

ENGINEERING IN THE MAKING:
AN ETHNOGRAPHY OF PRODUCT DEVELOPMENT

A Thesis

Presented to

The Faculty of the Department of Anthropology
San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Arts

by

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May 2008

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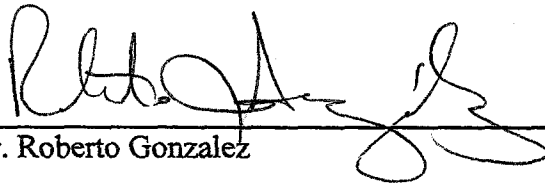
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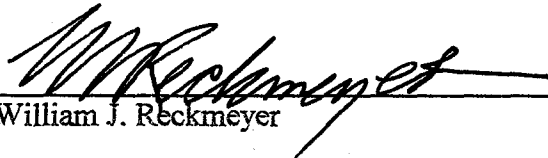
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ABSTRACT

ENGINEERING IN THE MAKING: AN ETHNOGRAPHY OF PRODUCT DEVELOPMENT

by Armineh Noravian

While there are many known factors that contribute to the success or failure of small innovation companies (SIC), the product development processes (PDPs) for these companies are generally poorly understood. The goal of this thesis is to understand PDPs and their consequences in such a company. Fieldwork is performed onsite using ethnographic methods, and the unit of study is the project, consisting of prior projects, projects in progress, and new projects.

The results show that PDPs are interpretive and not just sets of rules followed by individuals. Although there are patterns that emerge in how things are done, individual characteristics and the social processes by which they interact shape the construction of the actual PDPs. This has consequences on the way Engineering is organized and managed, and on engineering education.

ACKNOWLEDGEMENTS

Many individuals have made the research and writing of this thesis possible. At SIC, these include the owner, the managers in the various departments, the engineering, industrial design, and manufacturing staff, and other personnel who provided assistance during my research. At San Jose State University, Dr. Charles Darrah has provided invaluable assistance and guidance in every aspect of this thesis. He has been demanding, honest, generous, and patient. Drs. Roberto Gonzalez and William Reckmeyer have provided helpful insights. At home, my husband, John Kerns, and friend, Erna Wenus, have been the sounding boards for my ideas, while my sons, Mark and Ben, and my mother, Juliet Noravian, have cheered me along.

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CHAPTER 1: PROBLEM

“Innovation drives the economic success of Silicon Valley. The ability to generate new ideas, products and processes is an important source of regional competitive advantage” (Joint Ventures 2006:14). An array of small innovation companies characterizes the region and provides the innovative edge that makes Silicon Valley a major gateway to the global economy. “More than twenty five percent of all venture capital in the United States is invested in Silicon Valley...About 23,800 net new firms (with an average size of seven employees) were created during the 2000-2002 period. In fact, Silicon Valley is constantly renewing its company base: 46% of all the region’s firms were started in the five years spanning 1998 to 2002, representing 30% of all the region’s jobs” (Joint Ventures 2006:9). However, many of these businesses struggle or fail.

“At the heart of [a] company’s competitiveness is its product development process” (Raja 2001:25). While there are many known factors that contribute to the success or failure of innovation companies, the product development processes (PDPs) for small innovative companies are generally poorly understood. A review of some of the literature reveals a variety of different models (Brown and Eisenhardt 1995; Blanchard and Fabrycky 1998; Otto and Wood 2001; Roozenburg and Eekels 1995; Karvi and Belikoff 1996; Hoedemaker et al 1999; Kusiak and Park 1990; Anthony and McKay 1992; Cunha and Gomes 2003; Fairlie-Clarke and Muller 2003; Calantone and Benedetto 1988). Some models include activities such as business analysis, marketing, technical engineering design, development of manufacturing plans, and validation.

Sometimes distribution channels for strategically marketing and introducing the new product are also included (Otto and Wood 2001:5). Generally, research of technology used in product development and manufacturing is not included in PDPs (Otto and Wood 2001:6). Although the literature on PDPs is vast, it tends to be generalized, prescriptive, and theoretical, but it does not apply to small innovative companies that adopt idiosyncratic PDPs.

Furthermore, PDP is in the lexicon of those involved in product development at various levels, but it is invoked in context dependent ways and means different things to different people. For instance, the following excerpts from interviews conducted at Small Innovation Company (SIC) reflect the variety of definitions. The sources have been deliberately not identified to protect their anonymity.

Example 1: “You can’t train people on how to do stuff when things change all the time... Things should be more routine than they have been. It seems that everything we do is an exception to the rule. We shouldn’t have to struggle to figure out how to do things that can be routinized.” For this individual, process is a set of rules that allow efficiency on things that are routine. Following these rules simplify things.

Example 2: “This is a mature company. Product development process is not clearly defined. It is in the heads of people. There is an informal methodology in place. We are 120 people. What if we became [a] \$100 million company? How would we be today? We would then need to teach and educate people what our process is. Structurally we are informal. The philosophy at the top is that we want to remain entrepreneurial, fast, helping customers, and meeting customer expectations. This principle is doing things fast, there is a lot of ramifications. Fast means we are not perfect.” He added, “We are

struggling with execution. Why? Because we lack effective decision-making. We don't have a behavioral framework that all employees understand...Another reason is clarity around accountability. Why would a senior executive not have the authority to make decisions? So we flounder and all decisions get pushed out. People are not empowered to make decisions." For this individual, process would allow effective decision-making and accountability.

Example 3: "One of our problems is communication. We never have company meetings. So the leadership doesn't communicate. Different departments are in different silos. The top leadership job is to link us all with a common message. There is no message. We don't talk to each other." For this individual process is communications between different functional groups.

Example 4: "[the owner of SIC] just comes in here and tells people to stop working on what they are working on and do something else." "One thing that's been driving people crazy is [the CEO] getting involved in Engineering...I think that's wrong...is disrespectful, is sticking his nose in Engineering to solve day-to-day problems." When asked why he thought the CEO did this, he responded, "What [the CEO] does is create noise from information. It's not productive." He added, "[the CEO] is business minded. [The owner] enjoys the process of developing products and delivering a service. He doesn't think about business. It's more emotional for him." For this individual, process means organizational clarity and conformity to rules.

Example 5: An individual was discussing a recently discovered problem on an established product. In answering what could have been done to catch this problem earlier, he said, "[This kind of problem] and other field problems we can always minimize with a process.

It is partially the process ... You don't need to have geniuses working here, but with a better process, you could do better. You can't just depend on having the best in the business, but a better process would help." So, for this individual process eliminates individual judgment and fallibility. When asked what that would be, he said, "By and large, engineers have a decent handle on some kind of process. Engineers seem to understand that there is a need for one, less chaotic product development process. I make an effort to get it. Didn't get that far." This process would come from engineers, as opposed to management.

Example 6: An individual was trying to explain what went wrong on his project, "Things can go wrong by not following proper engineering processes." He explained process as follows: "Something like ISO allows you to have everyone bobbing up and down in step, even if it's not the best step, at least it's the same step. In larger companies, technicians do technician work, electronics engineers do electronics, mechanical engineers do mechanical engineering, and so on. In a small environment, you do what ever is required to get the job done. [So] it adds chaos. It's something that runs on its own. Now you have many heads bobbing up and out of sync doing their own gig. In a two-man operation, it's essential. Even here, it can be [essential] as long as the interface between departments are [SIC] properly structured." For this individual process means clarity of functions and planning.

Example 7: "You know they are struggling for money... but they also waste a lot of money. Rush jobs, premier pays, etc. Existing products cost a lot of money because they are not reliable or manufacturable. This is costly." Another said, "They are [doing well] but could do better and could make more money. For a little company, they spend a lot

of money on projects that should never get started.” Process for these individuals means planning.

Example 8:

“There is not typical process.” Yet another said, “Product development process is what we don’t have here. I would say [the owner] has an idea and we just do what he wants. What we don’t have is that we don’t brainstorm how things need to be done. He tells us how to implement. We then implement things in a toy like manner.” He also added,

“I like the HP way... You need to go through a feasibility study before ‘green-lighting’ a project. ‘Green-lighting’ requires the feedback from every group in the company. This was the worst company for that. [The owner] gives approval, but does not look at feedback. The net effects are low quality product, a rush to market, and a hit to morale. We need to have a process that is scalable to grow the company. One guy making decisions doesn’t allow this. I believe that building a company is related to processes. At SIC, there is more than one example of [the owner] has an idea that he believes has some market potential. We are thrown in a dramatically different direction in Engineering. I worked on [a project], which was really hot and the most important thing in the company, but within two months it disappeared. We built a prototype, it went to a trade show, came back from trade show, didn’t work too well there because we didn’t have time to do it right. It then sat on the shelf and it was forgotten about, in lieu of other opportunities.”

It appears that this individual believes that the current process is doing whatever [the owner], the founder-owner at SIC, says. He, however, would prefer a process that could be used as a tool for negotiating, participating, and contributing. It could also be seen as a way to make sense out of what is going on.

Example 9: When asked about PDP, this individual said, “controlled chaos. There is a vision from [the owner of SIC], and his interactions between products, customers and others, also from his history and knowledge. He is the technical expert of the company.

He gets insights about products. The problem is that [the owner] has all these ideas in the pipeline and instead of doing 70%, we try to implement 90% of them...Chaos is the innovation and creativity.” When asked one thing about this process that he would like to change, he replies, “more project planning.” So for this individual, the PDP is everything and anything.

Example 10: “It takes a lot of time to get a product out the door. We don’t have a clear repeatable process for that.” This individual was referring to product development as something that can be used to develop products in a mechanical fashion.

Therefore, PDPs seemingly have different meanings and functions for different individuals. But a common theme seems to be that it brings clarity to what is going on, within the context that matters to each individual. According to Spradley (1979:5), people interpret experience and generate social behavior based on their acquired knowledge. However, this map is flexible and does not compel people to follow a particular course (Spradley 1979:7). A PDP is thus used in an interpretive endeavor and not just a set of rules that individuals follow. Through different assumptions, meanings, and contexts individuals construct the nature and function of a PDP. This would mean that individual characteristics and histories, and the social process by which these individuals interact are important components in the construction of a PDP. This study will focus on understanding PDPs from this interpretive perspective.

Cunha and Gomes (2003:174) argue, “that organizations are developing new approaches to the product innovation process as they realize that traditional approaches may no longer be appropriate, given the characteristics of today’s competitive game.” Otto and Wood (2001:12) tell us “Every company has a different development process

out of necessity; there is no single “best” development process; the design process and the product development process are misnomers. The sophistication of the product, the competitive environment, the rate of change of technology, the rate of change of the system within which the product is used: These and many other factors that shape a product development process change for different companies.” The goal of this thesis is to understand how people do product development in a small innovation company and the consequences that follow from their distinctive way of doing things. The knowledge gained from this study provides insight into (1) the conditions that exist in small innovative organizations, which influence PDPs in such organizations and (2) the skills needed to navigate the product development of innovative products in such organizations.

The anthropological-ethnographic literature relevant to PDPs is relatively small. Kunda’s (1992) ethnography of the engineering division in a large high-technology corporation describes, interprets, and evaluates the experience of the members of the organization as they are being influenced by the management’s imposition of organizational ideology in an attempt to control the hearts and minds of the workers. Downey and Dumit’s (1997) collection of case studies explores how science, technology, and medicine penetrate everyday lives and change the boundaries of how people think about themselves and the world around them. Schiffer’s (2001) edited volume addresses the perspectives of archaeologists and socio-cultural anthropologists on technology. Among the chapters, Kingery’s “The Design Process as a Critical Component of the Anthropology of Technology,” where he discusses the flow chart used in engineering texts showing engineering analysis as a sequence of problem solving activities taught to engineering students as *the* design process, is especially relevant. It is, he says, a “naïve

model widely accepted by the engineering community”(2001:126). He proposes five specific activities that characterize the problem solving design process, which he believes provide a more comprehensive framework for past technological change and future prospects. The activities (purpose and goals, normal configuration, operational principles, performance characteristics, and design tools) are however, broad generalizations. Finally, Vinck’s (2003) book of ethnographic case studies describes how things are actually done in different engineering environments. The ethnographies examine the complexity of technical practices, the social and cultural worlds of designers and technical action practices, and the role of writing practices and their end products. None explore the PDP of a small innovation company, as is done in this thesis.

