is an essential part of an enhanced product design process. A flexible system is one in which the goals are not necessarily the same for each task and may even change during the task as the design evolves. The final statement concerns whether the engineer feels that others involved have similar goals. Agreement with this statement indicates that the there is some form of communication that would allow the others to figure out how the goals were evolving and develop a set of shared goals.

The idea of flexible goals is one of the important parts of a flow condition. When an environment is conducive to flow the individual is continuously adjusting his goals to try to stay in the flow condition. When things are working right the adjustment is naturally to a more ambitious agenda since this is required to maintain the challenge that keeps him engaged. Externally set goals cannot be adjusted with either the proper timing or the right increment. Only the individual can adjust his goals perfectly.

4.6.4 Category 4. Immediate Feedback

Useful and timely feedback varies by task and individual needs. It is used to appropriately adjust the goals as the project progresses.

I work alone.
Co-worker feedback influences my work.

Do I have a best friend at work? is the way Buckingham (1999) was able to learn about feedback in a similar way. A close and valued relationship with many co-workers is believed to offer the kind of feedback essential to the success of a task. A product designer may work in relative isolation, relying mainly on an approved specification for guidance. This arrangement loses out on the subtle interactions between other parties working on the project. "Co-location helps engineers develop a shared language and allows them to slowly reveal their tacit assumptions to one-another. (Bernstein 2001)" Close relationships provide feedback beyond that required by a formal system. The result may be an enhanced design that reflects many cycles of feedback and redesign and produce features beyond those specified.

There is continuous feedback on my work.
The amount of feedback on my work is just right.

Design reviews are the main form of feedback.

The balance between too much and too little feedback is achieved in the flow condition. The statement concerning design reviews tries to find out how much reliance there is on a more formal, discontinuous feedback system. The Gallup survey (Buckingham 1999) makes the assumption that feedback occurs within seven days. For flow, a schedule for the feedback cycle is not required. Instead, the feedback cycle time is adjusted for the specific task to create a more continuous form of feedback.

I use customer feedback during the design process.
My feedback educates the customer.

The above two statements deal with the effectiveness of the feedback. A further dimension to the meaning of the feedback to a design engineer occurs when he feels like his design is reflecting the real needs of the customer and that the interaction is helping the customer make good decisions. This kind of feedback adds to the feeling of deep involvement in the project.

4.6.4.1 Selected Example of Feedback Tools In The Design Environment

This survey does not address specific hardware or software tools that increase the opportunity for achieving the flow condition because the focus of the study is on the experience people have within the system their organization uses. However, there are many tools used that may enhance the experience. Simulation tools are especially important to the flow category of rapid feedback.

Simulation tools are a standard part of most design processes now and offer and a valuable form of feedback. However, simulation is not used for the same purpose in all the design processes. Questions arise about whether the simulation is for the customer, the manger, or for the technical personnel involved directly in the design process. Once these questions are answered the documentation of how a simulation was used over the evolution of a design becomes an important form of feedback. This documentation allows the discovery of when design decisions are made and how the decisions are made. Lessons learned may be documented through evaluation of the evolution of the good and bad prototypes and their simulations. "A retrievable and auditable record of the design process is a core element of a firm's organizational memory (Schrage 2000)".

The goal of this process is to understand what created an innovative or successful design. If insight into the process is obtained, then, perhaps this success will be more easily replicated. It is not as important to determine what decisions were bad as to see how bad decisions were made. This process is the one that most relates to a flexible design process. The design process at IDEO reviews the progression of CAD designs not only internally but also with the customer. (Schrage 2000)

Simulation has a variety of uses in the design process. Its narrowest application is in the technical domain. Tolerance studies, design for assembly, and static and dynamic analysis are examples of mechanical design applications that are enhanced with simulation tools such as Computer Aided Design (CAD) and Finite Element Analysis (FEA). The tools assist in rapid evaluation of designs and trade off studies that respond to questions posed by personnel involved with many aspects of the project.

Additional benefits from simulations may also be realized. The purpose of the simulation does not have to be defined in a narrow technical category. Instead, the simulation may be built around other uses. Perhaps the simulation's main purpose is to explain the concept or problem to the customer, management, or to other domain specialists. It is in this use that the simulation's value to the design process becomes enhanced. Complex products are composed of a variety of competing features and problems that may not be completely understood by all the members of the product design team. (Bernstein 2001) The simulation may better explain the goals of each of the players and the effect of trade offs and design changes.

Simulations often serve as tools to express the goals of the technical members of a design team as well as the goals of the management or customer. Methods of expressing the goals can be enhanced by making simulations accessible to the other players and extending the reach of the rapid feed back that simulation provides. An example of this type of extension of feed back through simulation is allowing people outside of the company access to the simulation using a system called DOME. (Abrahamson 2000)

4.6.5 Category 5. Control Over One's Actions

During large, complex design projects, few, if any individuals completely control the outcome of the effort. When thousands of engineers contribute over long periods of time it becomes difficult to measure the actual contribution of an individual to the final product. The flow construct recognizes this question by describing the experience, as "the sense of control" since actual control of many of the activities is not possible. (Csikszentmihalyi 1990)

I have control over important design decisions.
There are many opportunities for my design inputs.
My work is visible in the final product.

The above three statements measure the various ways an engineer feels about the core question of whether he controls the design. The flow condition is attained when the feeling of control over the design generates the ability to focus on the creative work of innovations and other product enhancements beyond the expected scope of a task.

Suggested changes to the product specification are easily incorporated.

This statement determines whether an extrinsic force can be changed to allow an action that the engineer deems more appropriate. The specification itself is sometimes viewed as an impediment to innovation. However, the ability to easily change it gives control back to the designer.

Most of my time is spent responding to special requests.

This statement partially addresses the question of whether the engineer feels like he controls his opportunity to devote himself to the design process. Sometimes the work environment itself makes some engineers feel like the whole design process is not in their control. Preparations for presentations, excessive time spent in meetings, and non-design related responsibilities make some engineers feel like they are unable to spend the right amount of time on the activities that they feel they should be working on.

I interact with the sales department
I influence marketing decisions.

These two statements gage how far an engineer feels his influence reaches outside of the traditional technical realm.

4.6.6 Category 6. Deep But Effortless Involvement

Feeling deeply involved with a project is a requirement for flow. A worker in a factory experiencing deep but effortless involvement is probably experiencing a challenge to both his physical capabilities and mental skills. At the right balance many of the factors that are discussed in relation to flow come into play. The right combination of the factors "clears a workers mind of distractions and draws him deeper into the work where his concentration makes the work feel effortless. (Csikszentmihalyi 1990)"

I feel personally involved with a project.
My projects reflect my skills and interests.
Solutions to problems often come to me when I am not at work.
My work is part of my personal identity.
Sometimes my work feels like an exciting adventure.
My contributions to a design are meaningful.

For a product design engineer there is no physical aspect to deep involvement in a project but there are many levels for him to be involved. The statements above address some of these. Personal interest in a project is one of the ways to enhance deep involvement. For example, at IDEO, a leading product design firm, the designers pick which group they wish to work in. For certain projects, personal experience with similar products is considered to be helpful. Designers with children may already have a special interest and experience that prepares them for design of a new car seat. (Kelley 2001) In the case of this company the system is set up to maximize how well the projects reflect the skills and experience of the designers and encourage deep involvement.

For some engineers their involvement is reflected in how they identify themselves with the work they are doing. Many also find the day-to-day activities so exciting that they view their involvement as an adventure.

4.6.7 Category 7. Loss of Self-Conscious Behavior

I often seek help from my peers.

I do not hesitate to ask for help.

These two statements measure the frequency of seeking help and whether asking for help is a problem. Although there is some overlap in these statements it appears that the ability to interact easily and frequently with others indicates a reduced inhibition about voicing new ideas and challenging old ones.

I work with engineers on projects other than my own.
I share my special knowledge and expertise with other group members.

Reduced self-consciousness is also associated with reduced self-interest. Under this condition an engineer can much more easily offer his expertise to other projects and share his expertise with associates who benefit from his knowledge

I frequently present new ideas to my co-workers.
I frequently challenge the work of others.

Being able to comfortably present new ideas and question and challenge the work of others, indicates that the engineer is able to address important steps in the development of a design without fear that his activities somehow being held against him.

My designs incorporate ideas that have some risk.

Risk taking behavior also indicates reduced self-consciousness. Fear of increased risk of failure is less likely to drive design concerns when self-consciousness is reduced.

4.6.8 Category 8. Altered Sense of Time

How engineers feel about issues related to time is another category that the survey measures. While many people believe that time pressures may jumpstart the creative process, evidence exists that creative thinking actually suffers under these conditions. "Freedom from the tyranny of time does add to the exhilaration we feel during a state of complete involvement" (Csikszentmihalyi 1990). On the other hand "creative ideas will not often be produced in the complete absence of any time pressure whatsoever either self imposed or externally imposed" (Mueller 2000). The survey tries to measure whether the engineers can achieve the balance necessary for flow.

There is enough time to finish a project.

Agreement with this statement is taken to mean that the engineer feels that the amount of time that he can find to work on the project is flexible and can be tailored so the project can be finished. For flow, the actual amount of time spent may or may not change, but the engineer feels like it was enough for satisfactory completion of the task.

Needs of design determine how much time I spend on a task.
Contract schedule determines how I budget my time.

These two statements determine whether the time is allotted through an intrinsic requirement like the details of the design or an extrinsic constraint like the contract schedule.

I sometimes lose track of time when I am working.
I am often surprised by how much I have accomplished.

Under flow conditions, time may appear to be slowing down, speeding up or altered in some way. In general, people report that time seems to pass much faster (Csikszentmihalyi 1990). Losing track of time is an indication that the engineer is no longer using external references to control his actions. The combination of feeling like time is slowing down and involvement in the work may be associated with enhanced productivity.

4.6.9 Category 9. Challenging Activity That Requires Skill

This category has the clearest links between the Toyota Production System and the categories of flow. This category is an important component of the flow measurement.

My work is a challenging activity that requires skill.
Most of my tasks require concentration.
Solutions are obvious at the beginning the task.

The first two statements are fundamental to the flow condition. The third statement refers to the prospect of mundane work. Just going through the motions of a task that is not necessary may result in boredom, lack of attention, and, in the worst case, mistakes.

My workday is devoted technical tasks that directly affect the product.
My work adds to future opportunities of the company.
I am satisfied when a task is complete.

The first two statements in this group determine whether the engineer feels that he is involved with technical work and whether this work is helping the company. Satisfaction with the completion of a job is taken to mean that there was a challenge to begin with.

Each new project is a little more challenging than the previous one.
To perform my job I must frequently learn new things.

These two statements measure continuous improvement and the continuous change that is associated with the Toyota Production System. Continuous improvement is required to maintain the flow condition for an engineer. A project that is initially challenging and requires the highest of the engineer's skills becomes mundane once mastered. More challenging work or application of new techniques is required to maintain the flow condition for the engineer.

Chapter 5 RESULTS

The results of the survey are compiled in this chapter. In the first part, the entire data set is summarized and sorted using the absolute Likert scores from each statement. These scores, called flow ratings on the graphs and tables, are summarized by type of company and job description. Following these general summaries are narrower presentations of the data with discussions of the results. Where possible the results are interpreted to see if the hypotheses proposed in Chapter 4 can be confirmed.

5.1 Descriptions Of The Companies

Surveys from seventeen companies were used for evaluating the results. The people from fourteen of the seventeen companies were engineers and designers involved in part of the product design process. The engineers (or architects, in one case) from two of the companies were involved in design of buildings. One company, was not involved with product design. It was included as an example how the score of a company not involved in the product design process would compare to companies that were. Information about the companies that were surveyed is summarized in Figure 9. Additional written descriptions of the companies is also provided in a manner that describes the general work of the company but had to be kept generic and limited so that that the identity of the company is not revealed.

Company Description	Average Flow Rating	Number of Respon- dents	Number of People in Company	% Responding	Year Founded
Environmental Data Analysis	4.7	2	2	100%	1998
Architectural Design	4.3	4	500	1%	1969
Technical Sales	4.2	7	10	70%	1990
Large Product Design	4.1	11	400	3%	~1980
Structural Design	4.1	1	500	0%	~1950
Biotech Startup	4.1	5	20	25%	2000
Academic R&D	4.0	5	12	42%	1996
Specification Modification	4.0	5	7	71%	2002
Large Computer	3.8	9	150000	0%	1939
Test Equipment Design	3.8	5	100	5%	1972
Small Design 3	3.8	11	30	37%	1998
Small Product Design 2	3.7	3	20	15%	na
Small Product Design 1	3.7	5	30	17%	1986
Large Electronics	3.7	88	100000	0%	1922
Medium Product Design	3.6	3	60	5%	1993
Medium Optics Design	3.5	1	200	1%	1977
Consulting Engineer	3.5	1	1	100%	1982

Figure 9. Summary of Company Information

Environmental Data Analysis

The company with the highest flow rating is the only one not connected to the product design process. It is a two-person firm that performs statistical analysis of environmental test data on a contract basis. A non-product design company was initially chosen for the survey to see how it worked outside of product design. Since it is proposed that the principles of flow are transferable to other processes, testing the survey outside of product design is useful. Not only were the respondents able to complete the survey, their results raised questions about how to interpret the differences in flow rating from company to company and from domain to domain.

Biotech Startup

The company labeled Biotech Startup performs both research and development and design of electro-mechanical devices. They do not build their own hardware components but they do assemble the system from components they design. Many of the personnel are involved in a wide range of mechanical design activities for a new product. Their source of funding is venture capital.

Architectural Design

Although not mechanical designers the architects that were surveyed are involved with the design process. Their main products are large institutional and commercial buildings. They were included in the survey to measure the difference between professionals involved with design in different fields.

Technical Sales

The salesmen from this company are all mechanical engineers. They work with their customers to design, specify, build, and start up a variety of electro-mechanical test and manufacturing equipment. Their customers include large aerospace and computer companies.

Academic R&D

The members of this research and development group are mechanical engineers. They design and write software for web-based distributed product development services. Their research projects are funded by automotive and software companies. Successful implementation of their work will change the way product design is performed.

Large Product Design

This firm is a widely admired, award-winning design and development firm. The product design engineers are involved from early in the concept development to the beginning of production.

Structural Design

This firm's main activity is the design and analysis of structures for buildings. The single respondent to the survey follows most designs from early concept phase to completion of construction. He is responsible for the safety of the structure, meeting the architect's design requirements, and managing the budget and schedule.

Small Design 3

Print design, website design, corporate identity and photography are the main activities of this company. The design process is an important part of their work but their product is not hardware, like many of the other firms.

Small Product Design 1

This company works on both consumer and industrial products of low to moderate complexity (Ulrich 2000), including hand tools, medical devices, and electronics. The work of the designers is to convert client's concepts into commercially successful products.

Large Electronics

The mechanical engineers and designers at this firm perform a variety of functions including, circuit card layout, design of electromechanical devices, design of test equipment, device testing, packaging, specialized analyses, and material studies. Customer needs statements are turned into system specifications from which more detailed performance specifications are developed and used by the engineers and designers. The projects are complex, the volume small, and the time from concept to deployment can be over ten years.

Specification Modification Team

All the members of this group are employees of the Large Electronics Company. This group was separated in this study because of the special nature of their work. The task they reported on was the rewriting of an archaic general welding specification. Their goal was to develop a specification flexible enough to be suitable to the range of products currently in design and production. This group was chosen because of their influence on the specification development process.

Large Computer

The main products of this company are computers for the consumer to high end market. The product design team surveyed performs the entire computer system mechanical design.

Test Equipment Design

This company designs and manufactures innovative analytical instruments based on electro-chemical processes for the detection of harmful materials in the environment.

Small Product Design 2

This company is a full-service product design and development firm which offers design research, industrial design, human factors design, graphic design, environmental design and mechanical engineering services. It's products include toys, house wares, and electronic consumer products.

Medium Product Design

This company designs software and hardware for computer-assisted design. It differs from the other product design firms because it focuses on one product.

Medium Optics Design

This company designs and builds optics for government and commercial clients. Some of the products are used in satellites. The single engineer that responded to this survey is primarily involved with thermal and structural analysis of the mechanical assemblies.

Consulting Engineer

The primary responsibility for the engineer in this one man company is to design and analyze structures to withstand the forces generated by storm driven waves and wind. The design cycle time for these structures is short, one to six months, and the useful life of the structures is often greater than thirty years. The products are civil structures like, such as docks and breakwaters.

5.2 Summary of All Data

Figure 10. is a summary of the data collected for this survey. It is a condensation of the information returned from approximately seventeen different organizations on approximately one hundred and seventy surveys. The scores are calculated from the choices that individuals made on the Likert scale for each statement and summarized by flow category. The table is sorted in vertical descending order by average score for all the people in the company. The order of the flow categories from left to right is based on the flow category scores for the Biotech Startup company. This order was chosen because the Biotech Startup had the highest average score among the companies that performed a broad range of activities associated with the product design process.

Flow Category Type of Company	Deep Involve-ment	Chal-lenging	Loss Of Self Con-scious	Suc-cess	Feed-back	Control	Time	Goals	Concen-tration	Aver-age
Environmental Analysis	5.7	4.9	5.4	4.7	4.6	4.9	4.5	4.3	3.9	4.7
Arch Design	5.0	4.9	4.7	4.4	4.2	4.6	3.6	4.2	3.1	4.3
Technical Sales	5.3	4.5	4.7	4.1	4.4	4.2	3.6	4.0	3.1	4.2
Large Product Design	4.8	4.7	4.4	4.3	4.6	4.2	3.4	3.4	3.1	4.1
Struct Design	4.5	4.5	4.7	4.6	3.8	3.6	3.8	4.1	3.0	4.1
Biotech Startup	4.8	4.5	4.3	4.2	4.2	3.9	3.7	3.5	3.5	4.1
Academic R&D	5.0	4.4	4.1	4.2	4.2	4.2	3.1	3.8	2.7	4.0
Specification Mod.	4.5	4.3	4.2	4.6	3.9	3.4	3.2	3.7	3.7	4.0
Large Computer	4.9	4.5	4.3	4.1	3.3	3.0	3.4	3.7	3.4	3.8
Average by Category	4.4	4.2	4.3	4.1	3.8	3.3	3.3	3.5	3.0	3.8
Test Equipment	4.2	4.5	4.4	4.2	3.1	3.6	3.5	3.3	3.1	3.8
Small Design 3	4.4	4.4	4.5	4.0	3.7	3.6	3.2	3.6	2.4	3.8
Small Product Design 2	4.1	4.2	4.1	3.6	3.8	3.6	3.2	3.9	2.8	3.7
Small Product Design 1	4.1	4.0	4.2	3.7	3.4	4.1	2.6	3.7	3.3	3.7
Large Electronics	4.2	4.1	4.3	4.1	3.7	2.9	3.3	3.4	3.1	3.7
Medium Product Design	4.3	4.3	5.2	3.4	3.1	3.6	2.7	3.3	2.0	3.6
Medium Optics	3.8	4.4	3.3	3.7	3.4	3.4	3.4	3.3	3.0	3.5
Consulting Engineer	4.3	4.4	3.9	3.9	2.7	3.1	2.8	3.4	3.1	3.5

Figure 10. Summary of Flow Ratings By Type of Company

A final conclusion about the relationship between flow and product design is not possible from this summary table. What does emerge is the beginning of a picture of what kind of experience an engineer has during the product design process. Hypothesis Number 7 from Chapter 4 suggested that if the company was producing creative products the engineers might be experiencing flow. This researcher speculated that product design firms do the most creative work, but the results shown above place only one product design firm near the top and the rest bunched below average. (See Figure 11.) The breakdown of the flow ratings by flow categories gives some insight into the different experiences that the workers have. The ability to concentrate on the task at hand at Small Design 3 and Medium Product Design is approximately one third lower than at Large Product Design. Since the definition of when an individual or company is in flow is not specifically defined in this study, other measures of success are needed. Only limited information indicating relative success of the companies is available for this study. The Large Product Design firm has collected more Industrial Design Excellence Awards than Small Product Design 2 in 2002 and also over the last five years. (Nussbaum 2002). Big differences occurred in two categories; the feeling that there was an opportunity for a successful outcome and the ability to concentrate on the task at hand. More discussion of this group will follow in Case Study1.

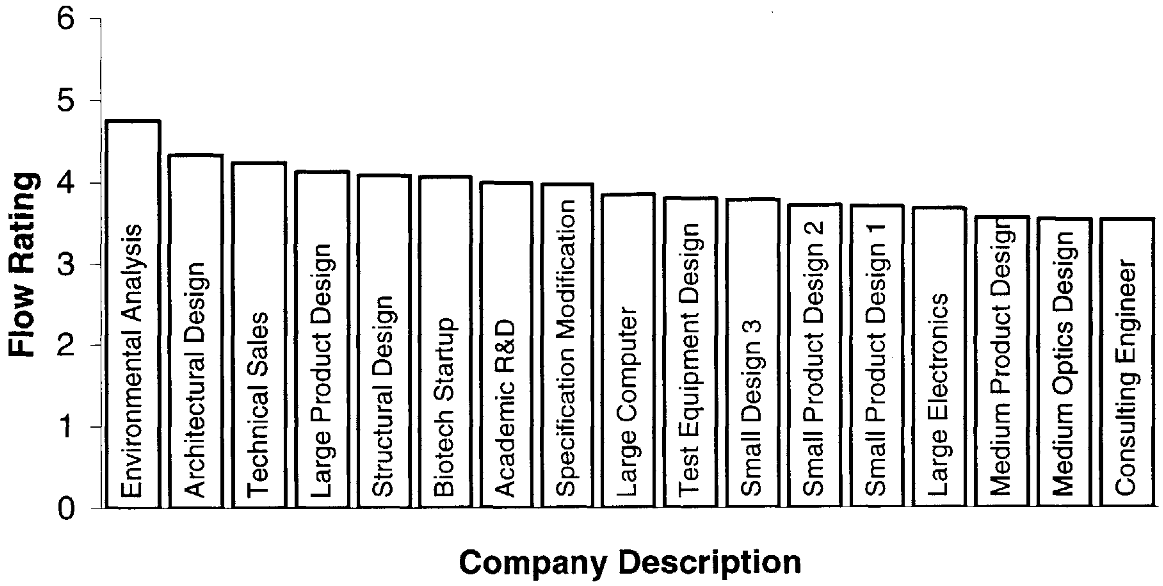

Figure 11. Summary of Flow Rating by Company

Figure 12. summarizes all the data by company and exposes the flow categories where the companies excel and which categories may be impeding the flow experience. In general the companies are strong in deep involvement, challenging activity, and loss of self-consciousness and weak in concentration, duration of time, and control. Strength in the first three categories appears to reflect professional values that the engineers and designers have. They maintain their high flow rating in these categories independent of organization or product. All companies experienced weakness in the ability to concentrate on the task at hand. This measurement reflects the strength of the forces that act to disrupt a continuous design process. Few individuals are able to concentrate in this environment. The chart also indicates that the workers are slaves to extrinsic time constraints rather than the specific requirements of their projects. While this is a real-world constraint, increased flexibility in the way time constraints are applied may improve this low flow rating.

Figure 12. shows which flow categories are important to the overall flow rating of a company. The company with the lowest average flow rating is at the top of the chart and the company with the highest average flow rating is at the bottom. This table provides insight into how an

individual company differs from the ones with the highest or lowest flow rating and how they differ from companies with similar flow ratings. Case studies of grouping of companies will be evaluated separately later in this chapter.

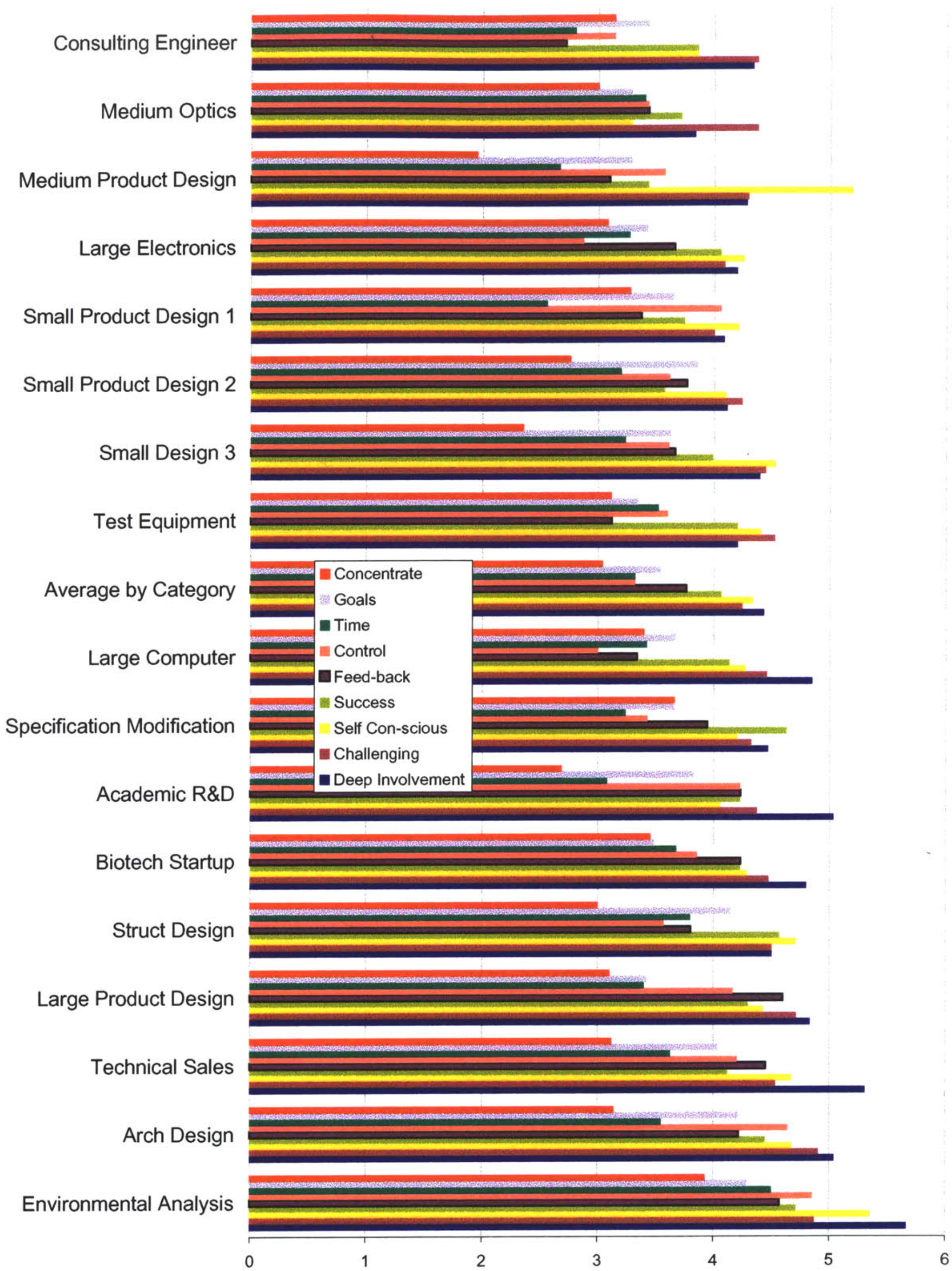

Figure 12. Summary of Flow Rating by Type of Company (Graphical Summary)

5.2.1 Summary of Flow Ratings By Work Description

Figure 13. breaks down the data by flow category in a manner similar to Figure 10. This time, the data is sorted by work description merging people from different companies. The job classification with the highest flow rating is at the top. The order of the flow categories displayed from left to right was chosen based on the descending order of the categories from the work description with the highest average flow rating.

Flow Category Work Description	Deep Involve-ment	Loss of Self Con-sciousnes	Chal-lenging Activity	Con-trol	Average Score	Success	Alter-ation of Time	Feed-back	Goal	Con-centrate
Owner/Technical (6)	5.2	4.9	4.7	4.4	4.3	4.3	4.0	3.9	3.8	3.3
Designer/Analyst (51)	4.5	4.4	4.5	3.5	3.9	4.1	3.5	3.9	3.6	3.1
Engineer and Manager (31)	4.6	4.4	4.2	3.5	3.8	4.0	3.1	4.0	3.6	2.9
Average by category	4.4	4.3	4.2	3.3	3.8	4.1	3.3	3.8	3.5	3.0
Design (35)	4.4	4.2	4.2	3.1	3.7	4.1	3.4	3.7	3.4	3.3
Department Manager (6)	4.3	4.5	4.1	3.5	3.7	4.1	3.0	3.4	3.9	2.4
Analysis (12)	4.1	4.2	4.1	2.5	3.6	4.1	3.3	3.3	3.7	3.2
Manager (19)	4.2	4.3	4.0	3.1	3.6	3.8	3.2	3.6	3.3	2.7

Figure 13. Summary of Flow Rating by Work Description

The measurements link high flow rating with work descriptions that describe the greatest variety of responsibilities. An owner of a company who still has major technical responsibilities has a variety of challenging tasks. While still impacted by difficulty in concentrating on the task at hand he feels that he can control the tasks important to the product. Workers who describe their activities as including both design and analysis also reported a high average flow rating. Their expected strength in involvement, loss of self-consciousness and challenging activities is added to in the control category. This was surprising since most of the designer/analysts in the survey are from the Large Electronics firm where the control flow rating is low.

Workers who described their activities as mainly management suffered in the challenging activity category compared to managers with some technical responsibilities.

Figure 14. is a graphical summary of the average flow rating as a function of work description. This plot shows the higher flow rating for workers with diverse work descriptions.

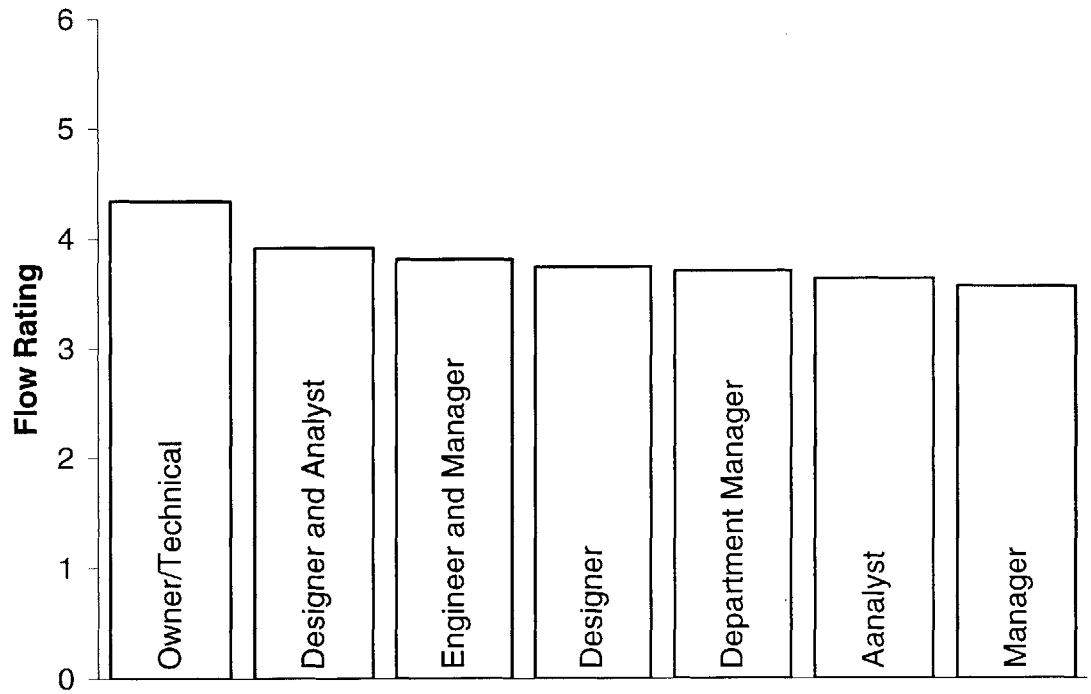

Figure 14. Flow Rating and Work Description

5.2.2 Case Study 1: Product Design Company Comparison

In this section five companies are compared. They are referred to as the product design group. As a group they are slightly below average. This surprising result will be investigated in this section. A summary of the design group is provided in Figure 15.