In summary, PDPs have different meanings and functions for different individuals, is interpretive, and is different for different companies and even for different products in the same company. This has consequences on the way Engineering is organized and managed, the way it functions, the skills required by engineers who work in such an environment, and engineering education. It is the goal of this thesis to explicate and understand these consequences.

CHAPTER 2: METHODOLOGY

Because PDPs have different meanings for different individuals, their characteristics and histories, and the social processes in which they participate, are relevant to how PDPs are constructed and used in a company. A PDP is not presented as a single and formal structure that guides action. Instead, it is actively created by individuals drawing upon different assumptions, meanings, and practices, as they encounter the real challenges of moving from ideas to tangible products. A survey will not adequately provide an insight into these various factors; therefore, an ethnographic method of data collection is used.

Data collection was done onsite at SIC. During a nine-month period, thirty-two trips were made, with an average of five and a half hours per trip spent on site. After each trip, another five to six hours were spent transcribing field notes and for reflection and analysis.

Data was collected from people in different positions in the organization who influenced or participated in different ways in product development. The positions ranged from those working on the assembly line to the founder-owner of the company.

The data collection strategy is consistent with ethnographic standards and practices. "Ethnographers make cultural inferences from three sources: (1) from what people say; (2) from the way people act; and (3) from the artifacts people use" (Spradley 1979:8). Data collection was thus done using several methods.

Open-ended conversation with people concerning products under development was one source of data. This included information on the nature of the product being

developed, as well as the roles people assumed or were assigned, their educational backgrounds, histories, work experience, and their perception of the work that needed to be done.

Another source of data was observation of various people at work. This included engineers in the laboratory, the industrial designers in their area, the test group at their equipment, or the people working in the assembly area. However, in an office environment, where people sat at their desks and worked on their computers, this type of observation did not provide valuable data. Data collected through open-ended conversations and observations was documented and used to make inferences about what people said they did, what they did, and how they did it, as related to product development.

Project meetings were also a rich source of data. Here, interactions between different functional groups or between members of an engineering team could be observed. During the latter stages of this study, meeting minutes became available, which became part of the collected data. This type of data was used to follow what was occurring on the various projects and to obtain insight on the process of how ideas were transformed into products on different projects.

During the entire study, all the people working on projects were under time pressure. In situ interviews were conducted while they were working. This meant that they talked about what they were doing and why they did it as they worked. However, this could not be done for prolonged periods of time because it would have affected their work. So, this type of data collection was done in frequent intervals of short duration.

However, data collection during meetings was different in that I was ignored and could freely collect data.

Information specific to each project, such as a timeline for its various phases, was also collected. Although I never saw an officially-documented timeline, the oral timeline was taken very seriously. Other information in this category included product features, which defined what the product needed to be able to do, and reports from the test department, which documented whether the product passed or failed certain tests. Only the reports from the test department were documented on paper. Features of completed products were on the website, although, features for products under development were all oral. This type of data showed what people were working to achieve on a technical level and the constraints they worked within.

The website provided a complete list of SIC's entire product line, their features, and their prices. It also showed a list of industries that use SIC products. This was used to learn about the different products that SIC produced and provided a list of projects to study.

A Google search on SIC produced a number of hits about the company's history and the founder-owner; most were newspaper articles about the company. Various patents were also described on the Internet. This was used to gather public information about the company, company history, and founder's story.

The physical layout of the company, the various artifacts that were in the lobby, and how Engineering was organized were also documented in my field notes. This information is provided to orient the reader to the functional layout of the company. Appendix A gives the reader a detailed description of the layout of the company.

Most people at SIC were extremely busy individuals. They were very open and helpful about discussing what they did, but care was taken that collecting data did not adversely affect their jobs.

Since product development models include activities such as business analysis, marketing, engineering, manufacturing and field support planning (Otto and Wood 2001), PDPs include a number of different people from different functional groups who interact with each other for the specific purpose of developing a product, within a certain time and a certain budget. "A project can be considered to be any series of activities and tasks that have a specific objective to be completed within certain specifications, have defined start and end dates, have funding limits (if applicable), consume human and non-human resources (i.e., money, people, equipment), and be multifunctional (i.e., cut across several functional lines)" (Kerzner 2001:2). Therefore, to study the PDP, the appropriate unit of study is the project, as opposed to individuals or functional groups. This captures the range of activities involved in the process of developing a product, the different ways that functional groups and different individuals contribute to the development of a product, and how individuals interact within and outside their own functional groups. Furthermore, there were a number of different projects in progress and each project was at a different stage. Studying these different projects allowed comparison and contrast between the development processes for different products.

Different individuals work in different phases of projects; some even work outside their own functional groups. Looking at projects as the unit of study provides insight on the skills needed to participate in various phases of product development and how these individual contribute to the construction of the process. Therefore, I collected

data on PDPs on a project basis; i.e., on products that had been developed before I arrived, products that were under development, and products that were just starting up.

My own background affected this research. Having worked as an engineer, in both technical and managerial capacities for over twenty years, makes an engineering environment seem like home to me. There were perhaps many things that I took for granted or assumptions that I made, and it's possible that I might have seen things differently had I not been one of the "natives" myself. However, this background was also beneficial for a number of reasons. According to Spradley (1979:17) knowing the language allows the ethnographer to communicate, to know how to categorize experience and how the natives use these categories in customary thought. This allows the ethnographer to ask questions that make sense to the informants. Also, "language not only functions as a means of communications, it also functions to create and express a cultural reality" (Spradley 1979:20). Therefore, if the ethnographer doesn't speak the native language, the informant may feel the need to translate so that the ethnographer would understand. When this happens, it presents a handicap to discovering their culture (Spradley 1979:20). Product development, especially the product design portion, has specialized language that people in other functional departments of the same organization often cannot understand. In this case, I was able to understand this language without the need for translation.

On language and ethnographic description Spradley (1979:22) asks, "how is it possible to describe a culture in its own terms when using an alien language? The answer lies in the fact that every ethnographic description is a translation. As such, it must use both native terms and their meanings as well as those of the ethnographer." In this case,

the native terms and those of the ethnographer are almost the same. In writing this thesis, although I have used much of the insider's language to provide the reader this insider's perspective, I have also tried to translate to a language that is not that of the insiders, or the ethnographer, but that of anthropologists who would not necessarily have knowledge of it.

I cannot claim to be a detached observer for another reason: my engineering ethics. As an engineer, I look at product development as a process that brings an idea into life, which hopefully benefits society in some way or at least does not hurt it. My ethics dictates that there should never be shortcuts when it comes to product quality because a poor quality product may be harmful to the user; imagine the nightmare of having to evaluate what went wrong when someone used the product you designed and got electrocuted or traveled across the bridge that collapsed. This aspect of my engineering background is so ingrained in me that I cannot objectively participate in a study where the technical aspect of the product is involved. I have therefore stayed away from this and have focused on product development from the perspective of the path that an idea travels through to become a product. The success of the product in the marketplace is something that I evaluate from the number of years that the company has been in business and how much it has grown.

Onsite, I was only able to collect data. The opportunity to sit back and analyze what I learned was rare because a lot was going on and the environment made it difficult for me to obtain the necessary detachment to do so. However, away from the site, after each fieldtrip, I was able to sit back and reflect on the data that I had collected and to obtain the necessary detachment that I needed to analyze what was taking place, as an

anthropologist. I spent almost as many hours offsite as onsite reflecting on what I had learned.

Individuals at SIC who participated in this research received and signed an 'Agreement to Participate in Research' in which they were told about the purpose of this research, that their participation was voluntary, and that information that could identify them would not be included in the published results.

I also signed a 'Non-Disclosure Agreement' in which I agreed to keep confidential information that was disclosed to me concerning the development and the engineering of parts, equipment, processes and/or services.

In summary, ethnographic methods were used to gain insight on how products were developed at SIC. I collected data by talking to and observing various people who worked on different projects. Data was collected on product that SIC had developed and was in the process of developing. This included (1) prior project, that is projects that had been completed before this research began, (2) projects that were in progress, that is projects that had begun before this research and were continuing, and (3) new projects, that is projects that began after this research. The process of product development includes activities related to business, marketing, technical design, development of manufacturing plans, and validation. Data collection was done in such a way as to minimize any disturbance to the people involved.

In the final analysis, the insight gained from understanding how people do product development at SIC can identify conditions that affect PDPs in small innovative technology companies. Knowing these conditions, in turn, allows us to better understand the skills needed to function in such an environment.

CHAPTER 3: A COMPANY OVERVIEW

SIC is a small privately held innovation company in the San Francisco Bay Area that develops products to meet its customer needs. It was started in 1983 by the current founder-owner, Ed (pseudonym). The company employs over 100 people and markets its products through a network of 200 dealers and distributors around the world (SIC website, August 21, 2007). It is rumored to have an annual sales of 20 million dollars, although this figure could not be confirmed since the company is private. The operating funds come from sales of products and from loans.

Product

SIC designs products for a niche market, that is, a distinct segment of a market. This means that their products are specialized and serve a specific market need. There are very few other companies competing with SIC for market share. This creates a challenge; mentioning SIC's product in this research is likely to lead to the identification of SIC as a company. Therefore, to protect their anonymity, an analogy is provided with another product: printers and ink cartridges. This should provide the reader a tangible representation of the product so that they can understand the company's business model and the description of the PDPs.

SIC has two categories of products: machines and consumables. Printers are analogous to the SIC machines, and the ink cartridges are analogous to the SIC consumables. Machines are sold in small volumes, while consumables are sold in high volumes. The SIC business model is to sell machines to enable the sales of consumables.

The profit margins on machines are generally small, while most of the profit comes from selling consumables.

Put differently, customers who purchase SIC's consumables must have a machine to either use them or to provide a service to others with these consumables. The machines are thus the initial and substantial investment needed by SIC customers.

Some of the industries that can use their products are government, financial service organizations, libraries, legal firms, schools, and private individuals. The current products include nine types of machines and 16 categories of consumables. Within each category of consumables there is a range of different options that customers can choose from. Using the ink cartridge analogy, it would be much like different ink colors or different types of ink for different applications, although many of SIC's products are patented. A part of the market that the company addresses is new and evolving very fast.

The products studied during this research are listed in Table 1, in the three categories that they will be studied: (1) prior projects, (2) projects that were in progress, and (3) new projects.

Table 1 - Project Categories Studied

	Prior projects	Projects in progress	New Projects
Machines	Model-1 Model-2 Model-3 Model-4 Model-5 Model-P1 Model-P2	Model-6 Model-7 Model-S	Model-Bz Model-Q
Consumables	1 st consumable	Auto-consumable	Special orders Model-Q consumable Model-Q-M Model-Q-N

Functional groups

Since the machines and the consumables are two distinct product categories, SIC requires two different sets of resources with specialized expertise to develop each product category. On the machine side, the Engineering group is required to have expertise in electronics, firmware, and mechanical engineering. Electronics components are used to drive or control various mechanical parts. The firmware, which is the computer program that is embedded in electronic components such as memory chips, is executed by the processor chip to control various mechanical parts. The mechanical parts are both stationary and moving parts, and make up the bulk of the machines. Industrial design expertise is used to design the user interface and the look and feel of the product.

On the consumable side, knowledge of chemical engineering is required. The industrial design team assists the founder-owner in the design of the various consumables.

The manufacturing of these two categories of products is also separate. The machines are assembled on an assembly line by assemblers, while the consumables are manufactured using different types of machinery and different people who can operate them. Manufacturing is the group that assembles the machines and manufactures the consumables.