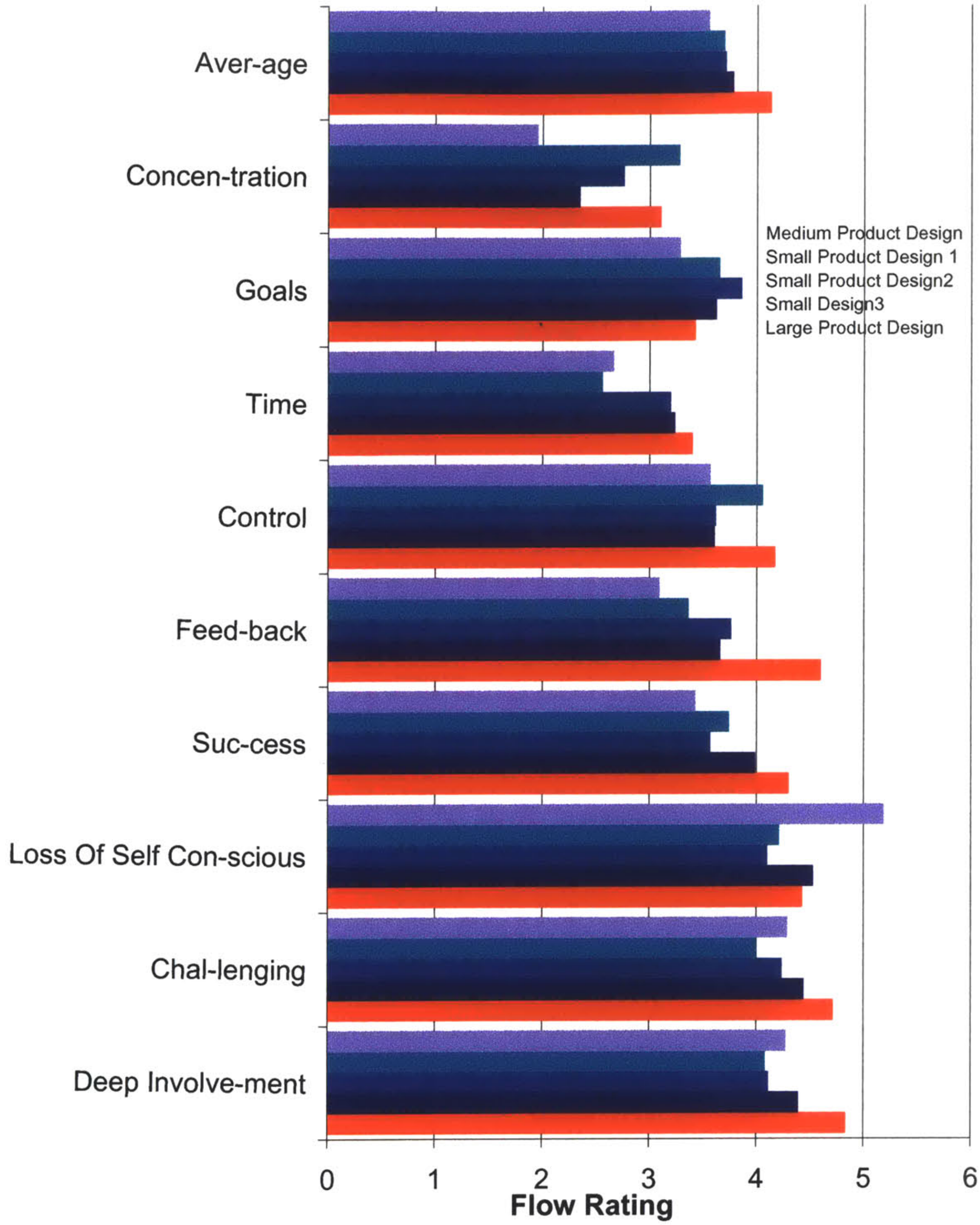

Figure 15. Case Study 1. Comparing Design Companies

Companies that rely on the creative process were expected to have generally high flow ratings. The Large Product Design Company was strong in the three expected categories and added feedback and control to the list of categories where it was especially strong. The Medium Product Design Company and Small Product Design Company 1 were especially low in the duration of time category. The dominance of the Large Product Design Company cannot be explained by a single flow category. It has a higher flow rating than the other four companies in six out of the nine flow categories.

5.2.3 Case Study 2. Traditional Mechanical Engineering Companies

The four companies in this case study, Biotech Startup, Technical Sales, Large Computer, and Large Electronics, were chosen for comparison because the work their engineers do is the most traditional mechanical design compared to other companies in the survey. Hypothesis 2 in Chapter 4 proposed that a low flow rating might be expected for a large company. The chart shown in Figure 16. confirms this. More revealing is the breakdown of the individual components of flow. Workers in the Large Electronics Company reported lower involvement and less challenging tasks. At both the Large Computer Company and the Large Electronics Company there was a significant difference in the experience with regard to rapid feedback and control over ones actions when compared to the Technical Sales and Biotech Startup Companies. These two categories are traditionally difficult to address for large companies.

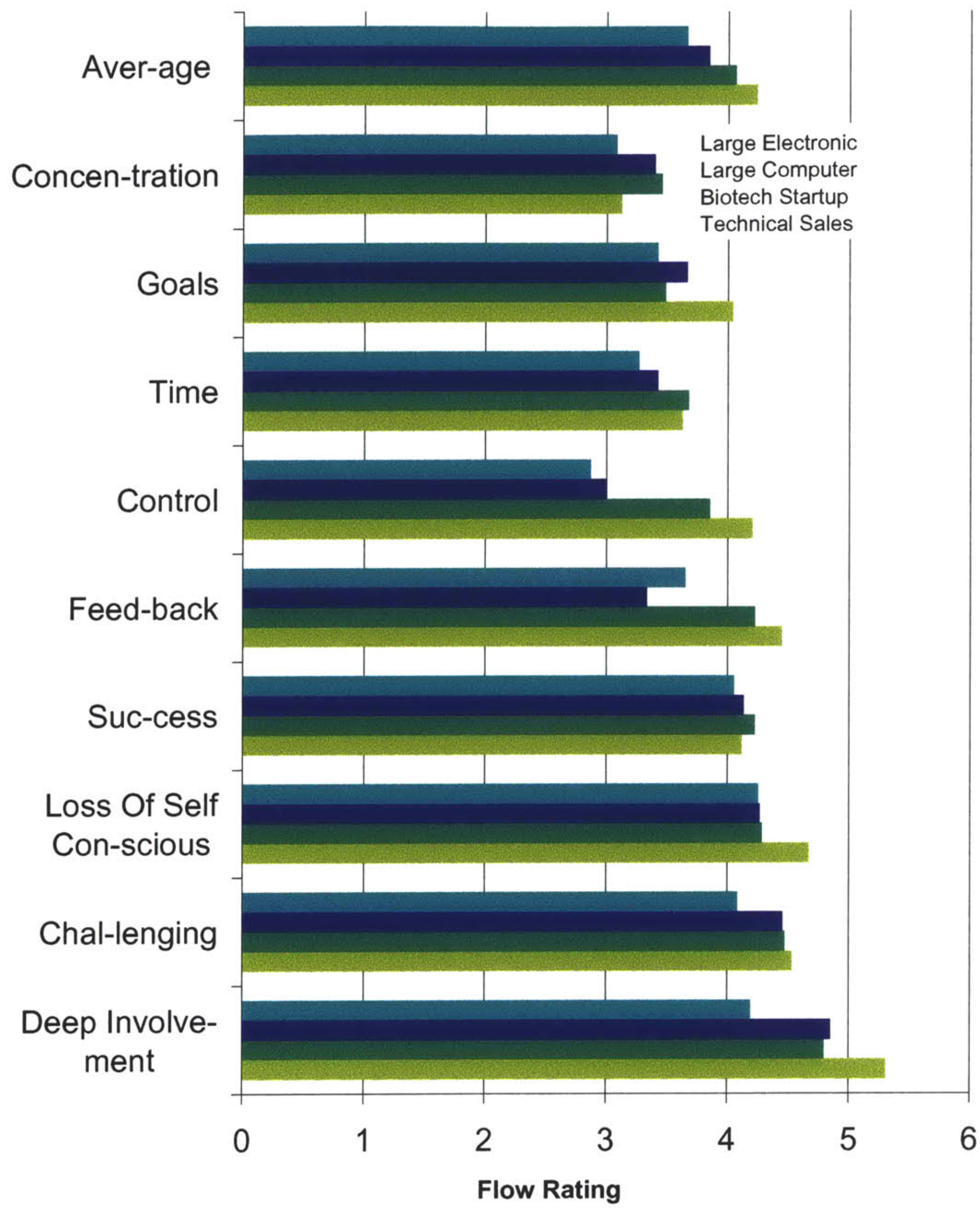

Figure 16. Case Study 2. Summary of Flow Ratings for Companies Involved with a Broad Range Mechanical Engineering Activities

Summary of Flow Rating by Size of Company

Case Study 2. compared companies involved with design of a range of products. This section presents the data for number of employees and flow rating for all the companies in the study. See Figure 17. A single conclusion cannot be reached from this data.

The largest companies tend to have flow ratings from average to below average. The other companies appear to have flow ratings that are not related to size of the company. An engineer's experience does not have to be influenced by the size of the company but rather by the kind of connections he has with members of his group and others involved with the design process. This can be seen by comparing the flow rating of the Specification Modification Group to the overall flow rating of the Large Electronics Company (the company it is part of). Even though these workers come from the same company their flow rating is quite different.

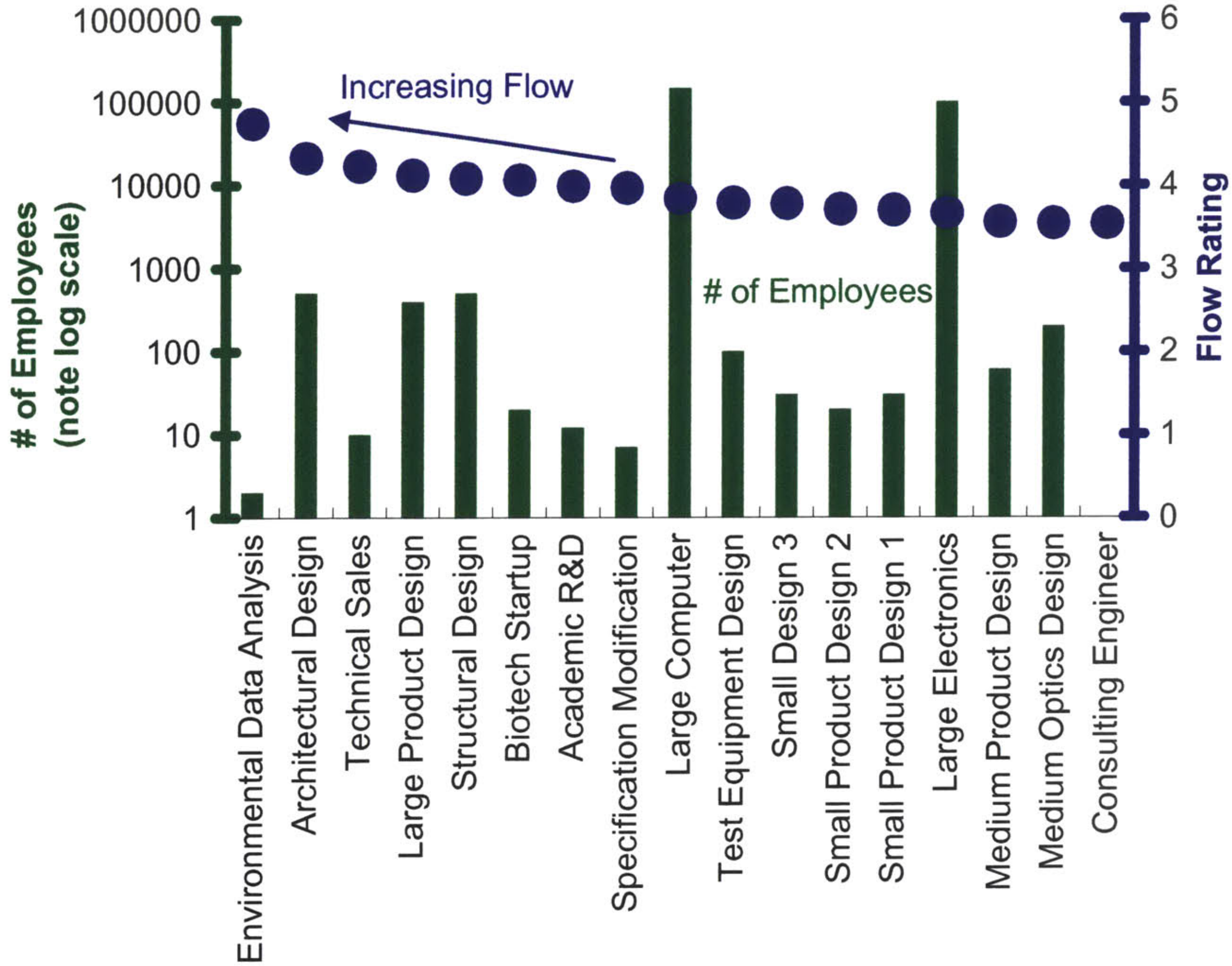

Figure 17. Summary of Flow Rating by Size of Company

Chapter 6 SUMMARY AND CONCLUSION

The experience engineers have during the design process was measured using a survey based on the principles of the Toyota Production System and the psychology of optimal experience. The results are discussed in terms of the flow rating. A higher flow rating indicates a higher potential for flow and a greater potential for an enhanced product design process. The following hypotheses from Chapter 4 listed below will also be reviewed to determine whether any can be confirmed from the survey data:

1) High flow rating is related to whether the organization is a desirable place to work.
2) Low flow rating is associated with a large number of employees in a company.
3) High flow rating is associated with small group size.
4) High flow rating is related to faster product design cycle time.
5) High flow rating is associated with popular products.
6) High flow rating is associated with new companies.
7) High flow rating is related to the creative process.

6.1 Flow and Work Description

The results of the survey clearly link work description with flow rating. More specifically, the more diverse work descriptions are associated with higher flow ratings. This important finding can be useful when designing the scope of tasks for individuals with specialized responsibilities. Adding some related responsibilities to a specialist's task or giving more flexibility in the way a specialist performs his work and implements his work is likely to increase the flow rating. A connection between work description and flow rating was not initially postulated.

6.2 Flow and Size of Company

The largest of the companies surveyed tend to have a lower average flow rating. This conclusion confirms hypothesis number 2. Low scores in the flow categories of feedback and control brought this about. In the midst of this low flow state in a large organization, individual engineers and specific groups of engineers may have a different experience. Flow ratings of some individuals within large companies are among the highest measured. This is likely the result of an individual who instinctively follows the principles of flow despite conditions that encourage other behaviors. Similarly, groups with high flow ratings within large organizations are guided by principles different than the rest of the company. For example, the Specification Modification group (that was part of the Large Electronics Company) was asked to change the specification (high flow rating) while the rest of the engineers and designers are asked to follow the specification (low flow rating). The range of flow ratings within a large company suggest that there is an opportunity for change and improvement once the reasons for differences are identified and understood.

6.3 Flow and Creativity

Hypothesis 7 proposed a link between companies that were involved in the creative process and the flow rating. The author of this study assumed that the design firms would have a high flow rating because the work was assumed to be creative and that flow is often present during the creative process. No link was found. Although the flow measurement confirmed the relative position of two companies as measured by number of design awards they received over a five year period, it did not confirm that there was more flow at design companies. What seemed like an obvious outcome (predicted by a novice researcher) underscores a point that is made in the writings of Amablie and Csikszentmihalyi: measuring and managing creativity itself cannot be done. Earlier in this study the Toyota Production System was described as having a creative procedure for designing their manufacturing processes. But even in this case, creativity does not result in the most creative product in its class. Instead the creativity is in the unique manufacturing process that produces lower cost, higher quality, but only incrementally improved products. Other measures of creativity need to be defined before a link to flow can be established.

The Large Product Design Company had a high flow rating and is also dominant in the design award competition. This study could not determine whether this is caused by an organization that optimizes the potential for flow or a group of designers and engineers with autotelic behavior.

6.4 Where Is Flow?

Individuals can experience the potential for flow in almost any kind of organization. An autotelic engineer will pursue his agenda of seeking challenging work and continuously setting new goals while meeting the requirements set by his company and the product. The results of individual responses to the survey confirm that some of the engineers with the highest flow ratings work in organizations that appear to discourage flow. The highest two flow ratings were for engineers from companies with below average scores: Large Electronics Company and Test Equipment Design. The next three highest flow ratings were for engineers from Large Product Design, Technical Sales, and Biotech Startup. The lowest five flow ratings were from the Large Electronics Company. The literature confirms that autotelic behavior exists in adverse conditions. What is not as clear is whether designing an organization that encourages the categories of flow will change the flow rating of the company. This study did not determine whether a high flow rating for a company resulted from the individual behaviors or the organization.