The executive team listed on the website indicates a number of different functional groups, each headed by a vice president. The founder/president is at the helm of the organization. The CEO reports to the founder, and a number of vice presidents

report to the CEO. Each vice president heads his or her own functional group. See Figure 1 for an executive level organizational chart.

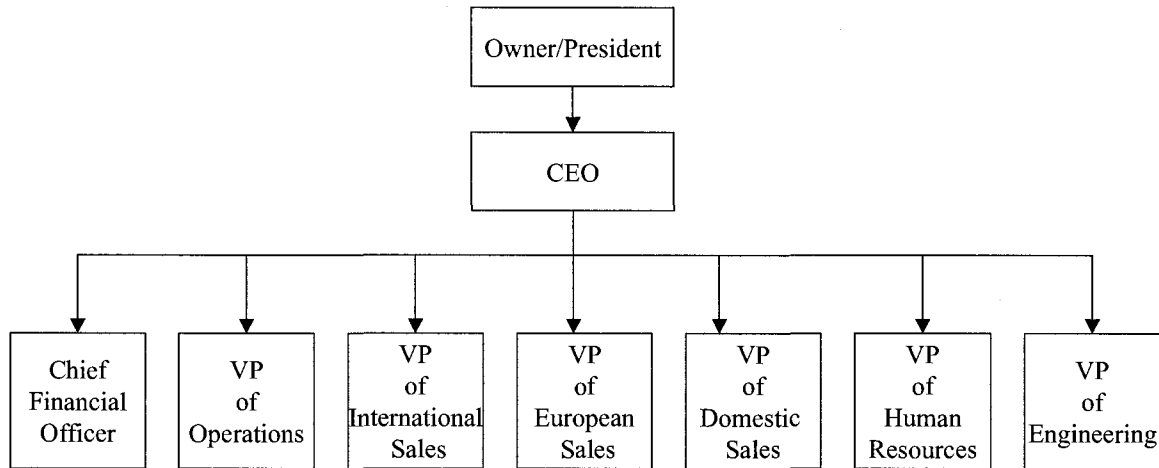
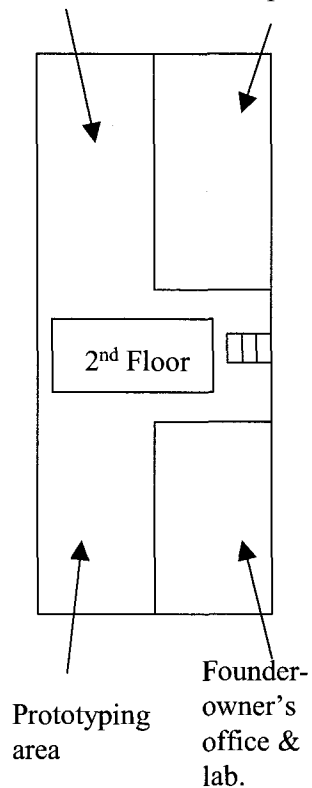


Figure 1 – Executive Level Organizational Chart

The functional group that is not mentioned in Figure 1 is the marketing group. There is no executive heading the Marketing group within the organization. This is a function that is primarily directed by the founder-owner, with assistance from the CEO and the Product Marketing Manager. The market for the new products that SIC is entering is new and rapidly evolving due to technological changes. The products evolve as the markets evolve.

The functional layout at SIC is shown in Figure 2. All the functional groups are located on the first floor, with the exception of the industrial design group and the founder-owner's office, which are on the second floor. The two vice presidents that do not occupy an executive office are the VP of Engineering and the VP of Operations. They stay in their own functional areas. The VP of European sales is located overseas. A detailed grand tour is provided in Appendix A.

Industrial
Design area unoccupied



Not to scale

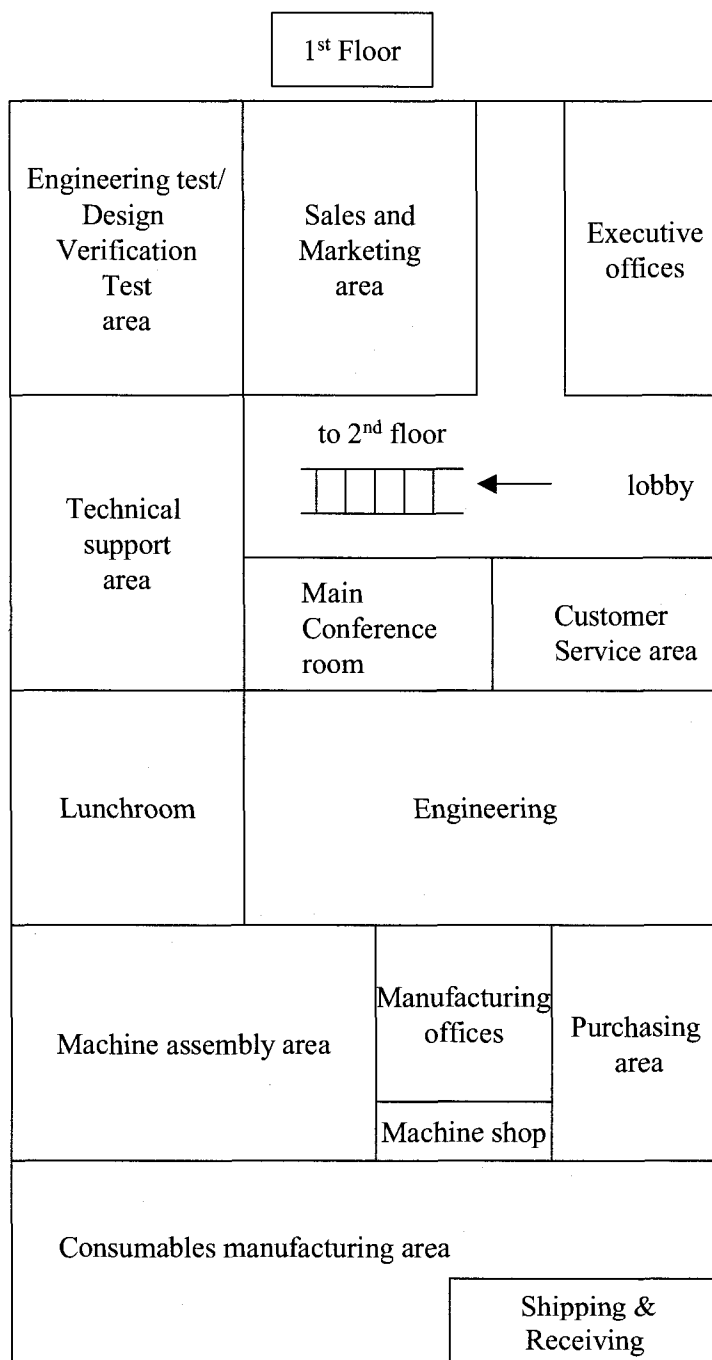


Figure 2 - Functional Layout at SIC

Founder's story

An overview of the company is not complete without a discussion of the founder-owner, Ed. He has been featured in a number of newspaper articles which discuss how his interest in the machine and consumable technology got started in the basement of his parents' home in his teenage years, and how he started SIC when he was in college. Currently, as the founder-owner of SIC, he performs high-level managerial functions, but is also involved in the PDPs or any other technical activity at his discretion. The company is named after him and in the lobby at SIC the display of products shows the evolution of the products from Ed's basement to now. This display might give the impression that SIC is a continuation of Ed's basement or his product development activities.

The founder's story, according to some written sources, inside and outside SIC, began with Ed's high school teacher, who knew of his interests and his talents. When Ed was a university student, his teacher asked him to solve a problem with a consumable that he was selling in his side business; he was receiving complaints about poor quality from his customers. This is analogous to a printer ink cartridge that had problems. Ed took some time off from his studies to do this, but soon realized that to make these consumables, he would need a machine that would cost thousands of dollars. So he set out to build a machine in the basement of his parents' home from parts he gathered in junkyards. To return to the analogy, this would be much like developing a machine to produce these printer ink cartridges. Once this was done, he gave his company a name and started selling these consumables through his high school teacher's business. Later

on, he built the machine that customers would use with these consumables. This machine became the Model-1, the company's first machine. In effect, this is analogous to having produced the first printer that would work with the printer ink cartridges that he developed.

Why SIC?

Some years ago, I spent four months as a consultant at SIC, where I managed various active projects and helped recruit a permanent head of Engineering. I learned that the PDPs at SIC could not be adequately understood through current literature on this subject. I also saw that while most companies were taking their manufacturing offshore, at SIC, most of the products were and still are conceived, developed, and manufactured in the same facility, that is, under one roof in the San Francisco Bay Area. The company manages to develop innovative products that are in demand and make money. Therefore, when looking for a small innovation company where I could study its PDPs, I decided to approach the founder-owner, Ed, and to ask him if I could do an ethnographic study of the PDP at his company. After seeking approval from the Vice President of Engineering, who was new at the time, I was able to begin this research.

CHAPTER 4: PRIOR PROJECTS

This chapter includes projects that were completed before the research began; it is therefore a historical perspective. The history of machines was more readily available than that of consumables. Table 2 shows the list of the projects described in this chapter. Model-1 through Model-5 belong to one product line, while Model-P1 and P2 belong to another.

Table 2 - Projects in the Prior Projects Category

	Prior projects
Machines	Model-1 Model-2 Model-3 Model-4 Model-5 Model-P1 Model-P2
Consumables	1 st consumable

Reconstructing the history of a company with high employee turnover is difficult, but one engineer, Peter, has been at SIC from the beginning. In fact, he was there when SIC first started. His photo is in the lobby on the wall above the early models of machines that SIC developed. He said, “I love machines. I have this fascination with machine technology. I don’t have a formal background in anything. I learned electronics and software working at SIC. There was a need for it to be done and we were four or five people at the time we started. So somebody had to do it and I was willing and able. I was a hobbyist before joining SIC. I have done electronics, software, firmware, and mechanical design on all the products. I joined SIC as a draftsman and worked on every

one of the products.” Although the historical perspective lacks details, it provides continuity for the stories that are told.

1st consumable

According to the founder’s story, he developed the first consumable and then put together a special machine that manufactured this consumable from parts he gathered in junkyards. At that time, these consumables worked on other manufacturer’s machines. After a time, he decided to build his own SIC machine that would use SIC consumables, the result being Model-1.

Figure 3 shows the process that the first consumables appear to have gone through. Today, there are 16 categories of consumables built at SIC on specialized manufacturing equipment. New consumables continue to be developed, which drives the development of new SIC machines. Some new consumables also require new manufacturing technology, which can be either purchased or developed.

Model-1 machine

Model-1 was the first machine that SIC produced. Although the oldest machine, Model-1 is the top of the line when it comes to capabilities in this product line. It is capable of handling a number of different consumables that SIC produces, which makes it a versatile machine. Peter, who worked on this model says, “Model-1, which was the [first machine that SIC produced], got out on the market slowly so that you would ship one, there would be issues, and then you would fix it and ship more.” This simple process became a pattern that was established in the early years of SIC and is one of the patterns that can be seen in the development of products at SIC today. It is based on a symbiotic relationship between SIC and its customers, where SIC depends on its

customers' feedback to improve and develop its products, while the customers depend on SIC for a machine that would allow the use of SIC's consumables to cater to their own customers.

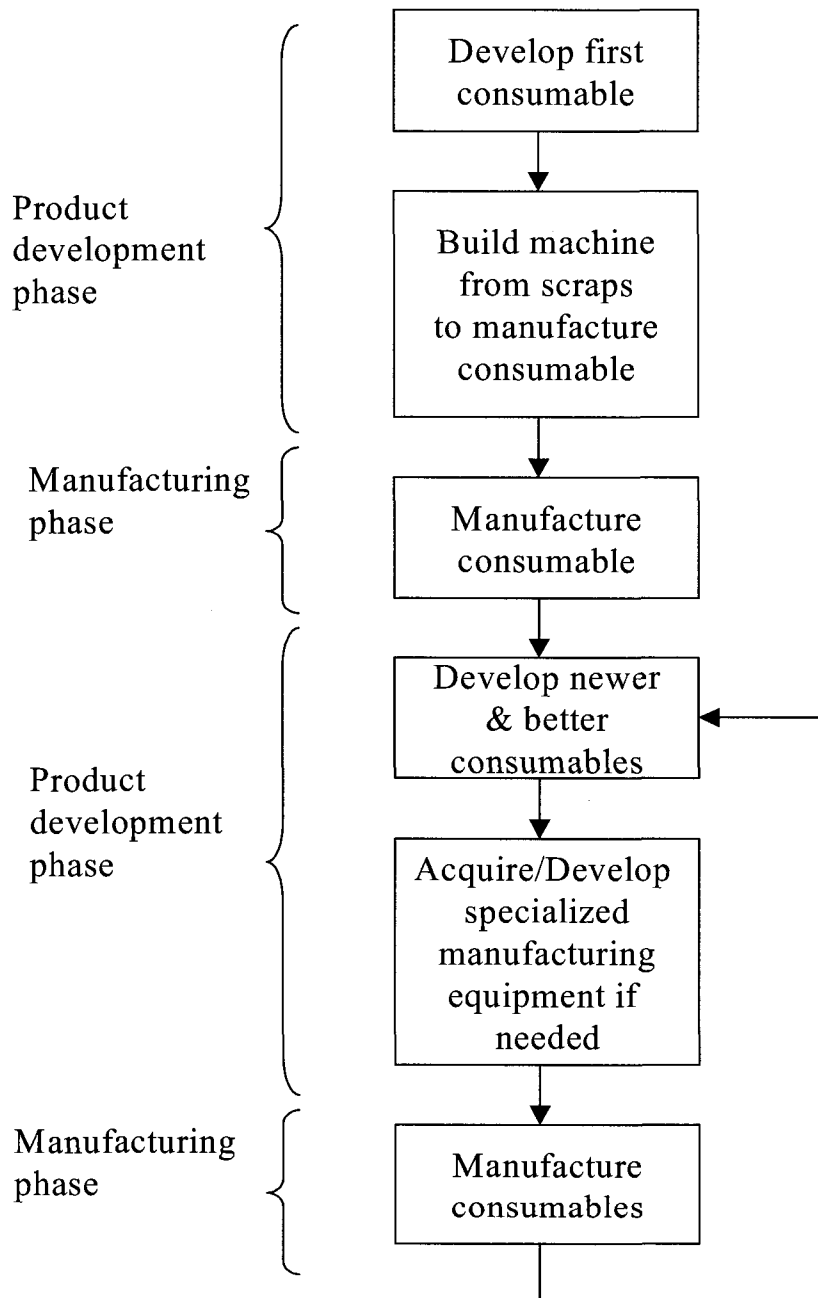


Figure 3 – First Consumables Development Elements

Although the flagship product in the product line, Model-1 still undergoes changes, both in the form of upgrades and added features or continuation engineering. Continuation engineering is fixing problems that are reported back from the field. Today, Model-1 is being manufactured by SIC Manufacturing and it is still “really a prototype that wasn’t [meant to be] manufacturable. It takes [many hours] to assemble.” Some say it’s “too old” technologically. Looking at it being assembled on the assembly line, there are many parts that need to be assembled and adjusted by hand as opposed to the other models in this product line, which have fewer parts and can be adjusted electronically. Nevertheless, it is still the model that can handle a wide variety of consumables. Furthermore, the “guts” of Model-1 are being integrated into a new product that will be discussed later. Building Model-1 allowed SIC to develop a variety of other consumables, which expanded its consumable offerings. Figure 4 shows the process that Model-1 appears to have gone through.

Model-2 machine

Model-2 was meant to be a replacement for Model-1. According to Peter, it was “meant to be more manufacturable than the Model-1.” A prototype of it was built and it worked. But since it did not fill a different position in the product line, it was set aside and not pursued. Some say that there have been numerous attempts to revive Model-2, but “some new product development pulled all the engineers off the project.” This means that another project came along that needed the resources. The reason for this decision can be understood by looking at the importance that the company places on external versus internal needs.

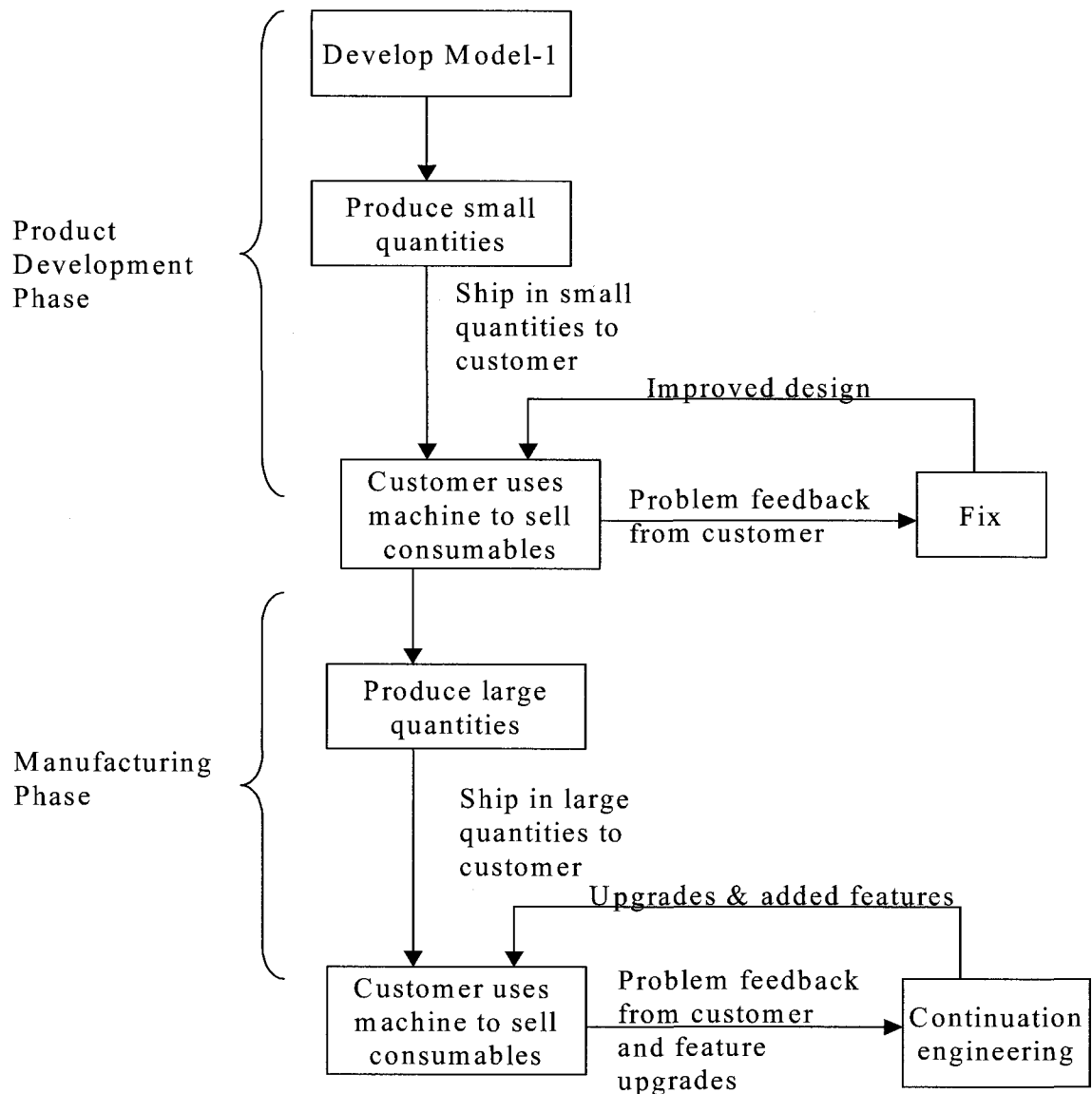


Figure 4 - Model-1 Product Development Elements

The external needs are defined as needs that lead to growth and resource acquisition, while internal needs are needs that lead to stability and control. The external needs focus on the external environment and flexibility in structure, whereas the internal needs focus on the internal environment and a control in structure (Quinn and Rohrbaugh 1983:369). External needs might require activities such as developing new products or

changing a product to satisfy a need in the market. Internal needs might require activities such as making a product more manufacturable or creating documentation. The former addresses the market needs, while the latter might address Engineering or Manufacturing needs. Although both are important, in a small company where many projects compete for scarce resources, one typically dominates the other. Model-2 addressed an internal need because it was to replace Model-1 as a more manufacturable product, without satisfying a new market need. The new product development, which was an external need, took precedence over the internal need. So, at this early stage at SIC, the external needs won over the internal ones. This pattern was established early and is still followed.

Model-3 machine

According to Peter, Model-3 is a product that has a limited set of features compared to Model-1 and handles only limited types of consumables. So, when Model-2 was abandoned, work was started on Model-3, which is smaller and less expensive than Model-1, therefore fills a different need in the product line. Peter also mentions that a lot of money was spent on tooling to make this model, which was technologically similar to Model-1, but more manufacturable. What was learned on Model-1 and Model-2 was applied to Model-3. This machine has emerged as a reliable and manufacturable model with electronic adjustments for manufacturing.

One of the differences between the development of Model-1 and Model-3 was that Model-1 was developed following a more experimental model, both in terms of technology and even market needs. By the time Model-3 was being developed, many lessons had been learned from Model-1 and 2, which were applied to it. So, Model-3 was being developed with a different level of confidence. SIC was now knowledgeable about

both the technical needs and market possibilities of this product line. The focus was to produce a quality product that was manufacturable, reliable, and could be sold for less than Model-1. Investment was made in tooling, which allowed a design that would be more manufacturable and reliable. This type of development takes much more time and money, and changes to such a product can be difficult because of retooling needs.

Model-3 is thus distinct since it satisfied both the external and the internal needs of the company.

The main difference between the development processes of Model-1 and Model-3 could perhaps be attributed to a higher level of confidence in the company's knowledge of the technology and market needs.

Model-4 machine

Every company has a legend. At SIC, it's Model-4. A local subsidiary of a larger company had developed a machine, which filled another gap in SIC's product line. This subsidiary was bought by SIC, which provided them this machine and its rights to it. The machine, which was a different technology than the other SIC machines, was modified after it was purchased, developed under an aggressive schedule with enhanced features, and shipped out to customers. Everyone, regardless of whether they had worked at SIC or not at the time, recounted horror stories about what happened next. One individual outside of Engineering said, "Model-4 was a disaster from what I hear. I wasn't here thank heavens." An engineer who wasn't at SIC at the time had this to say: "If you send out a product before it's ready, it'll come back to haunt us. No one wants to be put on the fast track to correct a problem like this. On the Model-4, the customer was screaming about the product. We had a 100% failure rate. All the product had to be

recalled. We had to scramble and make the next [revision] of the product and it took a lot of our resources. That's when we came out with the Model-5. That works well."

Another comment about this experience was that it almost took the company down.

This fear of being haunted by problems if the job is not done well, and having to scramble and develop a new replacement could explain the commonly recited anecdote about engineers never wanting to let go of what they design.

In analyzing this situation, if Model-4 had been developed using the same process as Model-1, it is possible that it would not have been a legend maker. The product would have been shipped out in small numbers, customers would have communicated failures back to SIC, the engineers would have responded with incremental changes and improvements, and the risk would have been minimized. Since SIC profits from consumables, the high cost of building the machines is not a drawback, as long as it facilitates the sales of consumables.

It is difficult to compare the development process for Model-4 and Model-3 due to insufficient data, but it seems that Model-3 was a known technology for SIC, whereas Model-4 was new, or at least unfamiliar.