6.5 Other Hypotheses

The other hypotheses, 1, 4, 5, and 6, were too vague to confirm. This outcome is the result of overly ambitious and too broadly defined hypotheses and survey results that did not fall into neat, distinct categories. Published data was not available for many of these hypotheses. A system for ranking the companies in the study based on desirability as a place to work was not developed beforehand as it should have been. Although this information is available for some companies it was not available for most of the companies in the study.

Hypothesis 3 proposed that flow rating was related to group size. It was hoped that a size of group associated with a high flow rating would emerge from the data. The statement in the survey concerning group size was not phrased narrowly enough and many of the responses seemed to describe large departments rather than sub-groups. The data for this hypothesis was not useable.

6.6 Using The Results of This Study

One of the goals of the study is to contribute to the understanding of how to design a system that enhances the product design process. Some of the results accomplish this goal. The understanding how a work description with diverse responsibilities positively influences the potential for flow can be used to enhance an organization's product design process. The measurement of high flow within a low flow company is useful to large companies since it proves that the potential for flow is not excluded by overall company size. The study identified feedback and control as weak flow categories for large companies. This measurement gives a large organization a starting point for modification of its product design process.

Chapter 7 FUTURE WORK

A more formal statistical treatment of the data is currently underway. Preliminary analysis of the reliability of the results indicates that the way the questions were phrased and organized in the categories of time and goals lead to results that were not internally reliable. The other categories were found to be more reliable. The results will be reanalyzed with the questions that were found to be unreliable removed. Trends and conclusions discussed in the previous sections will be verified.

While this study established that flow could be measured, a clearer definition of what is being measured is essential. This requires a relationship with the companies being measured that is closer than what was established in this study. Survey data must paint an accurate picture of the company or specific entity. To do this, both a Likert scale survey similar to the one used in this study and personal interviews may be required. Proportional representation of different work descriptions is also required to obtain an accurate profile of a company. Another method of gaining more accurate data would be making the survey as brief as possible and to better explain to the people being surveyed that the questions are about their own experiences and perception of the product design process.

Metrics for the definitions of success should be developed with the help of the companies that are being surveyed and the individual engineers. This will fill in the information not publicly available. Each metric should be narrowly focused on a particular aspect of the design process. The relative value of each metric must be established to improve the accuracy of the flow measurement.

Since the ultimate goal is to be able to measure the potential for creativity in an organization, a significant effort should be devoted to establishing exactly what this means from both an academic point of view and from the point of view of the designer, the owner, and the customer for each of the companies surveyed.

Another important activity for future work is to use the results of the survey to identify where to design improved processes for engineers involved in the product design process. After changes to the organization, the survey should be administered again to measure the effect of the changes.

A study like this should include organizations recognized as excellent for the purpose of benchmarking the survey. Perhaps several troubled organizations that desire to improve their potential for creativity should be included to make the differences more visible and the changes easier to measure. In addition, organizations that currently practice the principles of the Toyota Production System should make up the core of the study.

Part of the attraction of using flow measurements is the notion that the principles are transferable to other fields besides manufacturing and product design. Workers in other fields, such as healthcare, could be measured using a survey tailored for their work. In a hospital, surgeons, nurses, respiratory technicians, ultrasound technicians, radiologists, pharmacists, admissions administrators, and even bill collectors could have their potential for flow measured.

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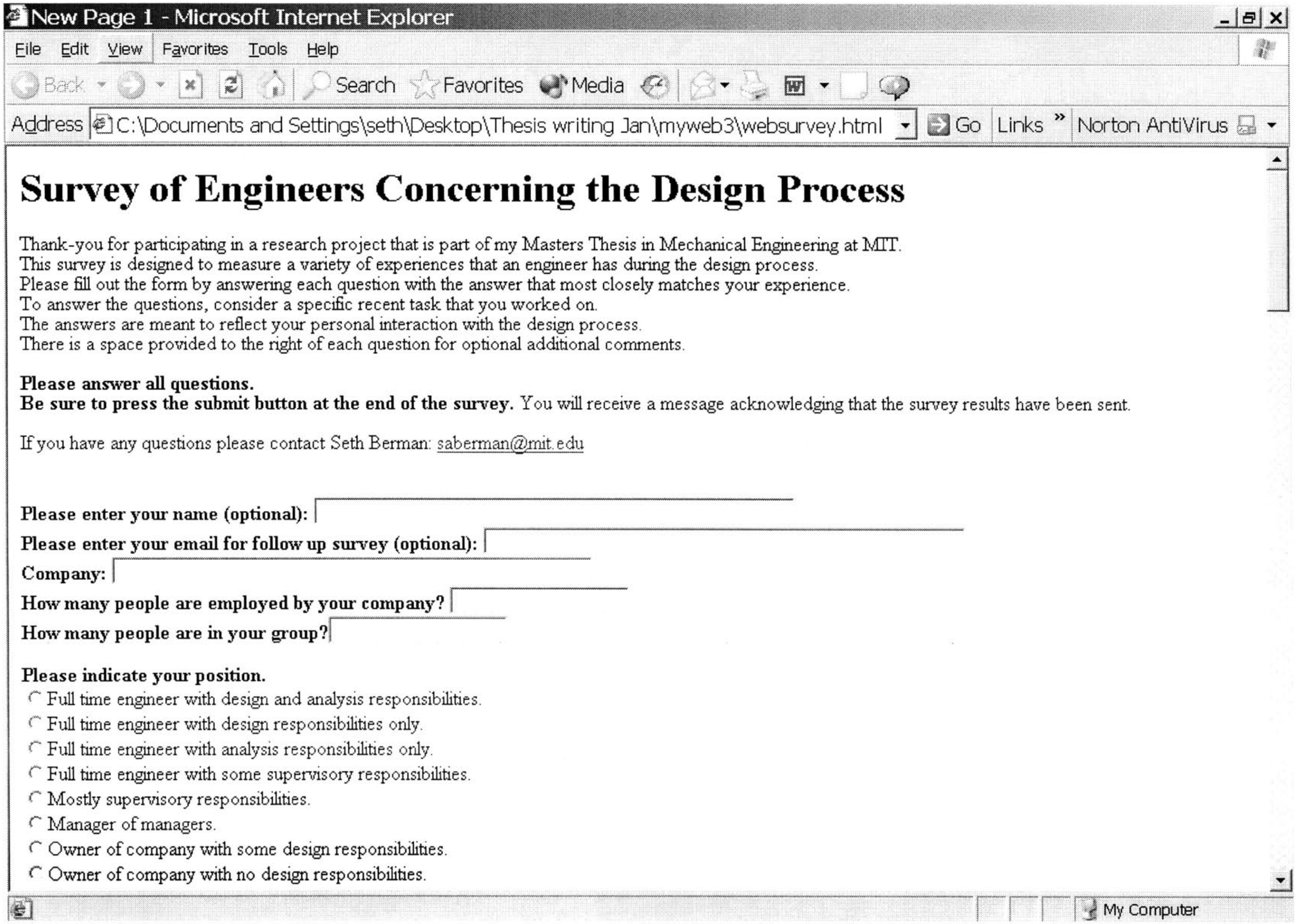

Survey of Engineers Concerning the Design Process

Thank-you for participating in a research project that is part of my Masters Thesis in Mechanical Engineering at MIT.
This survey is designed to measure a variety of experiences that an engineer has during the design process.
Please fill out the form by answering each question with the answer that most closely matches your experience.
To answer the questions, consider a specific recent task that you worked on.
The answers are meant to reflect your personal interaction with the design process.
There is a space provided to the right of each question for optional additional comments.

Please answer all questions.
Be sure to press the submit button at the end of the survey. You will receive a message acknowledging that the survey results have been sent.

If you have any questions please contact Seth Berman: saberman@mit.edu

Please enter your name (optional):
Please enter your email for follow up survey (optional):
Company:
How many people are employed by your company?
How many people are in your group?

Please indicate your position.
- Full time engineer with design and analysis responsibilities.
- Full time engineer with design responsibilities only.
- Full time engineer with analysis responsibilities only.
- Full time engineer with some supervisory responsibilities.
- Mostly supervisory responsibilities.
- Manager of managers.
- Owner of company with some design responsibilities.
- Owner of company with no design responsibilities.

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Mostly supervisory responsibilities.

Manager of managers.

Owner of company with some design responsibilities.

Owner of company with no design responsibilities.

Administrative/secretarial with no design responsibilities.

	Strongly disagree						Strongly agree	Optional Comments
I know when a task is successful.	○	○	○	○	○	○	○	
My immediate customer influences the project's goals.	○	○	○	○	○	○	○	
The number of tasks I work on is just right.	○	○	○	○	○	○	○	
Co-worker feedback influences my work.	○	○	○	○	○	○	○	
There are many opportunities for my design inputs.	○	○	○	○	○	○	○	
My contributions to a design are meaningful.	○	○	○	○	○	○	○	
Tasks are complete when my immediate customer is satisfied.	○	○	○	○	○	○	○	
	Strongly disagree						Strongly agree	Optional Comment
I work on a task from beginning to end.	○	○	○	○	○	○	○	
A task begins when I receive requests for help on a new problem.	○	○	○	○	○	○	○	
I use specifications to define task goals.	○	○	○	○	○	○	○	
There is continuous feedback on my work.	○	○	○	○	○	○	○	
I feel personally involved with a project.	○	○	○	○	○	○	○	
I interact with the sales department.	○	○	○	○	○	○	○	
I am able to concentrate on my tasks.	○	○	○	○	○	○	○	

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I feel personally involved with a project.								
I interact with the sales department.								
I am able to concentrate on my tasks.								
	Strongly disagree						Strongly agree	Optional Comments
I set personal goals for each task.								
Over the last 12 months all of my tasks were successful .								
Changes in customer requirements effect the quality of my final product.								
I frequently present new ideas to my co-workers.								
I use customer feedback during the design process.								
Suggested changes to the product specification are easily incorporated.								
Sometimes my work feels like an exciting adventure.								
	Strongly disagree						Strongly agree	Optional Comments
I work alone.								
Tasks are complete when the budget is exhausted.								
Design reviews are the main form of feedback.								
Distractions prevent me from doing my best work.								
I am satisfied when a task is complete.								
My goals are the same for each task.								
I am often surprised by how much I have accomplished.								
	Strongly						Strongly	

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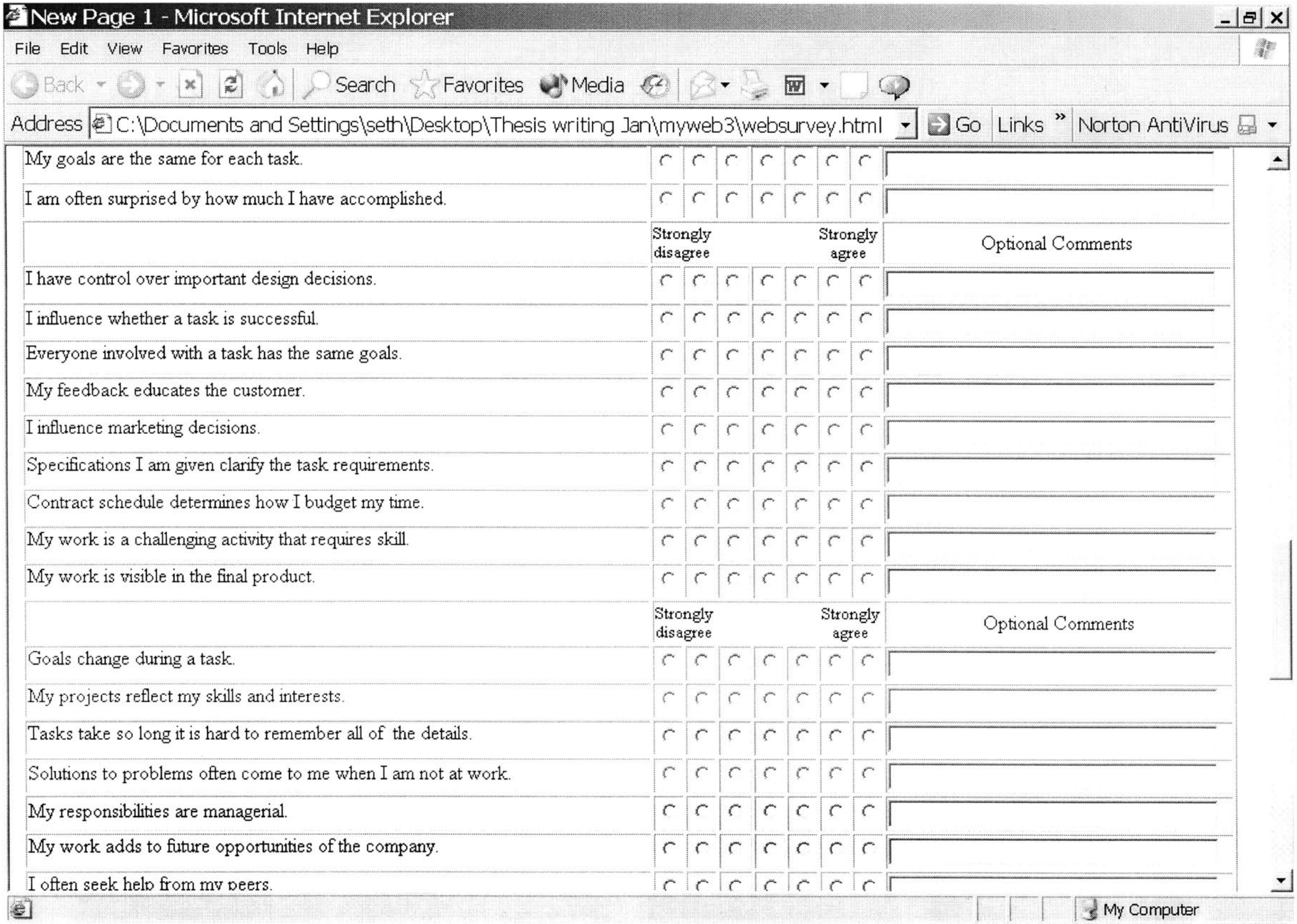

My goals are the same for each task.								
I am often surprised by how much I have accomplished.								
	Strongly disagree						Strongly agree	Optional Comments
I have control over important design decisions.								
I influence whether a task is successful.								
Everyone involved with a task has the same goals.								
My feedback educates the customer.								
I influence marketing decisions.								
Specifications I am given clarify the task requirements.								
Contract schedule determines how I budget my time.								
My work is a challenging activity that requires skill.								
My work is visible in the final product.								
	Strongly disagree						Strongly agree	Optional Comments
Goals change during a task.								
My projects reflect my skills and interests.								
Tasks take so long it is hard to remember all of the details.								
Solutions to problems often come to me when I am not at work.								
My responsibilities are managerial.								
My work adds to future opportunities of the company.								
I often seek help from my peers.								

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I often seek help from my peers.								
My work is part of my personal identity.								
	Strongly disagree						Strongly agree	Optional Comments
I work with engineers on projects other than my own.								
Each new project is a little more challenging than the previous one.								
Mangers define goals for each task.								
Solutions are obvious at the beginning the task.								
I share my special knowledge and expertise with other group members.								
I sometimes lose track of time when I am working.								
I frequently challenge the work of others.								
	Strongly disagree						Strongly agree	Optional Comments
There is enough time to finish a project.								
My workday is devoted technical tasks that directly affect the product.								
I do not hesitate to ask for help.								
Most of my time is spent responding to special requests.								
Needs of design determine how much time I spend on a task.								
Most of my tasks require concentration.								
	Strongly disagree						Strongly agree	Optional Comments
To perform my job I must frequently learn new things.								