Model-5 machine

An engineer who joined SIC when Model-5 was being designed said, "Model-5 was a complete redesign of Model-4. That project was done differently." Model-5 is sturdy and the least expensive model in this product line.

Some of the people who worked on Model-5 said that things were done differently. Sam, an engineer who worked on Model-5 said, "We had a feasibility study to get a plan, cost and time. Then the work was broken up among various engineers. We

built a prototype, tested it, did the pilot build and then production. It was a pretty smooth project.” Another engineer who also worked on Model-5 said, “Since that was a hot project, we had many engineers working on it and we had a good manager. He knew what he was doing.” It appears that Model-5 was developed much more cautiously. They wanted to be sure that when it was sent out, there were not going to be any major problems. The risk was minimized through what appears to be a more cautious and methodical development approach. The company’s reputation was at stake.

Model-P1 machine

Model-P1 machine was designed by another company some years ago. SIC received the prototype and documentation for it so that it could manufacture it. So, the development phase was done outside, but the manufacturing was to be done at SIC. Model-P1 is a sophisticated design, with a special consumable. Although some of the knowledge transfer from this outside company to SIC was explicit, there was much that was implicit. The prototype given to SIC was the output of an engineering team in another company, with whom SIC engineers did not appear to have had much interaction. Although the schematics of the electronics, the software, and the mechanical drawings were transferred in such a way so that the engineers at SIC could access and modify them, taking the product into manufacturing appears to have been a challenge. This part of the process, that is, development of the manufacturing plans, was the part of the PDP, which SIC needed to complete. Peter, who was at the company when the prototype of Model-P1 was received said, “Model-P1 was designed by an outside company. We got the prototype and documentation from them so that we could build it here. But when we

got it, we spent another six months or so working out the bugs, enhancing it, testing for compliance, and testing the firmware.”

Ryan, the line manager, explained that there were no manufacturing drawings. He worked with the engineer in charge to do what was needed to get the product in manufacturing: “It has many tiny parts. So I said we need to come up with instructions. First, we documented all the parts. Then [the engineer] and I documented the machine with instruction sets.” In this way, they came up with a system of putting the machine together. This special way of doing things between Engineering and Manufacturing is something that Ryan, the line manager, allows. His tolerance for ambiguity, his ability to work in this capacity, and his effort is what allows products to go from Engineering to Manufacturing at SIC. Ryan is the translator of engineering knowledge to manufacturing knowledge. In fact, he has determined the appropriate language: “Before we used to work off these big drawings. There were three leads and each interpreted the drawings differently. So now with these instructions, that doesn’t happen.”

According to Brannen and Wilson (1996:102), recontextualization is the evolution of meaning in a new cultural context. “Some technologies and processes [are] recontextualized to a greater extent than others. Processes with high embeddedness and a large tacit knowledge base [are] recontextualized to a greater extent than those with low system embeddedness and high explicit knowledge” (Brannen et al 1998:23). They define embedded knowledge as “the degree to which technologies and processes [are] more or less tightly integrated with other technical and social systems” (Brannen et al 1998:22).

It appears that the product underwent recontextualization when it went from an external engineering organization into SIC Engineering and Manufacturing. SIC Engineering made this product their own by spending time working on the product and doing what they thought was needed to make it meaningful for them. The line manager worked with the engineer on the project to document the product so that it would be meaningful for manufacturing.

Model-P1 also works with a specially designed consumable that was also designed by the outside design company. It fills a new market space.

Model-P2

This machine was developed by a Japanese company and they continue to manufacture it for SIC, with SIC's name and colors. SIC wants to upgrade the electronics and software, but the manufacturer has told them that they will upgrade the electronics, but SIC needs to find another company to upgrade the software. Therefore, the software upgrade is being done by another company. Peter explained, "We are trying to verify and check things out. The hardware is done in Japan and the software in England. We verify integration and give feedback to the people." So, in this case, SIC acted as the customer, giving feedback to those who are doing the development work for them.

Much like Model-P1, Model-P2 uses a specialized consumable, designed by an outside company. It fills a new market space also.

Summary

Although this historical perspective necessarily lacks detail and does not take into account those who were involved in product development at different times, it provides

some insight. The company has developed a number of consumables and machines that have allowed it to be profitable and grow from four or five employees to one hundred twenty. The Model-1 development process allowed SIC to learn about the technology and markets for such a product and to get on a footing where it could pursue further projects and growth. This particular model is externally focused, it allows for experimentation, learning, and growth, and depends on a symbiotic relationship with customers. It, however, did not produce a product that is very manufacturable.

There does not appear to be one PDP that SIC followed for these products, although, in some cases, the process for developing a machine appears to have been built on the previous one. For example, Model-3 PDP was built on lessons learned from Model-1 and Model-2, while Model-5 PDP was built on lessons learned from Model-4. Also, the process of developing these models (Model-3 and Model-5) appears to satisfy both the external needs, that is the market needs, as well as the internal ones, that is the engineering and manufacturing needs.

One advantage of a process that satisfies both internal and external needs is that the outcome is a product that is better engineered and manufacturable, while meeting a specific market need. However, even though this would have advantages, it does not support today's business model at SIC, which is to sell machines in low volumes and make profits out of selling consumables in high volumes. Therefore, the effort and expense in making a machine better engineered and more manufacturable may not, in any significant way, add to the company's profits in the volumes at which these machines are sold. So the internal needs are trumped by external needs, as will be seen in the following projects.

Another aspect of this model of balancing the internal and external needs is that it is perceived to require a longer development cycle. The concern is that the company would miss the market window because of the long cycle time when developing products for fast changing or newly developing markets. Furthermore, the company will not be able to get the kind of customer input that it does from a more externally focused PDP, such as Model-1.

It is unclear what led to the Model-4 disaster. The 100% failure rate and the total recall had a major impact. Some say that the product was shipped before it was completed, while others say the problem was the person in charge of Engineering at the time. If ethnographic data could have been obtained on the development process for Model-4, it could have shed some light on what went wrong in this process.

There are three instances where SIC has acquired products, although in very different forms and with different outcomes each time. One of these is Model-P2, where the product is designed and manufactured by an outside company for SIC, with SIC's business name and in SIC's colors. In this case, SIC is the customer. It requests upgrades and provides feedback on the performance of changes. Another example is Model-P1, where another company designed the prototype, but the design is owned and manufactured by SIC. The third example is the acquisition of the product that led to the development of Model-4. The acquired product came with an engineer, Mark, who develops proof of concept designs for SIC offsite. The acquired design was modified and developed at SIC, with the outcome being Model-4. So, this model of acquiring products may be used to obtain products or the design of products to diversify the SIC product line. Models-P1 and Model-P2 are products in a specific product line. To develop these

at SIC, special expertise would have been needed. Acquisitions such as these allow for diversification without first building this expertise. The acquisition of Model-4's precursor appears to have been for a different reason. This acquisition did not offer SIC a new product line, but a fast track development to a different model in their existing product line. The motivation behind this decision might have been the perception that it would require less development effort if they acquired an existing product and modified it.

CHAPTER 5: PROJECTS IN PROGRESS

Projects in progress include those that had begun before the fieldwork and that were still active. Table 3 shows the list of the projects in this category. The histories of these projects were collected as much as possible along with ethnographic data collection on the continuation of the project.

Table 3 - Projects in the Projects in Progress Category

	Projects in progress
Machines	Model-6 Model-7 Model-S Model-Q
Consumables	Auto-consumable Model-Q consumable

Before discussing these discrete projects, there is an ambiguous category of projects called “continuation engineering.” These ongoing projects consume considerable engineering resources and will be discussed first.

Continuation Engineering

Continuation engineering was estimated to consume 42% of SIC’s engineering effort (fieldnotes from bi-weekly meetings 2006:3). This was engineering effort spent on products that had already been released to manufacturing and it was also known as sustaining engineering. Problems that halted manufacturing, also known as “line stoppers,” were given the highest priority. One of the engineers said, “Anything that stops or slows down manufacturing is unacceptable and needs to be dealt with fast. [The

owner's] personal primary concern is product development. He takes for granted that you'll support manufacturing on the side."

Another engineer said in frustration, "There is another problem that I am starting to get involved with...I keep getting pulled off to go back and do fixes on past products. A lot of things I see are based on proper engineering not [being] done in the first place. It's not the people, it's just the way we do things." He concluded that it was very distracting and time consuming.

Continuation engineering is an inherent part of the PDPs at SIC. Although this is typically a function that can be performed by a unit outside Engineering, at SIC it is done internally. Any engineer, regardless of formal assignment, supports products he once worked on even after they are in manufacturing. This adds to the responsibilities and workload of engineers doing product development.

Model-6 machine

History of Model-6

Model-6 was a slightly modified version of Model-5. Small modification in the mechanical, electronics and firmware were made so that Model-6 could handle a consumable that was originally designed for another application. So the incentive behind Model-6 was to sell this specific consumable, even though there were no immediate customers.

This project started with Ed, the founder-owner, asking the manufacturing engineer, John, to modify a certain mechanical part on the Model-5. Since Model-6 was very similar to Model-5, through John's help Manufacturing was able to produce a small number of the modified Model-5 machines for engineering tests. One engineer had made

a firmware modification, while another engineer, Peter, had made some electronics changes to this modified Model-5. Then three prototypes were built for design confirmation. This was not a new design, but rather a modification of an existing design to produce a new product.

Model-6 during fieldwork

The product was being tested and characterized by the Engineering Test/Design Verification Test department. As a service to Engineering, this department performs tests on the engineering designs to see that the designs perform as required and reports the results back to the engineers. As a Quality Control function, they also perform tests on products being released to manufacturing to ensure that they pass certain tests. This function is generally performed by an independent department, although at SIC, the manager of this department reports to the head of Engineering. Still, the need for independent quality control is agreed on at SIC, although the result is blurred responsibilities.

Engineering was also preparing to release the documentation package for Model-6 to Manufacturing so that its workers would know how to build the product. Therefore, there were discussions between the firmware engineer, Bob, who was also the project lead on Model-6, and the manufacturing engineer, John, concerning the requirements for a release to manufacturing. These requirements were not written down, but were discussed and negotiated instead. Two things that were being negotiated were the form and contents of this documentation package. A new document control person had been hired by the new vice president of Engineering and he was setting up procedures for

documentation. This meant that there were no set rules yet, but that new ones were being developed.

Document control departments are generally a function of Manufacturing because they set up the documentation requirements to meet Manufacturing needs; Engineering does not normally dictate these needs. This is another example of the blurred responsibilities between different functional groups. Accordingly, there was conflict as to what type of documentation and what level of documentation was enough. There were those, like Bob, who believed that a compromise should be made as a short-term solution, so that an interim process would allow this product to be released to manufacturing. On the other hand, there were those, like John, who believed that a total change was needed and if a full set of documentation was not completed at this stage, it would never be done later.

This situation raised several questions. What was done before? Why was there a need for change? In what way did this make the product easier to handle internally? What change would this bring about in the interaction between Engineering and Manufacturing? The answers to these questions differed. Someone in Engineering said, “[Engineers] hate not having things properly documented ...because they want to do it right.” Another individual in Engineering said, “They [engineers] don’t like the fact that the documentation is all wrong on all products.” Some said that it was what was needed for a formal release to manufacturing. But another person in Engineering said, “I think we need to do things slowly,” implying that they needed to take small steps towards the change that they were looking at implementing. In this case, the change was defining the procedure and documentation necessary for releasing a product to manufacturing. It

almost seemed that being able to satisfy such an internal need was a long-awaited luxury. The new document control person had enabled them to have this option.

Documentation defines a product explicitly. This documentation is part of the hand-off from Engineering to Manufacturing. It includes a bill of materials that defines the parts needed, drawings that define the parts, assembly drawings that define how the parts are put together, and various other specifications that define various requirements for the manufacturing of parts and the machine. At SIC, there do not appear to be formal rules on how to do this; it seems to be an ad hoc negotiated process.

In another project, described later, this hand-off between Engineering and Manufacturing is done as a joint effort between the two departments, while in others, the necessary documentation starts in Engineering and is finalized in Manufacturing. How things are done seems to differ for each project. As one person on the Manufacturing side put it, "Engineering is a development department, but also a support for the line. They need to work with [Manufacturing] and to learn what is needed for manufacturing support. We need to communicate, work together, learn from each other." So, at SIC, the line between Manufacturing and Engineering appears to be blurred; this has allowed things such as manufacturing release documentation to fall into a gray area where a close interaction between an individual on the Engineering side and one on the Manufacturing side enables the release of a product to manufacturing, even without a complete or formalized documentation package. The manufacturing release is continuously negotiated between Engineering and Manufacturing.

For Model-6, however, new rules were in the process of being defined as to how explicit the knowledge transfer between Engineering and Manufacturing had to be. In effect, this was also defining a new relationship between these two functional groups.

The more explicit the documentation, the less need for the groups to interact, and the less ambiguous and more defined that interaction would be. The debate I observed on Model-6 was due to a disagreement on the extent of this change in the rules of interaction. Defining clear boundary lines between Engineering and Manufacturing would reduce ambiguity and require more standardized ways of doing things.

Documentation satisfies an internal need; it does not directly affect the external or customer needs. Due to limited resources, external needs take priority over internal ones. For instance, one of the engineers who was working on the documentation for one of the products was pulled off to work on the design of a new product. So, instead of tending to the internal needs, the engineering resource was directed at an external need. Such reallocation upset those people who were internally focused. The Model-6 project was put on hold at this point. It appeared that the reason behind this decision was a lack of interested customers.

Model-6 summary

It appears that people at SIC decided the rules based on their experience, skills, and focus. These are then negotiated, and not just applied. Therefore, depending on the individuals who are doing the negotiation and on the nature of the particular project, projects can follow different processes. So, the way things are done is not rule based, but develops through an interpretive approach and negotiations. Rules become, in effect, ex post facto accounts of practices.

The project to develop Model-6 was founder-owner initiated and motivated by a need to support a special consumable. This is consistent with the SIC business model that consumables are what make the company money and that machines are there to support the sale of these consumables.

The functional responsibilities between Engineering and Manufacturing groups are blurred. For instance, the Document Control function is generally under the control of Manufacturing, but at SIC, it is in Engineering. Also, the Quality Control group is an independent group, but at SIC, it is under the domain of Engineering. This affects the way things are done and the reasons for this are not clear. The new vice president of Engineering felt very strongly about having proper documentation and hired a document control person because he saw the need for one. He felt that the Quality should be separated from Engineering. But this did not happen during the time that he was there.

Model-S machine

History of Model-S

This project had begun a couple of years ago, driven by a new market for a specialized consumable. It required the development of a brand new machine, which was Model-S. Its beginnings seemed to fit the pattern of the other projects at SIC where the founder-owner worked with a mechanical engineer to develop a proof of concept model.

Proof of concept in this case means that an idea is turned into a rough physical model to allow the engineer to see if implementation is possible or feasible, and if the model can perform in ways envisioned. It gives shape to the mental idea and allows the development and testing of a number of different implementations.

A few of these models were built by Engineering, as opposed to Manufacturing, and shipped to customers worldwide. Each time a few machines were shipped, they generated feedback from customers, which was incorporated into the design of each subsequent machine. Then a few more prototypes were built and sent to more customers and the cycle continued. So, over the past two years, 40 of these prototypes, with many different revisions, were built and shipped, generating enormous sales of consumables, and paying for the development of the product, based on customer feedback.

According to some, if this machine had not been developed in this manner, it would have missed a market need. One of the engineers who worked on Model S said, “We have a long cycle time. By the time production is making it, the product becomes obsolete.”

This process allows customer feedback, experimentation, implementation, and production in a very similar way to Model-1 was developed. Mark, the mechanical engineer who developed the proof of concept for Model-S said, “[Model-S] is an enabling technology. We make small numbers and send them to customers, who help us with our learning curve.” For brand new products, such as Model-S, if there is no interest from customers or trade shows, then SIC doesn’t pursue the concept. Also, there are no great investments made in tooling for manufacturing of these machines because the machines are low volume. According to Ed, the founder-owner, “We don’t need cheap solutions because we don’t have high volumes... The idea is to use these machines to sell consumables.” A customer will buy one machine, but many consumables, so reducing the cost of manufacturing the machines is not a priority. This business model also dictates the process for developing products. In this case, Model-S was developed over a

period of time, but it is still is not considered a machine that can be manufactured inexpensively because the focus of the development was to make a product with the right features that worked, as opposed to making a fully manufacturable product. As the founder-owner said, the idea was to get this machine out into the market place so that they could sell consumables.

However, there are contradictory views on the way that Model-S was developed. Some in Engineering say, “We are trying to get away from this [way of doing things]. The product [Model-S] has been around for two years and it has not yet been released to manufacturing.” It is not clear why there is such a disconnect between the business model that the founder-owner has and others in Engineering.

Much like the Model-1 process, SIC found motivated customers who were interested in the specialized consumables and were willing to work with SIC in developing the technology needed for this new and profitable market. This important symbiotic relationship with their customers allowed them to pursue the market. The customers were aware that they were getting prototypes and communicated performance issues back to SIC from the field. One of the people outside of Engineering said, “Customers are ...very accepting of problems because we call it beta and they have the mindset that they can call us and tell us what the problems are. They can call us and talk to us about it. This kind of opens up a way for us to communicate with them. It’s unusual to have one and a half years of beta, but part of this is the market.” Another said, “We [Engineering] built a number of different versions of this machine, A through L. We built A through L in about a 24-month period. The reason for this was to sell consumables... We made some versions of each model and sent it out.”

The consequences of this process were described as follows: “The way it was done allowed us to evolve our learning.” This learning took place as they captured the market and made lots of money for the company. This process allowed the development of a very unique and sophisticated machine, such as Model-S, and of a new market. “That’s helped us learn about the market and what the customers use...” This symbiotic relationship allowed SIC to learn what the customer wanted, how the customer used their equipment, and the problems with the prototype units. This was, in effect, the market research portion of the PDP. After two years, the machines and the consumables have been fine tuned to customer needs. Even though the machines are expensive to manufacture, SIC is able to follow its business model of making money from the sales of the consumables.

The engineer who worked offsite and the founder-owner designed the first few revisions of Model-S. The consequent models were developed further, debugged, and manufactured by Sam, the mechanical engineer at SIC. The engineering test/design verification test group was bypassed; that is the Quality Control function was bypassed because Manufacturing was not involved in making these units that were being shipped to customers.

Figure 5 shows a summary of what appears to have been the product development history of Model-S. To sum it up, research, development, and manufacturing of these prototypes all occur in Engineering. There are many benefits to this process. One is that that it helps SIC come up the learning curve with the help of its customers, who are using these machines to sell consumables to their own customers. The implementation of the customer feedback allows the development of a machine that caters to customer needs.

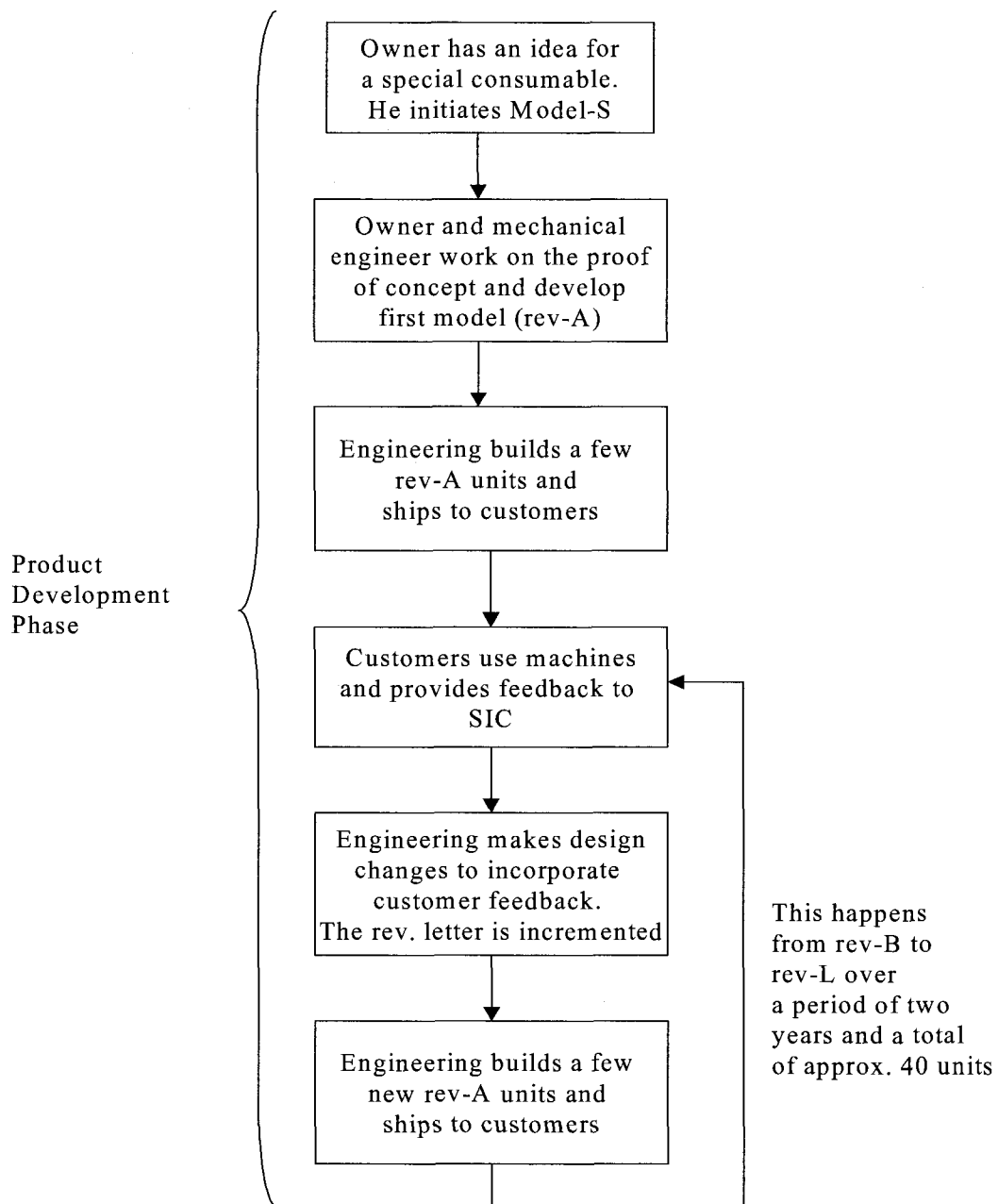


Figure 5 - Model-S Product Development History

The risk of development is minimized, particularly in areas where both the technology and the markets are new. This process fits the business model of making machines to sell consumables to make a profit. Developing machines such as Model-S

can be very expensive. This process also allows the development cost to be paid through the profits made through the sale of the consumables, thus reducing the financial burden of developing innovative products on a small company.

Model-S during fieldwork

Engineering was getting ready to release Model-S to manufacturing so that Manufacturing would build the units in the future. The mechanical engineer who had worked on this machine was involved in many different aspects of the development that might normally require many different people with different expertise. “I make, modify, and build it while I am thinking about it. It’s much faster. If you give it to the machinist, you need to have it well thought out and designed in CAD and then feed it into the machinist queue, which takes days. I can do it myself fast to prove the concept.” This basically describes the process of how machines are developed and how prototypes are manufactured by Engineering. It also describes the different functions that the mechanical engineer fulfilled. He said, “Most engineers don’t know machining. The more you know about manufacturing processes, the easier it is to do stuff.”

To release this product to manufacturing, the mechanical engineer working on Model-S in Engineering had documented assembly instructions for Model-S. He was working with the line manager in Manufacturing on assembling the first machine. It’s important to note at this stage that this was the first time anyone from Manufacturing had seen how the product was being put together, even though this product had existed in 12 different revisions for the past two years and about 40 units had been shipped to different customers.