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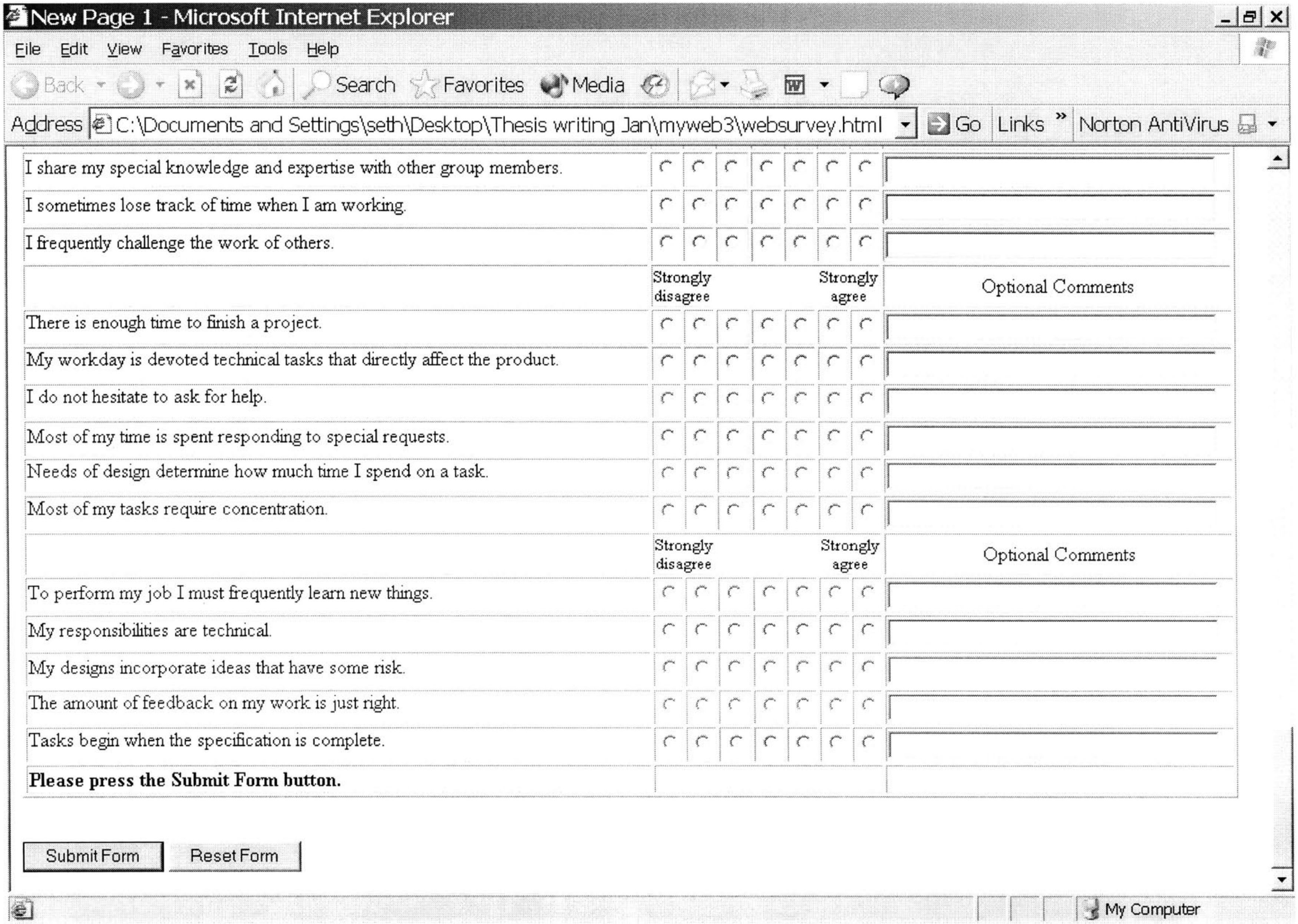

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I share my special knowledge and expertise with other group members.	◯	◯	◯	◯	◯	◯	◯	
I sometimes lose track of time when I am working.	◯	◯	◯	◯	◯	◯	◯	
I frequently challenge the work of others.	◯	◯	◯	◯	◯	◯	◯	
	Strongly disagree						Strongly agree	Optional Comments
There is enough time to finish a project.	◯	◯	◯	◯	◯	◯	◯	
My workday is devoted technical tasks that directly affect the product.	◯	◯	◯	◯	◯	◯	◯	
I do not hesitate to ask for help.	◯	◯	◯	◯	◯	◯	◯	
Most of my time is spent responding to special requests.	◯	◯	◯	◯	◯	◯	◯	
Needs of design determine how much time I spend on a task.	◯	◯	◯	◯	◯	◯	◯	
Most of my tasks require concentration.	◯	◯	◯	◯	◯	◯	◯	
	Strongly disagree						Strongly agree	Optional Comments
To perform my job I must frequently learn new things.	◯	◯	◯	◯	◯	◯	◯	
My responsibilities are technical.	◯	◯	◯	◯	◯	◯	◯	
My designs incorporate ideas that have some risk.	◯	◯	◯	◯	◯	◯	◯	
The amount of feedback on my work is just right.	◯	◯	◯	◯	◯	◯	◯	
Tasks begin when the specification is complete.	◯	◯	◯	◯	◯	◯	◯	
Please press the Submit Form button.								

Submit Form | Reset Form

APPENDIX B SURVEY DATA

Appendix B Survey Data

[Company]	[Number_c	[People_in	[position]	[Suc	[Suc	[Suc	[Suc	[Suc
Academic R&D		12	Engineer_Design_Analysis	5	3	4	4	5
Academic R&D	10000	12	Engineer_Design_Analysis	5	2	4	4	6
Academic R&D	10000	10	Engineer_Design	3	4	6	4	5
Academic R&D			Engineer_Design	4	5	2	2	5
Academic R&D	10000	10	Engineer_And _Manager	6	6	2	2	5
Architecural Design	200	25	Engineer_Design_Analysis	5	6	0	4	6
Architecural Design	180	35	Engineer_Design_Analysis	5	4.5	4	4	5
Architecural Design	160	25	Engineer_Design_Analysis	6	6	6	5	1
Architecural Design	500	25	Engineer_And _Manager	5	6	1	2	6
Biotech Startup	20	not applica	Engineer_Design_Analysis	6	3	3	5	3
Biotech Startup	20	3	Engineer_Design_Analysis	6	1	3	6	6
Biotech Startup	19	4	Engineer_Design_Analysis	5	5	3	2	6
Biotech Startup	20	10	Engineer_Design_Analysis	4	1	4	4	4
Biotech Startup	20	4	Owner_Technical	6	2	4	6	3
Consulting Engineer	1	1	Owner_Technical	5	3	4	5	2
Environmental Analysis	2	2	Owner_Technical	6	0	5	6	5
Environmental Analysis	2	2	Owner_Technical	6	0	6	6	6
Graduate Student	10000	2	Engineer_Design_Analysis	2	5	2	2	6
Graduate Student	10000	2	Engineer_Design_Analysis	4	2	3	1	5
Large Computer	150000	80	Engineer_Design_Analysis	5	6	5	3	4
Large Computer	100000	1000	Engineer_Design_Analysis	5	4	5	3	5
Large Computer	150000	6	Engineer_Design_Analysis	4	3	5	5	6
Large Computer	150000	1	Engineer_Design	5	5	1	1	5
Large Computer	150000	15	Engineer_Design	4	2	4	2	5
Large Computer			Engineer_Design	5	3	4	5	4
Large Computer	184000	4	Engineer_And _Manager	5	5	6	4	5.3
Large Computer	165000	40	Engineer_Analysis	5	6	1	1	5
Large Computer	55000	20	Engineer_Analysis	4	6	3	3	5
Large Electronics	100000	11	Manager	4	5	4	2	3
Large Electronics	80000	120	Manager	5	4	2	3	4
Large Electronics	70000	25	Manager	5	5	3	3	3
Large Electronics	50000	16	Manager	5	3	3	2	4
Large Electronics			Manager	4	3	3	4	5
Large Electronics	65000	8	Manager	5	4	4	5	4
Large Electronics			Manager	5	5	4	5	4
Large Electronics	79000	12	Manager	5	4	3	3	4
Large Electronics	75000	4	Manager	5	2	2	5	4
Large Electronics	50000	35	Manager	5	5	3	4	1
Large Electronics	100000	160	Manager	5	5	5	5	5
Large Electronics	80000	34	Manager	5	5	5	4	4
Large Electronics		15	Manager	5	5	5	2	3
Large Electronics	100000	20	Engineer_Design_Analysis	5	1	4	5	4
Large Electronics		10	Engineer_Design_Analysis	1	2	3	1	3
Large Electronics	100000	125	Engineer_Design_Analysis	5	4	4	5	4
Large Electronics	3000	12	Engineer_Design_Analysis	6	5	5	5	5
Large Electronics	90000	70	Engineer_Design_Analysis	5	6	1	5	6
Large Electronics	100000	14	Engineer_Design_Analysis	4	6	3	3	0
Large Electronics		140	Engineer_Design_Analysis	5	2	5	4	2
Large Electronics	?	13	Engineer_Design_Analysis	4	4	3	4	3
Large Electronics	100000	150	Engineer_Design_Analysis	5	5	4	2	4

Appendix B Survey Data

[Company]	[Number_d	[People_in	[position]	[Suc	[Suc	[Suc	[Suc	[Suc
Large Electronics	30000	1	Engineer_Design_Analysis	6	6	5	5	6
Large Electronics	100000	120	Engineer_Design_Analysis	5	2	5	5	3
Large Electronics	80,000	150	Engineer_Design_Analysis	4	5	4	6	5
Large Electronics	90,000	12	Engineer_Design_Analysis	5	0	6	6	1
Large Electronics	10000	10	Engineer_Design_Analysis	5	5	3	5	4
Large Electronics	80000	100	Engineer_Design_Analysis	5	3	5	4	4
Large Electronics	80000	100	Engineer_Design_Analysis	5	3	5	4	4
Large Electronics	?	150	Engineer_Design_Analysis	6	3	2	5	0
Large Electronics	80000	17	Engineer_Design_Analysis	3	1	4	2	4
Large Electronics	90000	60	Engineer_Design_Analysis	3	5	5	5	1
Large Electronics			Engineer_Design_Analysis	2	4	3	4	3
Large Electronics		12	Engineer_Design_Analysis	4	3	5	5	3
Large Electronics	110000	120	Engineer_Design	5	6	3	4	3
Large Electronics		10	Engineer_Design	5	3	5	4	3
Large Electronics	100000	100	Engineer_Design	4	6	5	4	3
Large Electronics	87200	120	Engineer_Design	5	6	5	3	5
Large Electronics	3000	130	Engineer_Design	5	5	4	5	5
Large Electronics	80	150	Engineer_Design	6	4	4	4	5
Large Electronics	90000	7	Engineer_Design	6	3	3	5	6
Large Electronics	??	50	Engineer_Design	2	5	3	4	0
Large Electronics	a lot	24	Engineer_Design	3	4	3	2	4
Large Electronics	Thousands	120	Engineer_Design	4	6	3	5	4
Large Electronics	100000	150	Engineer_Design	6	5	5	3	6
Large Electronics	25000	100	Engineer_Design	4	4	5	4	4
Large Electronics	100000	140	Engineer_Design	3	3	1	3	5
Large Electronics	75000	9	Engineer_Design	5	5	4	5	6
Large Electronics	75000	110	Engineer_Design	5	4	3	5	5
Large Electronics	500	30	Engineer_Design	6	4	5	6	4
Large Electronics	100000	150	Engineer_Design	6	6	3	5	6
Large Electronics		200	Engineer_Design	4	5	5	4	6
Large Electronics	50000	15	Engineer_Design	3	2	3	3	3
Large Electronics	100000	140	Engineer_Design	5	1	5	6	6
Large Electronics	5000	60	Engineer_Design	4	6	6	4	6
Large Electronics	40,000	160	Engineer_Design	4	5	5	3	4
Large Electronics	75000	140	Engineer_And _Manager	5	5	1	2	4
Large Electronics	100000	14	Engineer_And _Manager	4	4	4	3	4
Large Electronics	2000	15	Engineer_And _Manager	5	1	5	3	2
Large Electronics	thousands	40	Engineer_And _Manager	6	5	5	5	6
Large Electronics	75000	70	Engineer_And _Manager	6	5	3	5	6
Large Electronics	100000	10	Engineer_And _Manager	5	6	1	4	5
Large Electronics	100000	10	Engineer_And _Manager	6	5	5	3	4
Large Electronics	100000	6	Engineer_And _Manager	6	3	5	4	2
Large Electronics	5000	200	Engineer_And _Manager	6	4	4	4	3
Large Electronics	50000	10	Engineer_And _Manager	6	4	4	2	5
Large Electronics	100,000	25	Engineer_And _Manager	6	3	4	6	6
Large Electronics		120	Engineer_And _Manager	4	5	2	2	2
Large Electronics	20000	13	Engineer_And _Manager	4	5	3	3	4
Large Electronics	5000	100	Engineer_And _Manager	4	4	4	4	3
Large Electronics	40000	150	Engineer_And _Manager	5	3	3	4	5
Large Electronics	120000	20	Engineer_And _Manager	3	5	4	4	4

Appendix B Survey Data

[Company]	[Number_c	[People_in	[position]	[Suc	[Suc	[Suc	[Suc	[Suc
Large Electronics	100000	20	Engineer_Analysis	3	4	6	4	4
Large Electronics	100000	40	Engineer_Analysis	5	5	5	5	5
Large Electronics	76000	14	Engineer_Analysis	4	6	5	4	1
Large Electronics	89000	10	Engineer_Analysis	6	6	5	6	0
Large Electronics	10,000	10	Engineer_Analysis	3	3	4	5	###
Large Electronics	Unknown	Unknown	Engineer_Analysis	5	3	5	3	4
Large Electronics	many	135	Engineer_Analysis	5	2	5	3	3
Large Electronics	3000	180	Administrative	3	4	4	2	5
Large Electronics	120000	70	Department_Manger	5	5	2	5	5
Large Electronics	1500		Administrative	5	4	1	0	5
Large Electronics	85000	135	Department_Manger	6	6	6	1	2
Large Product Design	350	35	Manager	5	3	4	5	1
Large Product Design	400	40	Engineer_Design_Analysis	5	3	5	4	5
Large Product Design	400	40	Engineer_Design_Analysis	5	4	5	3	2
Large Product Design	450	21	Engineer_Design_Analysis	6	6	4	5	2
Large Product Design	330	n/a	Engineer_Design_Analysis	4	5	1	2	6
Large Product Design	350	30	Engineer_Design	6	3	4	4	3
Large Product Design	300	45	Engineer_Design	6	6	6	6	6
Large Product Design	400	20	Engineer_And _Manager	5	5	3	3	3
Large Product Design	400	40	Engineer_And _Manager	4	3	3	4	5
Large Product Design	400	37	Engineer_And _Manager	5	5	5	5	4
Large Product Design	400	40	Engineer_And _Manager	5	5	3	3	6
Medium Optics Design	200	20	Engineer_Analysis	4	4	3	2	4
Medium Product Design	60	5	Manager	4	4	2	2	2
Medium Product Design	53	20	Engineer_And _Manager	3	5	0	5	3
Medium Product Design	50	16	Department_Manger	6	2	1	4	5
sdfsdf	sdfsdzxc	zxcz	Engineer_Design_Analysis	6	0	6	6	0
Small Design 3	30	20	Manager	4	6	5	2	5
Small Design 3	22		Manager	5	4	1	3.2	5
Small Design 3	25	2	Manager	5	4	4	1	5
Small Design 3	30	15	Engineer_Design_Analysis	4	6	3	2	2
Small Design 3	20	5	Engineer_Design_Analysis	4	6	3	4	6
Small Design 3	25	10	Engineer_Design_Analysis	5	4	3	3	3
Small Design 3	20-25	5	Engineer_Design_Analysis	5	5	3	3	5
Small Design 3	25	11	Engineer_Design	6	5	2	3	5
Small Design 3	20	12	Engineer_Design	4	6	4	1	5
Small Design 3	30	12	Engineer_And _Manager	5	6	4	2	2
Small Design 3	30	10	Engineer_And _Manager	5	4	2	5	5
Small Product Design 1	25	15	Engineer_Design_Analysis	4	5	2	0	6
Small Product Design 1	22	4	Engineer_Design_Analysis	5	5	1	4	5
Small Product Design 1	30	10	Engineer_And _Manager	5	5	5	3	1
Small Product Design 1	approx 30	approx 5 o	Engineer_And _Manager	4	5	2	2	5
Small Product Design 1	30	13	Department_Manger	4	5	4	###	5
Small Product Design 2	20	5	Engineer_Design	6	3	3	3	1
Small Product Design 2	19	3	Engineer_Design	4	2	5	4	1
Small Product Design 2	23	22	Department_Manger	5	5	1	2	5
Specification Modification	81,000+	12	Engineer_Design	4	4	2	5	5
Specification Modification	100000	25	Engineer_Analysis	5	5	5	5	6
Specification Modification	90,000	7	Department_Manger	5	4	4	5	4
Specification Modification	80000	10	Engineer_Design_Analysis	6	6	6	3	6