The mechanical engineer and the line manager were adding parts to the assembly one at a time and the assembly instructions were being edited as needed. All the parts needed for the machine were arranged behind them for easy access. This was taking place in the machine assembly area, which was a part of Manufacturing. There were no assembly drawings, but a set of assembly instructions, which had color photos of parts, with instructions clearly marked. There was also a bill of materials that listed the parts needed to assemble the unit. One engineer commented, "This first one will take a long time to make because they need to find some parts, some parts don't fit and have to be adjusted, some parts need to be de-burred. We note all these and go from there." This still seemed like assembling a prototype and appeared very much like a learn-as-you-assemble kind of process, where they were both learning from the process and each other. Although the engineer had assembled many of these, he had not considered manufacturing in his previous assemblies. Now, together, the line manager and the mechanical engineer were trying to make it so that the assembly of the product could be made more feasible for manufacturing. The idea behind this was to get most of the assembly details worked out so that the assemblers could do their jobs without having to worry about what type of screw to use. In other words, they were getting the details all figured out for the assembly line. All of these details would be incorporated in the assembly instructions that the engineer had produced. This interaction between the engineer and his manufacturing colleague was the process of recontextualization (Brannen et al 1998) of this technology and process. According to Brannen and Wilson (1996:102), recontextualization is the evolution of meaning in a new cultural context. These assembly instructions for Model-S prepared by the mechanical engineer were

being translated into a form that would be meaningful to those who worked on the assembly line. The mechanical engineer passed along his explicit knowledge through the written assembly instructions and photos, and his implicit knowledge verbally and by helping in assembly. The line manager assembled the machine using the assembly instructions, asked questions, and noted what could be changed to make things more explicit or more integrated into their production system.

This translation went through another level of recontextualization when the line manager trained the assemblers and got their feedback on what was meaningful to them. As he put it, “they are the ones who are going to be doing it.” This implied that it had to also be meaningful for the assemblers. The line manager passed along his explicit knowledge through the written assembly instructions, photos, and by showing the assembly people how things should be done. In return, they provided comments, asked questions, and made suggestions on further improvements. Anything that was still implicit was documented and made explicit. The goal was to do what was needed so that anyone on the line could be trained to assemble any of the machines using explicit assembly instructions.

During this time, I observed the line manager look at parts and decide if certain tooling would be required to put subassemblies together. The purpose of this was to make assembly easier and faster. He looked also to see if he could recommend the use of parts that were already in house to Engineering, as opposed to the using brand new ones. So this knowledge transfer was not just from Engineering to Manufacturing. Since this was just the first manufacturing model, the assumption was that there was still room for change. The line manager would then communicate this information back to Engineering

and see if they could change some parts to in-house ones, that is, parts that were used in previous machines. All of this was done for the purpose of making things easier and faster to assemble, thus further recontextualizing the process and technology. The second machine was built using the instructions that had been appropriately translated.

For the past two years, Engineering had manufactured the machines that helped sell many consumables. Now the product was being released to manufacturing so that Manufacturing could take over the manufacturing function because an order of 50 Model-S machines needed to be filled.

This process of hand-off is still part of the development process. Planning for manufacturing on this project is not something that occurred totally in Engineering, but also during manufacturing. This does not actually make the machines more manufacturable, but it allows Manufacturing to build them. That is, it is the minimum requirement to get through production. The process of continuous iterative design for Model-S made it difficult for Manufacturing to get involved during the design phase. Those on the manufacturing side commented that it was a waste of time to get involved because the product kept changing. So the process where the line manager built the first unit was, in effect, to make up for the lack of manufacturing input.

In some industries, the front-end activity required before product design, which is called research, may or may not be considered a part of the PDP. In the research phase of new products, new technology is developed for incorporation into new products (Otto and Wood 2001:6). In large organizations, research is separated from the PDP. Research is used to develop new technology to the point that the product development teams can readily adopt it. In this way, product development does not get bogged down by research

(Otto and Wood 2001:6). At SIC, for Model-S, the research phase was included in the PDP. The line between research and product design was blurred. At times, research was not just the front end of product design, but the two phases seemed blurred as the product was developed.

It is possible that the machine could have been designed to be more manufacturable if manufacturing input had been present during the design phase. Design for manufacturability is a function that incorporates design features into a machine during the development phase to make it more manufacturable. Design for Manufacturing is not likely to occur in the research phase because it is not a relevant function to this phase since it is an experimental phase where frequent changes may occur. However, it is a relevant function in the development phase because the product is nearly ready to be manufactured. At SIC, research and development are blurred and proceed together. So as the engineer is incorporating customer feedback as a research function, the product is also undergoing development, that is, the design is being improved, certain design for manufacturability features are incorporated, certain documentation is done, and so on. But what manufacturing saw was a product that was constantly changing, so the process was more akin to research. Therefore, manufacturing did not get involved to contribute to design for manufacturability prior to the machine being released to manufacturing. Still, it is difficult to see how Engineering managed to manufacture 40 machines without manufacturing getting involved. This means that the design engineer was involved in research, development, and in manufacturing, all within Engineering. In fact, in this particular case, Engineering was acting as a company all on its own, which interfaced with the customer, did research, product development, and manufacturing.

The delivery of the wrong part by a bearing supplier exemplifies the cost of doing business this way. This occurred the first time that Manufacturing was going to build the machines. A bearing that SIC had ordered was correctly specified by Engineering at SIC, but was incorrectly filled by the bearing supplier. This caused anxiety and delays. It also caused some debate around the issue of why these parts had not been ordered ahead of time. Since Manufacturing had had the bill of materials for at least four months, the question that arose was why some of these new parts had not been ordered much earlier so that sub-assemblies could have been started. Problems would also have been detected and dealt with earlier to minimize delay. The debate was that since Manufacturing had known that such an order had to be delivered, they had not ordered these parts in a timely way so as to allow for such problems to be corrected without causing schedule slips. A margin of error had not been incorporated, for whatever reason. At this stage, it appeared as if Engineering and Manufacturing departments had not worked to the same plan.

Another serious issue, which was both a vendor issue and perhaps also related to how things were done or to lack of resources, further added to the stress of those working on the project and the delayed shipment. Some of the parts that came in did not meet the specifications drawn up by Engineering. This problem had not been caught when the parts were received from the vendor. Now, there was no time to send them back, so the engineer machined them himself. This was the mechanical engineer responsible for the design of Model-S. He was also involved in helping Manufacturing build these machines and now he was going to be machining the parts. When I commented on the number of hats he wore, he said, "We do what we need to get the job done." This was not just what he said, but it was what he actually did. I noticed that there were various other problems

with parts from vendors that needed to be changed during this process. Some pushed for a design change for the next build of these machines.

An older technology electronics board had an unusually high drop out rate because the vendor was apparently putting them together by hand. This high drop out rate was a concern because enough boards had not been ordered to compensate. This board was also used in other machines. As one individual put it, "They've scheduled and planned 50 Model-S's. They have bought 51 sets of parts, which would be OK for a mature product, but it isn't for something like this for the first production run." It was not clear why this had occurred. Some said that better planning would have allowed an earlier start on new parts and therefore more margin for error on a new product for manufacturing. It was unclear why this had not happened or who was responsible for the overall product. Perhaps one reason for what had happened can be explained by the following comment made by a person in Engineering: "Things should be more routine than they have been. It seems that everything we do is an exception to the rule. We shouldn't have to struggle to figure out how to do things that can be routinized." For this individual, the release of a product to manufacturing should have been routine. At SIC, this process was different for different products.

It appeared that no one was responsible for the overall process. Each department was doing its own thing and there was little coordination or communication between departments that interfaced across projects. These problems discussed above caused serious delivery delays, not to mention a stressful environment for engineers.

Another issue that came up during this rush to manufacture and ship these Model-S units was that one of the parts was mechanically wrong. The design of one part that

interfaced with it had changed, but changes had not been carried through for all the others. So there was a mismatch between two parts that needed to fit together. Due to the rush and anxiety to ship, this became very stressful for the engineer on the project. One of the explanations that was given to me by some of the engineers was that because of the numerous iterations that took place on Model-S, without allowing time for the documentation to catch up or for a systems test with each change, these kinds of mistakes were not only to be expected, but really inevitable. Another comment I heard from a number of different people in Engineering and Manufacturing was that the Model-S production release had turned into a mess “because there was no process.” One engineer said, “Things can go wrong by not following proper engineering processes.” This process was explained as follows: “Something like ISO allows you to have everyone bobbing up and down in step, even if it’s not the best step, at least it’s the same step. In larger companies, technicians do technician work, electronics engineers do electronics, mechanical engineers do mechanical engineering, and so on. In a small environment, you do what ever is required to get the job done. [So] it adds chaos. It’s something that runs on its own. Now you have many heads bobbing up and out of sync doing their own gig. In a two-man operation, it’s essential. Even here, it can be [essential] as long as the interface between departments are properly structured.” He perceived that a process or a more rule-based way of doing things would reduce some of the chaos that he saw and allow people to work more in concert with others, particularly at the boundary between different groups. So, everyone at this stage was doing whatever he or she could, but lack of rules to follow had made things much harder. Specific examples given were the

communication process, or lack thereof, between the various departments and between SIC and outside vendors.

Another consequence of this process was what came up in a status meeting for the manufacturing release of Model-S. A specific design issue was raised at this late stage. The fact that this kind of issue was being brought up when the product was going into Manufacturing prompted an engineer to comment, "this is happening all over the place and people are getting hammered." He was indicating that the problem was systemic and affected other projects. That is, problems were arising in different projects and people were having to scramble to fix them under pressure. Model-S had been under development now for two years, but it looked like there were still some design issues that needed attention.

It is not clear why this was happening. Some thought that the machines were just prototypes and had problems. What is meant by prototype is that Engineering had been putting together these machines for shipment to customers. So the machine had not even gone through the Quality Control functions. Since these prototypes had allowed the company to make money from the sale of consumables, the quality was not seen as an issue. How quality was incorporated into SIC's business plan or if this was considered a quality issue by everyone remained unclear, as did who defined quality in this type of process. One of the views expressed by an engineer who opposed this type of PDP was "The original party line is that we want to get customer feedback on features, but in reality, this approach has sold a ton of consumables. In fact, I asked Ed if we could get some customer feedback on features. He said no. No customer would be willing to do

this. They don't have time or the interest... we haven't gotten any valuable feedback on features."

There are some difficulties with managing such a development process. One such difficulty was described by an engineer who worked on the project: "Each time we built the prototype, it was shipped to customers..." The problem with this approach was that the engineer didn't have a machine to work on any more, so further development was hampered by lack of available machines. Another problem was expressed by another engineer: "We build the machines and need to tune the process for different consumables. Once you ship it, you need to make another machine. A lot of these parts for these machines are one off," by which he meant they were custom-made, one at a time. So to build another machine that acts the same way was a challenge. This made development of these machines very difficult and a time consuming venture for Engineering.

Others expressed similar views. That is, it was difficult for Engineering to work on the machine to improve its design when the product was being developed this way: as soon as a machine was built by Engineering, it was to be shipped to a customer. Therefore there weren't any machines available to work on and to fully test and characterize. An individual made the comment "The main problem is that they are willing to get the product out the door if it works most of the time." It appears that there was some ambiguity in the area of quality as seen internally.

In this case, it is not clear how the decision to release Model-S to manufacturing was made. This handoff to Manufacturing required Engineering and Manufacturing to work closely together. Since SIC had a large order for shipment for Model-S at this point, perhaps a decision to release to manufacturing was made based on the numbers

that had to be built. Up to this point, Engineering had been putting these units together for shipment to customers in smaller numbers. It is not clear what criteria were used to decide that Model-S was ready to be released to manufacturing because of the absence of an explicit process or the presence of a process that was not the same for every product.