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[Company]	[Number_c	[People_in]	[position]	[Suc	[Suc	[Suc	[Suc	[Suc
Specification Modification			Engineer_Analysis	4	5	6	5	5
Structural Design	500	26	Owner_Technical	5	6	2	5	5
Technical Sales	10	10	Owner_Technical	4	2	1	4	5
Technical Sales	8		Engineer_Design_Analysis	6	5	6	0	6
Technical Sales	9	9	Engineer_Design_Analysis	5	3	5	2	5
Technical Sales	10	10	Engineer_Design	4	6	6	2	2
Technical Sales	8	na	Engineer_And _Manager	6	6	6	0	3
Technical Sales	10	4	Engineer_And _Manager	4	3	5	1	4
Technical Sales	10	7	Engineer_And _Manager	5	5	2	5	0
Test Equipment Design	92	11	Manager	6	5	3	3	5
Test Equipment Design	100	12	Engineer_Design_Analysis	3	5	4	1	5
Test Equipment Design	100	12	Engineer_Design_Analysis	5	6	3	0	4
Test Equipment Design	150	7	Engineer_Design_Analysis	6	2	6	6	6
Test Equipment Design	93	12	Engineer_Analysis	6	5	3	1	6

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Academic R&D	5	5	3	5	4	1	1	5	2	5	5	1	2	5
Academic R&D	2	6	4	5	4	2	1	2	0	4	6	1	3	4
Academic R&D	6	6	6	5	1	2	0	4	2	5	6	0	0	5
Academic R&D	4	5	5	4	3	1	3	4	3	3	5	2	4	5
Academic R&D	0	6	1	2	0	2	4	2	1	5	4	2	1	2
Architecural Design	6	5	3	6	2	3	2	5	6	6	6	5	3	5
Architecural Design	4	5	4	6	2	1	2	5	2	4	4	3	2	5
Architecural Design	6	5	3	6	0	4	3	1	2	6	6	3	5	6
Architecural Design	1	5	1	3	4	2	3	4	3	3	6	5	3	5
Biotech Startup	3	5	4	6	4	3	3	5	4	5	4	3	5	6
Biotech Startup	5	5	6	5	6	3	1	6	4	3	6	0	0	5
Biotech Startup	4	5	1	5	0	0	2	2	1	2	5	2	4	4
Biotech Startup	5	3	3	5	5	1	5	4	5	5	6	2	1	5
Biotech Startup	6	6	5	5	2	2	1	4	3	5	6	0	0	1
Consulting Engineer	4	4	3	3	3	2	3	4	4	5	5	2	3	4
Environmental Analysis	6	6	6	6	6	0	0	6	6	6	6	0	3	3
Environmental Analysis	2	6	5	5	6	0	1	6	2	6	6	2	6	6
Graduate Student	1	5	5	4	5	2	4	5	5	4	4	4	5	4
Graduate Student	0	6	2	0	2	6	1	5	1	4	4	5	5	4
Large Computer	4	5	4	5	4	5	3	5	2	5	4	3	4	5
Large Computer	4	5	4	4	4	3	2	4	3	3	5	2	2	4
Large Computer	2	5	5	3	2	3	2	4	4	5	3	3	4	6
Large Computer	1	3	3	3	2	5	1	5	5	5	1	1	5	2
Large Computer	2	4	3	4	4	3	3	4	3	2	1	2	3	4
Large Computer	3	4	4	5	1	1	3	5	3	5	4	2	2	1
Large Computer	6	6	4	6	3	0	2	3	2	4	6	4	4	5
Large Computer	5	5	2	2	4	1	4	5	4	6	6	6	5	5
Large Computer	4	5	2	5	5	1	4	5	5	5	3	4	5	6
Large Electronics	4	4	2	2	3	2	3	4	2	3	4	2	3	4
Large Electronics	2	4	3	2	2	4	3	4	3	6	4	2	4	5
Large Electronics	1	5	2	4	3	3	1	4	3	4	4	1	2	5
Large Electronics	1	5	4	2	5	1	2	5	5	4	5	2	2	4
Large Electronics	5	4	3	4	1	2	2	4	5	4	5	2	2	3
Large Electronics	5	4	3	4	2	3	2	4	3	4	4	2	3	1
Large Electronics	3	5	2	4	3	1	2	4	5	5	4	2	3	2
Large Electronics	4	4	3	5	4	1	2	3	3	4	5	3	3	4
Large Electronics	3	4	2	5	2	1	3	2	5	5	4	1	2	4
Large Electronics	3	5	3	5	1	2	3	4	1	4	3	3	2	1
Large Electronics	5	4	3	5	4	3	0	4	2	6	6	0	2	3
Large Electronics	4	4	1	4	5	5	3	5	4	6	6	1	2	3
Large Electronics	2	2	1	1	1	1	3	3	2	2	4	2	5	1
Large Electronics	4	5	5	5	3	1	2	5	2	5	5	0	2	2
Large Electronics	1	1	2	1	2	5	4	1	2	2	3	3	4	4
Large Electronics	3	5	3	5	2	3	2	2	3	4	5	1	2	4
Large Electronics	6	6	5	4	2	1	2	5	3	5	5	2	2	5
Large Electronics	2	6	3	6	1	0	0	4	1	6	6	3	6	5
Large Electronics	3	4	4	1	5	2	4	4	4	3	4	4	5	6
Large Electronics	5	5	5	3	3	2	1	4	4	4	5	2	2	3
Large Electronics	2	3	3	4	4	3	3	4	3	3	4	3	4	3
Large Electronics	2	4	4	4	1	2	5	2	2	3	4	2	4	1

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Large Electronics	6	4		4	5	2	1	1	4	5		4	6	1	2	6
Large Electronics	4	5		3	5	1	0	1	5	4		4	5	1	2	4
Large Electronics	4	3		4	4	2	1	2	4	4		4	5	2	4	2
Large Electronics	5	2		0	0	5	4	2	6	5		5	4	1	1	4
Large Electronics	5	4		3	1	3	3	2	5	4		5	5	1	3	5
Large Electronics	5	6		5	2	5	3	1	5	2		5	6	2	2	4
Large Electronics	5	6		5	2	5	3	1	5	2		5	6	2	2	4
Large Electronics	3	6		2	4	6	0	0	6	3		6	6	0	0	3
Large Electronics	3	5		2	2	4	1	1	5	0		5	6	1	1	5
Large Electronics	5	3		4	5	0	4	3	3	1		5	6	1	3	1
Large Electronics	4	4		3	2	2	2	2	4	2		4	4	1	2	2
Large Electronics	5	3		2	4	2	2	1	4	5		4	3	1	1	2
Large Electronics	2	4		5	5	4	2	5	5	4		3	2	5	6	1
Large Electronics	4	3		5	4	3	3	1	3.2	3		5	5	2	2	1
Large Electronics	3	4		2	1	1	1	1.7	4	1		4	4	1	2	4
Large Electronics	0	5		5	5	3	3	4	4	2		4	5	1	6	6
Large Electronics	4	3		5	5	2	1	4	3	2		5	5	2	3	2
Large Electronics	5	5		5	2	4	3	1	5	4		5	5	1	2	3
Large Electronics	0	5		5	3	5	5	1	3	5		5	0	3	5	1
Large Electronics	3	0		0	0	5	3	3	5	6		4	3	3	3	4
Large Electronics	1	3		2	1	5	2	2	4	2		3	3	3	3	5
Large Electronics	5	5		5	6	3	6	2	5	3		6	6	2	3	0
Large Electronics	6	6		1	3	1	1	5	5	3		3	6	1	5	4
Large Electronics	6	4		4	5	3	0	1	4	4		5	6	1	1	4
Large Electronics	4	0		1	1	1	1	3	2	1		4	4	3	2	2
Large Electronics	3	4		4	4	3	0	5	4	2		4	6	2	3	3
Large Electronics	4.3	4		3	5	2	3	1	3	3		3	2.7	1	5	3
Large Electronics	4	6		6	4	4	3	2	5	4		6	4	2	3	0
Large Electronics	0	6		6	6	0	1	0	6	6		6	6	1	3	0
Large Electronics	4	6		1	5	4	1	3	5	3		4	4	3	3.5	3
Large Electronics	5	5		6	4	2	5	3	6	3		5	6	2	0	5
Large Electronics	6	5		5	6	4	3	1	6	6		5	6	0	1	6
Large Electronics	5	5		3	3	2	0	4	5	4		5	4	1	3	6
Large Electronics	3	4		5	5	4	2	2	5	4		5	5	1	3	1
Large Electronics	3	5		4	3	3	0	1	3	5		4	4	2	4	6
Large Electronics	4	4		4	2	3	2	3	2	3		4	4	2	4	4
Large Electronics	5	4		4	6	3	1	3	5	2		4	5	2	4	5
Large Electronics	3	4		3	3	4	5	2	5	3		5	6	2	5	4
Large Electronics	3	5		5	6	5	3	0	6	5		4	6	2	5	3
Large Electronics	3	4		4	2	2	2	3	4	4		4	5	3	5	3
Large Electronics	1	5		3	5	2	1	2	5	3		4	5	0	1	3
Large Electronics	4	3		3	1	3	2	3	4	3		4	6	2	4	4
Large Electronics	3	4		6	4	4	2	1	5	3		6	6	2	2	5
Large Electronics	4	5		3	5	3	2	1	5	5		6	6	1	3	4
Large Electronics	4	5		1	4	6	6	1	5	6		3	0	1	1	3
Large Electronics	2	4		3	2	1	2	2	3	1		4	1	3	3	3
Large Electronics	5	4		1	2	1	2	1	2	2		4	5	2	3	4
Large Electronics	5	6		3	5	2	0	4	4	2		3	5	3	2	3
Large Electronics	2	5		4	5	2	1	2	3	5		2	5	3	4	6
Large Electronics	4	4		4	3	2	2	3	4	4		5	5	2	2	4

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Large Electronics	5	4	2	4	1	2	2	3	1	4	4	5	3	5
Large Electronics	5	5	4	5	5	1	1	5	3	6	5	2	4	5
Large Electronics	3	3	1	1	3	0	5	5	2.5	5	4	1	6	5
Large Electronics	1	4	5	3	6	5	3	5	2	1	4	5	2	6
Large Electronics	5	4	4	2	4	2	3	3	5	4	3	3	4	5
Large Electronics	3	3	2	1	3	2	4	3	3	3	5	2	3	2
Large Electronics	2	4	5	5	5	2	3	5	3	4	5	1	2	4
Large Electronics	2	3	2	4	3	3	4	3	1	2	5	1	4	4
Large Electronics	4	5	3	3	0	2	2	2	3	4	5	2	3	4
Large Electronics	5	1	0	5	5	3	5	5	2	4	4	6	0	1
Large Electronics	2	5	0	0	1	0	2	1	2	4	4	3	5	6
Large Product Design	5	4	4	4	1	1	1	5	2	3	5	3	2	3
Large Product Design	4	5	4	4	5	2	1	5	4	5	5	1	2	5
Large Product Design	5	6	5	6	3	2	3	5	2	6	5	1	2	5
Large Product Design	0	6	2	5	3	0	0	5	4	2	6	0	3	6
Large Product Design	1	6	5	1	2	2	1	2	3	1	5	0	4	4
Large Product Design	6	4	6	3	1	1	1	4	3	5	6	2	3	4
Large Product Design	6	6	6	6	6	6	0	6	2	6	6	0	1	0
Large Product Design	3	5	4	4	2	2	2	2	3	5	6	1	5	5
Large Product Design	4	4	4	5	4	1	2	4	3	4	6	2	3	5
Large Product Design	5	6	2	6	0	3	2	2	4	3	5	2	2.8	2
Large Product Design	1	5	3	5	2	1	5	3	4	1	5	3	3	5
Medium Optics Design	5	4	4	2	2	4	2	5	2	4	5	2	3	4
Medium Product Design	2	5	1	4	1	2	4	3	0	2	1	5	2	5
Medium Product Design	0	6	1	3	0	0	2	1	5	3	5	0	0	6
Medium Product Design	5	6	2	1	3	0	0	2	6	6	6	0	0	6
sdfsdf	6	6	6	6	0	0	0	6	0	6	6	0	0	0
Small Design 3	4	4	2	4	1	1	2	2	4	4	5	2	4	3
Small Design 3	2	2	1	3	2	2	2	3	5	1	6	2	4	4
Small Design 3	3	4	0	2	1	1	3	1	1	3	4	3	3	3
Small Design 3	3	4	2	3	0	0	2	3	3	4	6	2	2	2
Small Design 3	5	6	1	5	0	0	6	3	6	4	4	3	5	6
Small Design 3	5	4	3	3	4	2	2	4	4	4	5	3	4	3
Small Design 3	5	4	2	4	3	2	2	3	3	2	5	2	4	4
Small Design 3	2	5	2	3	4	4	3	2	4	3	6	2	1	4
Small Design 3	3	5	1	3	1	1	1	4	2	3	4	4	4	1
Small Design 3	3	5	0	2	4	0	2	2	1	2	6	3	5	3
Small Design 3	5	5	1	5	3	1	1	3	3	4	5	1	4	4
Small Product Design 1	1	5	3	2	4	4	1	4	3	2	5	5	5	5
Small Product Design 1	1	5	3	5	2	1	1	6	5	6	4	1	4	5
Small Product Design 1	4	5	4	2	5	1	1	5	5	5	3	1	2	5
Small Product Design 1	4	4	3	4	3	2	3	3	4	3	5	3	4	5
Small Product Design 1	3	3	3	4	4	3.7	3	4	4	3.8	5	2	5	5
Small Product Design 2	3	4	3	4	4	1	5	5	6	5	3	5	3	6
Small Product Design 2	4	6	2	5	2	2	1	4	3	5	3	1	2	4
Small Product Design 2	4	4	2	1	1	1	2	1	3	4	5	3	3	5
Specification Modification	2	4	3	5	3	4	4	4	4	3	4	3	4	4
Specification Modification	5	5	5	5	3	1	3	5	5	5	5	3	3	5
Specification Modification	5	4	4	5	3	5	3	4	4	4	5	3	3	4
Specification Modification	1	6	2	6	3	4.2	2	6	6	6	6	0	4	5

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Specification Modification	5	5		3	5	1	1	1	3	3		5	6	0	3	0
Structural Design	4	5		3	4	4	1	2	4	3		4	5	4	1	5
Technical Sales	3	5		3	3	1	2	3	4	4		4	5	1	2	4
Technical Sales	6	6		3	5	6	6	0	6	6		4	6	6	6	6
Technical Sales	5	5		5	6	3	2	0	5	3		3	6	1	4	5
Technical Sales	4	6		2	4	2	0	2	4	2		2	6	2	4	2
Technical Sales	0	6		2	6	6	0	0	6	6		0	6	3	6	6
Technical Sales	6	6		2	5	1	0	1	3	3		4	6	1	5	0
Technical Sales	5	5		5	4	3	0	1	4	3		6	6	5	4	3
Test Equipment Design	3	5		1	6	1	2	2	3	2		5	2	0	2	3
Test Equipment Design	4	4		2	3	4	1	5	4	3		3	3	4	4	3
Test Equipment Design	4	6		3	1	2	2	0	6	1		5	4	1	2	5
Test Equipment Design	4	6		6	6	6	6	0	6	6		6	6	0	3	6
Test Equipment Design	1	5		1	3	3	3	5	2	2		5	4	1	5	5

Appendix B Survey Data

[Company]	[Go	[Goal_C		[Fee	[Fee	[Fee	[Fee	[Fee	[Fee	[Feedba		[Cor	[Cor	[Cor	[Cor	[Cor
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Academic R&D	4	6		6	2	6	1	0	4	2		6	2	5	3	4
Academic R&D	6	6		3	3	6	6	6	6	4		4	3	5	6	6
Academic R&D	1	6		3	3	6	3	5	6	4		5	0	5	1	3
Academic R&D	2	6		1	5	4	6	4	6	4		6	5	6	4	2
Architecural Design	3	5		6	5	5	4	2	6	5		6	4	5	5	3
Architecural Design	3	5		5	2	4	2	5	6	4		6	4	6	2	5
Architecural Design	0	6		3	1	4	6	3	6	5		5	5	5	6	2
Architecural Design	1	4		6	3	5	1	3	6	5		5	2	5	3	4
Biotech Startup	0	4		2	6	6	2	5	5	2		4	3	2	3	4
Biotech Startup	2	5		2	6	6	6	6	6	5		5	3	6	6	3
Biotech Startup	2	5		2	4	4	4	3	5	4		5	1	4	3	2
Biotech Startup	5	5		2	4	5	5	4	5	4		2	1	4	1	1
Biotech Startup	5	4		3	1	5	5	5	4	5		6	6	6	5	4
Consulting Engineer	2	3		0	2	3	3	3	4	4		4	2	3	1	5
Environmental Analysis	6	4		2	1	6	6	6	6	6		4	5	6	6	3
Environmental Analysis	4	2		2	1	6	4	6	6	6		6	6	6	6	1
Graduate Student	3	3		3	4	4	2	2	4	2		5	0	5	0	4
Graduate Student	5	2		2	0	3	5	2	2	6		3	0	6	0	4
Large Computer	3	5		2	4	5	4	5	2	0		3	0	5	0	2
Large Computer	5	4		4	5	6	5	5	1	2		5	2	6	1	4
Large Computer	1	3		3	5	4	5	3	2	1		5	1	2	0	3
Large Computer	1	5		0	3	1	1	4	3	5		3	5	3	0	3
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Large Computer	6	6		6	1	5	3	4	5	6		3	6	5	0	1
Large Computer	0	4		4	2	4	1	2	4	4		1	4	4	0	4
Large Computer	0	3		1	5	5	2	2	4	4		5	1	5	1	2
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Large Electronics	1	4		4	3	5	3	3	4	4		4	2	4	1	3
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Large Electronics	1	5		5	1	5	3	2	5	4		5	3	5	1	0
Large Electronics	3	5		5	2	4	2	3	4	5		4	3	6	4	1
Large Electronics	4	4		4	5	4	4	3	4	3		4	1	5	1	2
Large Electronics	2	2		2	5	5	4	3	5	3		4	1	3	1	3
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Large Electronics	3	1		5	4	2	2	3	2	2		1	5	3	5	4
Large Electronics	3	4		5	3	5	4	4	4	4		4	1	4	1	2
Large Electronics	5	5		5	1	5	6	6	6	6		6	5	6	0	3
Large Electronics	0	6		6	4	5	5	4	4	3		6	0	6	0	2
Large Electronics	0	6		4	6	6	2	2	3	0		4	0	5	0	6
Large Electronics	3	5		2	4	5	5	5	3	5		2	0	3	0	2
Large Electronics	2	3		3	2	3	3	4	4	3		4	1	3	1	4
Large Electronics	2	4		2	4	4	3	4	4	4		3	1	5	1	3

Appendix B Survey Data

[Company]	[Go	[Goal_C	[Fee	[Fee	[Fee	[Fee	[Fee	[Fee	[Feedba	[Cor	[Cor	[Cor	[Cor	[Cor
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Large Electronics	3	3	3	2	4	4	3	5	3	3	2	4	4	3
Large Electronics	1	3	0	6	1	3	5	6	5	5	4	6	1	2
Large Electronics	1	3	4	2	5	3	5	4	4	3	3	3	1	4
Large Electronics	3	4	2	4	5	4	5	3	5	5	1	6	0	4
Large Electronics	3	4	2	4	5	4	5	3	5	5	1	6	0	4
Large Electronics	4	6	2	3	6	4	3	6	3	4	0	6	0	6
Large Electronics	4	6	4	1	1	2	1	4	6	2	1	3	0	4
Large Electronics	4	4	3	0	6	4	4	5	4	3	4	5	0	1
Large Electronics	1	5	1	4	5	1	0	4	4	1	1	4	0	2
Large Electronics	2	3	4	3	5	4	4	4	3	1	0	1	0	6
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Large Electronics	4	6	5	1	6	4	5	5	5	5	3	6	6	1
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Large Electronics	0	4	6	6	6	3	0	5	6	6	0	6	0	
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Large Electronics	5	4	4	1	4	5	5	5	5	4	3	5	3	5
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Large Electronics	1	5	6	3	5	5	3	5	3	4	2	5	0	2
Large Electronics	1	5	4	6	5	3	2	5	4	2	1	1	0	3
Large Electronics	1	3	6	3	6	4	3	5	4	4	5	0	6	4
Large Electronics	2	3	5	3	5	4	2	6	4	4	1	5	0	4
Large Electronics	1	2	6	6	1	5	6	1	0	5	0	4	0	5
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Large Electronics	3	5	5	1	5	4	4	4	4	4	4	5	3	2
Large Electronics	3	5	3	2	5	2	2	5	2	6	1	5	2	3
Large Electronics	2	5	6	3	4	3	2	3	4	4	1	5	1	4
Large Electronics	1	5	5	3	4	3	4	4	3	4	0	4	0	3

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Large Electronics	0	6	6	3	5	3	2	4	2	2	0	5	0	2
Large Electronics	0	6	0	5	3	2	3	4	2	1	1	1	0	5
Large Electronics	1	3	2	3	4	4	5	4	4	3	1	3	0	3
Large Electronics	2	5	4	4	4	4	3	3	3	2	2	3	2	2
Large Electronics	2	4	3	4	5	3	3	3	4	2	0	3	0	2
Large Electronics	1	4	4	5	4	3	2	3.7	4	###	0	###	0	2
Large Electronics	3	5	4	2	5	2	2	4	4	5	4	4	3	2
Large Electronics	5	2	3	5	5	2	4	1	2	0	0	1	0	4
Large Electronics	2	6	6	5	6	0	0	5	1	4	4	6	1	0
Large Product Design	4	4	6	3	5	4	5	5	5	4	4	5	5	2
Large Product Design	4	4	5	3	5	5	4	3	5	5	4	5	2	5
Large Product Design	4	5	4	2	6	6	5	6	6	4	2	6	5	3
Large Product Design	0	5	2	6	6	6	4	6	6	5	6	6	3	4
Large Product Design	1	5	6	5	6	2	2	6	6	6	6	6	5	4
Large Product Design	4	4	4	3	5	4	5	5	5	4	3	5	3	3
Large Product Design	3	0	6	0	6	6	4	6	5	5	2	6	3	4
Large Product Design	1	4	4	4	5	3	4	6	6	5	4	6	2	5
Large Product Design	2	5	5	4	6	4	3	5	4	4	1	6	1	5
Large Product Design	2	3	5	3	4	3	3	4	3	6	2	6	1	4
Large Product Design	3	6	6	4	6	5	4	5	5	5	4	5	5	4
Medium Optics Design	2	3	4	0	4	4	4	4	4	3	4	5	3	3
Medium Product Design	4	5	2	3	4	4	2	2	2	5	1	4	2	2
Medium Product Design	0	6	5	6	6	3	1	2	1	4	4	5	6	3
Medium Product Design	5	2	6	1	1	2	4	6	2	5	5	2	6	4
sdfsdf	6	6	0	0	6	6	6	6	6	6	6	6	6	0
Small Design 3	2	4	5	1	4	4	3	5	2	6	3	6	5	3
Small Design 3	5	4	4	2	6	3	1	5	5	2	2	5	5	2
Small Design 3	3	5	1	3	4	2	2	5	3	3	3	3	5	2
Small Design 3	4	4	4	3	4	2	3	4	4	4	3	4	3	2
Small Design 3	3	6	4	3	4	5	1	6	5	6	6	5	6	3
Small Design 3	2	4	2	3	6	3	3	4	4	4	3	5	3	3
Small Design 3	3	4	4	4	4	2	2	5	4	4	0	4	0	2
Small Design 3	4	4	4	3	6	4	2	5	4	3	2	5	3	2
Small Design 3	3	2	3	1	3	4	1	4	5	3	1	5	1	4
Small Design 3	4	6	5	4	5	4	4	5	4	5	2	5	4	2
Small Design 3	5	4	5	4	5	4	2	5	5	5	5	5	5	2
Small Product Design 1	1	4	6	2	5	2	4	1	5	5	2	4	3	4
Small Product Design 1	1	5	1	3	5	3	3	5	5	5	3	5	4	3
Small Product Design 1	2	5	2	2	4	4	5	4	3	4	3	5	4	5
Small Product Design 1	1	4	5	4	3	2	2	5	3	5	3	6	3	4
Small Product Design 1	2	4	2	3	4	3	2	2.8	3	4	3	5	6	3
Small Product Design 2	4	5	5	3	5	1	4	5	3	4	5	5	3	5
Small Product Design 2	2	5	4	1	5	3	1	4	4	4	2	5	3	2
Small Product Design 2	3	5	5	4	5	4	4	5	4	2	5	2	6	1
Specification Modification	1	4	4	5	4	1	3	5	3	2	1	3	1	1
Specification Modification	3	4	3	5	4	4	4	5	3	4	1	5	0	2
Specification Modification	3	4	4	3	4	3	2	4	5	5	4	3	4	3
Specification Modification	4	1	6	6	6	5	3	6	6	6	1	6	0	5

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Specification Modification	6	5		5	1	3	1	0	6	6		4	5	5	5	1
Structural Design	5	5		4	3	5	4	2	5	4		5	4	5	0	2
Technical Sales	4	5		3	2	5	4	3	5	5		5	5	5	6	1
Technical Sales	4	6		6	4	5	2	1	6	6		4	2	5	6	3
Technical Sales	5	5		2	5	6	3	4	6	5		5	5	5	6	2
Technical Sales	4	5		5	5	6	6	6	6	6		6	2	6	6	1
Technical Sales	0	6		6	6	5	6	0	6	6		3	3	6	6	2
Technical Sales	2	4		4	4	2	2	2	6	4		4	4	2	6	2
Technical Sales	3	5		3	4	4	5	4	5	6		3	5	5	6	2
Test Equipment Design	3	3		5	4	4	4	4	4	2		4	4	4	4	2
Test Equipment Design	2	5		3	4	5	2	2	1	1		1	0	4	0	4
Test Equipment Design	1	4		2	2	5	4	3	2	3		6	4	5	4	3
Test Equipment Design	0	5		6	2	6	4	3	6	0		6	6	6	6	4
Test Equipment Design	1	6		2	6	5	1	1	0	1		3	1	4	3	4

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Academic R&D	2	5	4	6	5	5	6	4	1	2	2	1	4	2
Academic R&D	4	6	6	4	6	5	6	4	6	3	6	6	5	4
Academic R&D	4	5	5	6	5	3	6	3	5	5	5	5	4	4
Academic R&D	5	6	6	6	6	6	6	5	4	2	5	6	6	5
Architecural Design	5	6	5	5	6	5	3	6	6	5	5	6	5	5
Architecural Design	5	6	6	6	6	5	5	6	5	5	4	6	5	4
Architecural Design	5	5	6	5	6	6	6	6	5	3	4	5	5	5
Architecural Design	5	5	1	5	4	4	4	4	5	4	6	3	5	2
Biotech Startup	3	5	4	5	5	5	3	3	3	4	4	5	4	3
Biotech Startup	4	6	5	6	6	4	2	5	6	6	5	3	5	2
Biotech Startup	2	5	5	4	5	5	5	5	4	5	4	5	5	4
Biotech Startup	5	4	5	4	5	5	5	5	3	3	3	4	3	3
Biotech Startup	5	6	5	6	5	6	6	5	6	5	4	6	5	5
Consulting Engineer	2	5	4	5	4	3	4	6	4	3	4	4	4	4
Environmental Analysis	4	6	6	6	6	4	6	6	6	6	6	5	6	3
Environmental Analysis	4	5	6	6	6	6	4	6	4	6	6	6	6	6
Graduate Student	2	4	5	1	6	4	5	3	1	0	2	5	4	5
Graduate Student	3	6	4	3	6	6	5	5	5	0	5	5	3	1
Large Computer	4	5	5	5	5	5	5	6	5	5	4	5	5	4
Large Computer	3	6	5	5	5	4	3	4	6	5	6	3	5	1
Large Computer	3	2	4	5	6	5	5	5	5	4	3	5	4	3
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Large Electronics	3	4	4	4	4	4	5	4	5	4	5	3	5	4
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Large Electronics	2	4	6	4	5	3	4	5	6	5	6	4	4	4
Large Electronics	3	4	3	3	4	3	3	4	4	4	4	4	3	3
Large Electronics	2	5	4	4	5	3	4	1	4	4	4	4	4	3

Appendix B Survey Data

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Large Electronics	5	3		4	6	4	6	3	5		0	5	5	5	6	3
Large Electronics	1	5		5	4	5	5	4	5		5	5	5	4	5	3
Large Electronics	4	5		5	6	5	4	5	6		6	4	6	3	5	1
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Large Electronics	1	5		4	4	6	5	5	4		5	5	5	5	5	4
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Large Electronics	3	4		2	3	4	4	3	3		6	4	5	1	3	2
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Large Electronics	3	4		2	5	5	3	5	5		4	4	5	5	5	1
Large Electronics	1	5		4	4	4	4	4	4		5	5	5	5	4	4
Large Electronics	5	6		4	5	6	5	6	5		5	6	5	5	6	5
Large Electronics	4	5		5	5	3	5	5	5		1	5	4	3	4	2
Large Electronics	4	4		4	6	6	5	5	5		6	6	5	3	5	3
Large Electronics	1	5		5	5	3	5	3	6		4	5	6	4	6	3
Large Electronics	3	1		0	0	1	1	1	5		4	1	5	1	2	1
Large Electronics	1	3		3	3	4	4	3	1		5	3	6	1	5	3
Large Electronics	2	6		5	6	6	3	5	6		6	5	6	3	4	4
Large Electronics	1	6		1	6	5	6	3	6		5	3	6	5	6	4
Large Electronics	4	6		4	4	5	5	3	3		4	4	5	3	4	4
Large Electronics	1	4		0	2	5	0	4	5		3	3	4	3	1	3
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Large Electronics	2	6		6	6	6	6	5	6		5	4	5	6	6	5
Large Electronics	1	6		5	6	6	6	6	6		5.3	6	6	3	6	5.3
Large Electronics	4	5		4	5	5	4	3	1		5	5	6	5	5	4
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Large Electronics	4	6		3	6	5	6	2	6		3	6	3	4	6	1
Large Electronics	1	3		4	5	6	2	4	4		4	3	5	4	5	3
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Large Electronics	4	3		6	5	6	5	5	5		4	5	4	6	5	5
Large Electronics	0	4		5	4	5	3	5	5		4	6	4	4	6	4
Large Electronics	3	4		2	5	4	1	4	6		5	2	4	4	4	3
Large Electronics	3	5		4	5	4	4	4	4		5	5	3	4	4	4
Large Electronics	3	6		5	5	6	5	5	6		6	5	5	5	4	4
Large Electronics	1	6		4	5	5	2	3	4		5	4	6	4	5	4
Large Electronics	2	5		4	5	5	3	5	4		5	4	5	4	4	3

Appendix B Survey Data

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Large Electronics	3	4	4	4	4	3	5	5	5	5	5	5	5	4
Large Electronics	3	3	2	3	4	3	4	3	4	4	4	4	4	3
Large Electronics	4	3	4	3	4	5	3	3	4	4	4	4	4	2
Large Electronics	1	3	4	3.6	3	2	5	4	4	4	4	4	4	3
Large Electronics	3	4	4	5	5	3	5	5	4	4	3	3	4	3
Large Electronics	2	0	1	1	1	1	2	1	2	1	4	1	6	4
Large Electronics	1	5	3	5	5	5	6	4	6	6	6	5	5	5
Large Product Design	5	4	4	6	5	4	4	4	5	4	5	4	5	5
Large Product Design	4	5	5	5	5	4	4	4	4	4	5	4	5	4
Large Product Design	4	6	5	6	6	6	5	6	6	5	5	6	6	5
Large Product Design	3	6	3	4	6	6	3	6	6	5	5	5	6	3
Large Product Design	1	6	3	6	5	6	2	5	5	6	5	5	5	4
Large Product Design	4	5	4	6	4	4	3	4	4	6	6	4	3	3
Large Product Design	2	6	4	6	6	6	3	4	6	3	6	2	6	3
Large Product Design	3	6	6	6	5	6	6	6	6	6	2	5	6	2
Large Product Design	3	5	5	5	5	4	5	6	5	4	2	4	3	3
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Large Product Design	3	5	4	5	5	5	5	3	5	5	5	5	4	4
Medium Optics Design	1	5	4	5	5	3	3	3	4	4	3	3	3	3
Medium Product Design	2	5	3	5	6	5	5	5	6	5	5	1	5	4
Medium Product Design	2	6	3	5	6	1	3	6	6	6	5	4	5	5
Medium Product Design	2	0	2	5	5	6	2	4	6	6	6	5	6	6
sdfsdf	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Small Design 3	3	5	5	6	6	4	5	5	5	5	5	5	5	5
Small Design 3	3	1	4	5	4	5	4	4	5	3	4	5	5	4
Small Design 3	2	4	2	3	4	3	3	3	4	4	3	3	3	3
Small Design 3	4	5	4	4	4	4	4	5	5	5	3	4	5	3
Small Design 3	5	6	3	6	4	6	4	6	3	3	5	6	6	6
Small Design 3	4	4	4	5	5	5	5	5	5	5	4	4	5	3
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Small Design 3	2	6	3	5	4	4	6	6	6	6	5	5	6	3
Small Design 3	1	6	5	5	6	6	3	5	6	5	5	4	5	4
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Small Design 3	3	5	4	5	5	5	2	5	5	5	5	5	5	5
Small Product Design 1	2	6	1	5	3	1	2	1	5	6	3	5	4	4
Small Product Design 1	3	6	5	5	5	6	5	6	4	5	5	5	4	4
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Small Product Design 1	2	5	2	6	5	5	5	3	5	4	2	2	3	4
Small Product Design 1	###	3	3	4	5	3.5	3	6	4	5	5	4.3	4	4
Small Product Design 2	3	5	3	6	5	2	2	5	3	1	5	5	5	4
Small Product Design 2	4	5	4	4	4	4	4	4	4	4	4	4	5	4
Small Product Design 2	2	3	5	4	5	4	4	5	5	5	4	4	5	5
Specification Modification	2	4	2	5	4	2	5	3	2	4	4	3	5	3
Specification Modification	3	5	4	5	6	5	4	4	4	4	5	4	6	4
Specification Modification	3	4	4	4	5	5	3	5	3	3	4	4	5	4
Specification Modification	6	6	6	6	6	6	6	3	6	6	5	6	6	2

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Appendix B Survey Data

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Technical Sales	5	5	5	5	6	6	5	5	6	5	4	6	6	4
Technical Sales	4	5	4	6	6	5	6	6	6	4	6	2	5	0
Technical Sales	4	5	5	5	5	4	5	5	6	4	5	5	5	2
Technical Sales	4	6	6	6	6	6	6	6	6	6	4	6	6	4
Technical Sales	3	6	6	6	6	6	6	6	6	6	6	4	6	0
Technical Sales	4	2	4	3	6	4	4	6	3	6	4	5	5	4
Technical Sales	3	5	4	5	5	6	5	5	4	5	4	5	4	4
Test Equipment Design	4	5	2	4	5	5	5	3	4	4	5	4	5	4
Test Equipment Design	4	0	3	4	1	1	2	3	3	3	3	4	4	1
Test Equipment Design	3	6	6	5	6	5	6	5	4	3	6	5	4	4
Test Equipment Design	1	6	3	6	6	6	6	4	6	4	6	6	6	4
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Appendix B Survey Data

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Academic R&D	1	6	2	0	3	3	6	5	6	3	3	4	4	2
Academic R&D	2	5	4	1	4	3	5	4	3	4	5	1	5	5
Academic R&D	5	0	6	2	6	2	6	5	6	6	1	2	6	6
Architecural Design	5	1	5	1	5	5	6	3	5	5	5	3	5	6
Architecural Design	4	2	4	2	5	4	6	2	5	6	5	4	5	6
Architecural Design	6	2	4	5	4	6	6	3	6	6	6	5	6	5
Architecural Design	3	3	5	1	4	3	5	5	5	5	2	5	5	5
Biotech Startup	3	2	3	3	4	2	4	4	2	3	5	3	2	4
Biotech Startup	6	5	4	5	5	5	6	6	6	6	3	6	6	5
Biotech Startup	5	1	4	2	5	3	5	4	6	5	5	3	5	3
Biotech Startup	4	2	4	5	4	4	4	4	4	4	4	4	5	4
Biotech Startup	5	4	4	1	5	6	6	4	6	4	5	5	5	4
Consulting Engineer	4	2	4	2	4	2	5	3	5	5	3	5	5	4
Environmental Analysis	3	5	6	0	6	6	6	6	6	6	6	3	3	3
Environmental Analysis	6	5	6	0	6	5	6	6	6	6	1	4	5	5
Graduate Student	1	4	5	6	4	2	4	4	1	5	3	2	4	3
Graduate Student	3	4	4	1	5	3	5	6	3	5	5	2	5	4
Large Computer	5	4	5	2	5	3	5	4	5	5	4	5	5	5
Large Computer	5	4	5	3	4	3	5	4	4	4	5	5	5	5
Large Computer	2	2	4	1	4	5	5	2	4	5	2	4	3	5
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Large Computer	4	1	3	1	6	2	5	2	5	4	5	3	5	2
Large Computer	5	2	5	2	5	4	5	6	5	6	5	4	5	6
Large Electronics	4	3	3	3	5	###	4	2	2	4	5	4	5	5
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Large Electronics	3	2	5	0	5	4	5	2	5	4	3	3	4	4
Large Electronics	4	4	5	2	6	3	5	3	5	5	6	5	5	5
Large Electronics	3	2	4	2	6	3	5	3	5	5	6	4	4	4
Large Electronics	3	3	4	2	5	3	5	2	4	3	6	3	3	4
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Large Electronics	5	4	4	1	5	3	5	5	5	5	5	4	5	3
Large Electronics	2	2	2	4	2	3	2	1	3	2	2	3	3	4
Large Electronics	4	3	4	2	5	4	6	5	4	5	5	4	5	3
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Large Electronics	3	0	4	2	6	4	4	4	1	6	3	1	5	6
Large Electronics	4	5	4	1	4	4	4	4	5	4	5	4	5	2
Large Electronics	3	2	3	3	3	3	4	3	3	4	4	4	4	4
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Appendix B Survey Data

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Large Electronics	5	1	5	1	1	1	6	3	5	5	6	5	6	2
Large Electronics	5	3	5	1	5	3	5	5	5	5	3	3	5	5
Large Electronics	5	5	4	1	4	2	5	4	5	6	5	2	6	4
Large Electronics	5	5	4	1	4	2	5	4	5	6	5	2	6	4
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Large Electronics	6	0	5	3	6	5	5	6	5	6	6	2	5	6
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Large Electronics	5	2	5	2	5	4	4	4	4	5	5	5	5	4
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Large Electronics	4	2	4	2	1	4	4	2	4	4	5	4	5	3
Large Electronics	5	1	6	1	5	5	5	5	4	5	6	0	5	5
Large Electronics	5	2	4	2	5	3	4	4	3	5	4	4	5	3
Large Electronics	5	4	5	1	5	5	6	3	5	6	5	5	5	5
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Large Electronics	5	3	6	5	5	2	4	4	0	4	5	1	5	6
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Large Electronics	3	2	3	2	4	3	3	3	3	3	3	3	3	3
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Large Electronics	2	2	5	2	4	4	3	2	3	5	5	3	2	4
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Large Electronics	6	3	4	2	5	3	6	4	6	5	5	5	4	3
Large Electronics	3	3	4	1	4	2	5	4	4	2	4	5	6	4
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Appendix B Survey Data

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Large Electronics	3	2	4	2	5	3	4	4	3	4	2	1	4	6
Large Electronics	5	2	4	2	4	3	6	5	5	6	2	3	6	3
Large Electronics	3	3	5	2	4	3	5	1	5	5	5	2	4	5
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Large Electronics	4	3	4	2	1	4	5	3	3	4	4	4	5	3
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Large Electronics	1	5	1	5	5	0	0	1	0	5	2	1	5	3
Large Electronics	4	1	2	3	5	0	6	1	5	5	3	2	5	5
Large Product Design	4	4	3	1	4	3	5	1	5	5	3	5	3	5
Large Product Design	5	4	4	2	5	3	5	4	5	5	5	3	5	4
Large Product Design	5	2	5	2	5	5	6	6	6	6	5	6	6	5
Large Product Design	3	6	5	0	6	6	6	6	6	6	6	3	6	6
Large Product Design	6	5	4	0	5	4	6	4	6	5	6	0	6	3
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Large Product Design	4	3	6	0	5	2	6	5	6	6	6	3	4	6
Large Product Design	5	3	5	1	6	3	6	4	6	4	5	3	5	5
Large Product Design	5	2	4	2	4	3	6	2	5	4	5	3	6	4
Large Product Design	5	3	5	3	1	3	5	3	5	5	5	5	4	2
Large Product Design	5	1	5	3	5	1	5	3	5	4	2	4	6	6
Medium Optics Design	3	3	5	2	3	4	5	4	3	6	5	3	4	5
Medium Product Design	6	2	2	1	6	4	4	1	6	4	4	5	5	2
Medium Product Design	5	0	6	0	0	3	4	4	6	5	2	3	4	6
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sdfsdf	6	6	6	0	6	6	6	6	6	6	6	6	6	0
Small Design 3	5	2	4	2	5	4	6	3	5	4	4	5	5	4
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Small Design 3	4	1	1	2	4	4	6	1	4	4	4	2	2	5
Small Design 3	5	3	5	2	5	4	5	4	5	5	5	4	5	5
Small Product Design 1	5	1	3	1	6	2	5	1	5	4	5	0	6	5
Small Product Design 1	5	2	3	2	5	1	6	4	4	5	5	3	5	6
Small Product Design 1	4	2	1	0	1	2	4	3	5	3	4	1	4	5
Small Product Design 1	3	3	4	3	5	2	5	2	4	4	5	2	5	4
Small Product Design 1	4	3	4	3	3	2	4	1	5	4	3	5	4	5
Small Product Design 2	3	2	5	1	3	4	5	5.7	5	5	6	3	4	2
Small Product Design 2	4	2	4	2	5	4	5	4	4	4	2	4	4	3
Small Product Design 2	3	2	2	2	5	5	5	2	6	5	5	3	5	5
Specification Modification	4	2	4	2	4	3	3	1	3	4	3	2	3	5
Specification Modification	5	5	3	5	5	4	5	3	4	4	6	4	4	3
Specification Modification	3	3	3	2	4	4	5	4	5	4	5	4	4	3
Specification Modification	5	5	3	1	4	2	6	5	6	4	4	5	6	5

Appendix B Survey Data

[Company]	[Selfcons	[Tim	[Tim	[Tim	[Tim	[Time_P	[Cha	[Cha	[Cha	[Cha	[Cha	[Cha	[Cha	[Cha
Specification Modification	0	1	5	1	5	1	5	5	3	6	6	6	5	5
Structural Design	5	2	5	4	4	4	5	3	5	4	5	5	5	4
Technical Sales	5	3	4	3	6	5	5	5	6	5	5	4	5	2
Technical Sales	6	5	0	2	6	3	6	5	6	6	6	3	6	3
Technical Sales	5	4	5	0	5	4	5	5	5	5	5	2	6	3
Technical Sales	5	5	5	1	6	4	6	5	5	4	6	5	6	2
Technical Sales	6	3	6	0	6	0	3	6	6	4	6	0	6	6
Technical Sales	4	3	4	1	5	5	5	3	6	4	5	1	5	2
Technical Sales	4	3	1	4	5	5	5	1	6	4	5	3	5	4
Test Equipment Design	5	2	4	3	5	4	5	5	5	4	5	3	4	3
Test Equipment Design	5	3	3	2	4	4	3	4	0	4	5	2	4	4
Test Equipment Design	6	4	5	1	6	2	6	6	6	6	4	3	6	6
Test Equipment Design	4	6	6	0	3	3	6	6	5	6	4	4	6	5
Test Equipment Design	5	1	3	3	6	5	5	5	5	4	5	1	5	6

Appendix B Survey Data

[Company]	llen	[Re	[Re
Academic R&D		4	1
Academic R&D		2	0
Academic R&D		6	1
Academic R&D		5	1
Academic R&D		6	4
Architecural Design		5	3
Architecural Design		2	2
Architecural Design		1	3
Architecural Design		###	###
Biotech Startup		4	1
Biotech Startup		6	0
Biotech Startup		5	4
Biotech Startup		4	1
Biotech Startup		1	5
Consulting Engineer		6	3
Environmental Analysis		6	4
Environmental Analysis		6	3
Graduate Student		4	1
Graduate Student		6	3
Large Computer		5	0
Large Computer		5	0
Large Computer		4	2
Large Computer		3	1
Large Computer		5	1
Large Computer		5	1
Large Computer		5	4
Large Computer		6	0
Large Computer		6	0
Large Electronics		2	6
Large Electronics		4	4
Large Electronics		3	4
Large Electronics		3	5
Large Electronics		2	6
Large Electronics		3	5
Large Electronics		4	4
Large Electronics		4	4
Large Electronics		3	5
Large Electronics		5	2
Large Electronics		4	6
Large Electronics		4	5
Large Electronics		3	5
Large Electronics		5	2
Large Electronics		2	3
Large Electronics		6	5
Large Electronics		6	4
Large Electronics		6	0
Large Electronics		6	0
Large Electronics		5	0
Large Electronics		4	2
Large Electronics		4	2

Appendix B Survey Data

[Company]	llen(	[Res	[Res
Large Electronics		6	0
Large Electronics		5	1
Large Electronics		3	3
Large Electronics		6	1
Large Electronics		5	1
Large Electronics		5	2
Large Electronics		5	2
Large Electronics		6	0
Large Electronics		6	0
Large Electronics		5	1
Large Electronics		6	4
Large Electronics		3	0
Large Electronics		5	1
Large Electronics		5	1
Large Electronics		4	3
Large Electronics		4	4
Large Electronics		5	1
Large Electronics		5	4
Large Electronics		5	1
Large Electronics		1	0
Large Electronics		4	0
Large Electronics		4	0
Large Electronics		6	2
Large Electronics		4	0
Large Electronics		4	3
Large Electronics		5	3
Large Electronics		5	0
Large Electronics		6	0
Large Electronics		6	###
Large Electronics		3	2
Large Electronics		6	2
Large Electronics		5	0
Large Electronics		5	0
Large Electronics		5	1
Large Electronics		4	3
Large Electronics		4	1
Large Electronics		5	2
Large Electronics		5	2
Large Electronics		5	3
Large Electronics		5	2
Large Electronics		5	4
Large Electronics		4	2
Large Electronics		3	3
Large Electronics		4	5
Large Electronics		5	4
Large Electronics		2	4
Large Electronics		3	5
Large Electronics		4	4
Large Electronics		3	4
Large Electronics		5	4

Appendix B Survey Data

[Company]	llen	[Res	[Res
Large Electronics		###	###
Large Electronics		###	###
Large Electronics		4	1
Large Electronics		6	0
Large Electronics		6	0
Large Electronics		4	2
Large Electronics		5	1
Large Electronics		4	1
Large Electronics		2	6
Large Electronics		1	0
Large Electronics		4	6
Large Product Design		2	5
Large Product Design		4	3
Large Product Design		5	1
Large Product Design		6	2
Large Product Design		6	5
Large Product Design		5	5
Large Product Design		4	0
Large Product Design		5	6
Large Product Design		5	4
Large Product Design		4	3
Large Product Design		3	5
Medium Optics Design		6	0
Medium Product Design		1	4
Medium Product Design		5	5
Medium Product Design		0	6
sdfsdf		6	6
Small Design 3		4	5
Small Design 3		2	5
Small Design 3		3	5
Small Design 3		5	1
Small Design 3		3	4
Small Design 3		5	3
Small Design 3		5	3
Small Design 3		6	1
Small Design 3		5	1
Small Design 3		1	4
Small Design 3		4	4
Small Product Design 1		6	0
Small Product Design 1		5	1
Small Product Design 1		4	4
Small Product Design 1		4	2
Small Product Design 1		3	6
Small Product Design 2		3	3
Small Product Design 2		4	1
Small Product Design 2		2	5
Specification Modification		4	2
Specification Modification		###	###
Specification Modification		3	5
Specification Modification		4	2

Appendix B Survey Data

[Company]	llen	[Re	[Re
Specification Modification		6	0
Structural Design		###	###
Technical Sales		5	5
Technical Sales		6	5
Technical Sales		5	3
Technical Sales		3	3
Technical Sales		6	6
Technical Sales		4	3
Technical Sales		3	3
Test Equipment Design		5	4
Test Equipment Design		4	0
Test Equipment Design		6	0
Test Equipment Design		6	4
Test Equipment Design		5	1