Model-S summary

Figure 6 shows the process that Model-S appears to have gone through and would be likely to go through after shipping to customers. It is similar to the process of Model-1. This is a highly externally focused process. In the process of developing Model-S, Engineering performed many different functions; this included research, development, and manufacturing. The skills that the mechanical engineer on this project possessed were also diverse and crossed different functional groups; some of these were machining, design and development, and making prototypes. The market research function is very much a part of this process.

The advantages to this way of doing things are many. For new technologies and new markets, it reduces the risk of entry by limiting the resources required to test out the market. It is a fast and inexpensive way of finding out if a product has potential. It also allows for the development of innovative technologies to be financed with the sales of the consumables that it enables. It is also a process that allows a product to evolve according to customer needs. This process is possible only if the company's customers also benefit from it. In this case, SIC would make money by selling its consumables, while the customers would make money by offering a service to their customers using SIC machines and consumables. So they would have an incentive to work with SIC to develop this technology.

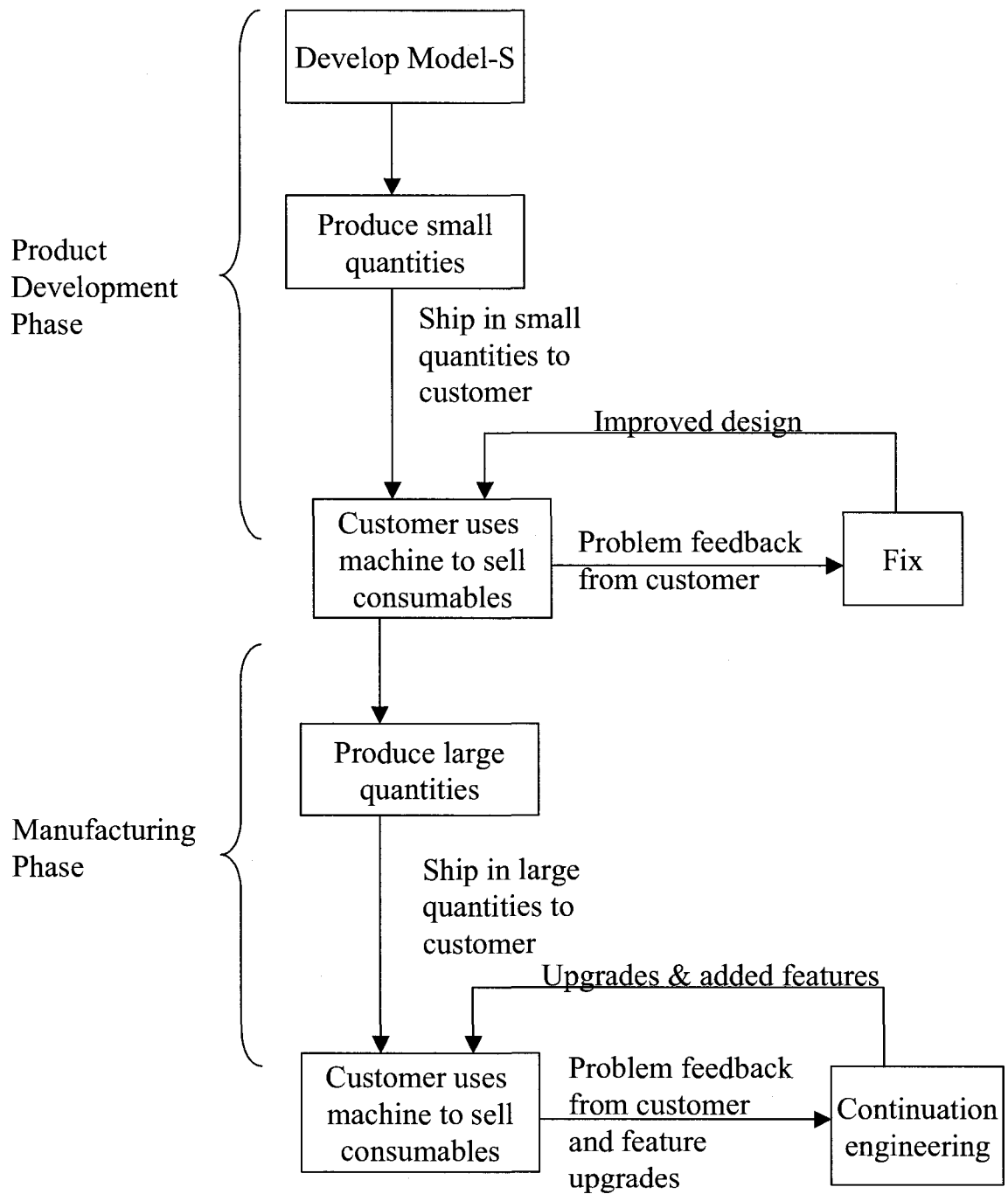


Figure 6 - Model-S Development Elements

This way of doing things, however, has consequences, which, if known, can be addressed. These have been described in detail above. The internal needs appears to be sacrificed for external needs. The product remains in Engineering, where almost the whole PDP occurs. There does not appear to be an outside person who, much like a project manager, would facilitate communication, planning, and coordination between Manufacturing and Engineering on a project basis. This causes problems. Although this process satisfies the business model, neither the business nor development models are explicit. It is difficult to see what or how quality fits in the process. Often the criteria used for going to the next step are not clear, for instance, the decision to release the product to Manufacturing.

More details about what happened next to Model-S are provided later.

Model-7 machine

History of Model-7

Model-7 is a modified Model-1. This machine is sold with a Model-S to produce a quality of output for the special consumables that Model-S handles. Much like Model-S, the founder-owner and a manufacturing engineer, who modified a Model-1 to build Model-7, started the project. Prototypes of Model-7 were built in Engineering and shipped to customers worldwide with each Model-S.

The story of how it all started is told by an individual in Engineering:

“Ed was working with the manufacturing engineer to make changes to the Model-1 for the first version of Model-7. So the first few units were that way. The marketing person and another technician built some more of those units, which went out to customers for feedback. Then Ed was still experimenting. He decided he would do some firmware changes instead of mechanical...He was able to get some good [results] that way. Then Jim [mechanical engineer] was given the unit that Ed was experimenting

with to do improvements. None of the ones that Jim worked on has gone out to customers. The machines that the marketing person has built had 20-30 parts that were different from Model-1. Ben [the marketing person] sent many of these to customers. He keeps track of it. The ones that Jim is working on have less than five parts that are different. Ed's ultimate goal is to have one machine that can do all the different consumables..."

Another individual told the same story from a different perspective.

"At first Ed modified Model-1 so that they could be shipped to customers. These were mechanical changes and calibration changes that he had made to Model-1. When Ben started, he took apart the machine and with the help of John [the manufacturing engineer] tried to document what changes Ed had done. This was to take the burden off Ed. So they were developing the product with a developing market. They took 15 off line and made changes to a dozen pieces, that then with Model-S were shipped off to a customer. In 18 months, they shipped off about 15 machines, but this translated into many consumables. So now, they are building to order...John [manufacturing engineer] made drawings to get the machine shop to do parts so that they had some consistency. Ed was building these to order before that. The ones that now Jim is working on are the same. Jim has done lots of experiments that have eliminated parts and simplified the design. So this is closer to Model-1. He tested to see if the changes Ed had made were needed. He found that only a few were needed. He has also been doing documentation and so on. He is doing what I call productizing it. Prior to Jim, John and Ben had to get parts built in house to get the Model-1s modified. Now production is going to do it all."

These stories are very similar. They both tell the story of how this product was developed. The founder-owner had an idea and made certain changes to prove the concept. He did this by building different prototypes and shipping them to customers for feedback. The marketing person and the manufacturing engineer who took over documented these changes so that they could produce these prototypes more consistently. These prototypes, much like Model-S, were manufactured in Engineering, on an as needed basis. They were shipped with each Model-S.

The marketing person, who has a masters degree in mechanical engineering, was involved in getting the changes documented and also put the product together physically

for shipment to the customer. This is a function he performed for Engineering because Engineering was manufacturing these units for shipment to customers. This meant that he worked outside his functional group. In fact, although he worked in Engineering to put these units together, he was actually doing something that the Manufacturing group would normally do. So, he worked not only outside his functional group, but also outside of the group that he was helping.

For reasons that are not clear, the mechanical engineer, Jim, got involved to develop and characterize the design, make the machine operate consistently with a minimum of mechanical changes, and make it manufacturable. This is what one of the individuals called productizing. According to Otto and Wood (2001:6), this research is used to develop new technology to the point that the product development teams can readily adopt it. Thus, Jim began a new phase. The phase prior to this can be regarded as the research phase, where the proof of concept for the new Model-7 had been performed to the point that Jim took over. He worked to develop and characterize the product and make it ready for manufacturing. So, unlike Model-S, the research and development phase for Model-7 were done in parallel, by different people, as distinct projects.

Model-7 during fieldwork

Jim, who worked on Model-7, frequently consulted the founder-owner and the marketing person on the quality of the output. There was no explicit documentation to indicate what changes in the machine's firmware would produce a specific change in output. These three people involved in fine-tuning the output quality appear to depend on experimentation and much implicit knowledge. The engineer who worked on this said, "Before I didn't have much experience with [how to control the output of the machine]."

When I first started, I really didn't know. But now, by doing a lot of different [experiments with the machine], I've learned through experience what parameters affect what. Also, I have good documentation to remind me what I've done. You can change a lot by changing those firmware parameters." He needed to convert this knowledge gained from experimentation to some external form so that he could remember what he had learned. Of course, if he left the organization, his knowledge would become implicit again and the newcomers would have to start over, unless the documentation were useable by others. This is a steep learning curve and likely to be expensive to build up or to lose. When I asked him what parameters would need to be changed to fix a problem, he said "Oh, it's complicated. There are a few of them that I need to try out." So even when he thought he knew what needed to be done, he still had to experiment. It's too complicated and there is a lot of tacit knowledge that's built through experimentation. Furthermore, quality is tactile and judged visually, so it is somewhat subjective and based on tacit knowledge.

Jim showed me hundreds of experiments he had done and the subtleties in the results that differentiated good and poor results. He had photographs of what happened with the machines and where the problems occurred after they were used for a while. He also talked about how slight firmware changes or calibration differences could make a big difference in the quality of how a machine worked and how it handled a consumable. He had learned all this by trial and error, and documented it so that he would not forget what he had learned. He communicated his findings with the founder-owner and the marketing person by showing them the output and asking them for their feedback. Each would give him different ideas to try.

Model-7 and Model-S were both being prepared to be released to manufacturing at the same time. However, the situation with Model-7 was very different from Model-S when it came to manufacturing release. Jim said, “The machine is 95% same as Model-1, which the Manufacturing knows how to build... We’ll work with production to get the first ten Model-7s built.” The release for Model-7 was not the same as the release for Model-S because of this factor. Model-7 was much simpler and did not involve the same close working relationship between Engineering and Manufacturing that Model-S had required. The engineer provided the necessary changes to the line manager in Manufacturing. Manufacturing didn’t appear to need much help because they were already very familiar with this machine. The engineer said, “Manufacturing had pretty much built these by themselves based on their knowledge of building Model-1s.” He was referring to the first few units that Manufacturing built after the Engineering hand-off of Model-7.

Model-7 summary

Figure 7 shows the process that appears to have been used for Model-7. Although this is externally focused, it is different than Model-1 or Model-S. It appears that Model-7 has undergone more distinguishable research and development phases. The research phase is where the proof of concept and experimentation of different approaches are done, while the development phase is where the output from the research phase is developed for consistency and made more manufacturable. These phases appear intertwined and difficult to distinguish in Model-1 and Model-S.

The marketing person had a mechanical engineering background, which allowed him to function outside of his functional group. This demonstrates how people involved

in product development perform tasks that are outside their functional responsibilities.

Much like the mechanical engineer who worked on Model-S, this type of skill is another factor that drives PDPs.

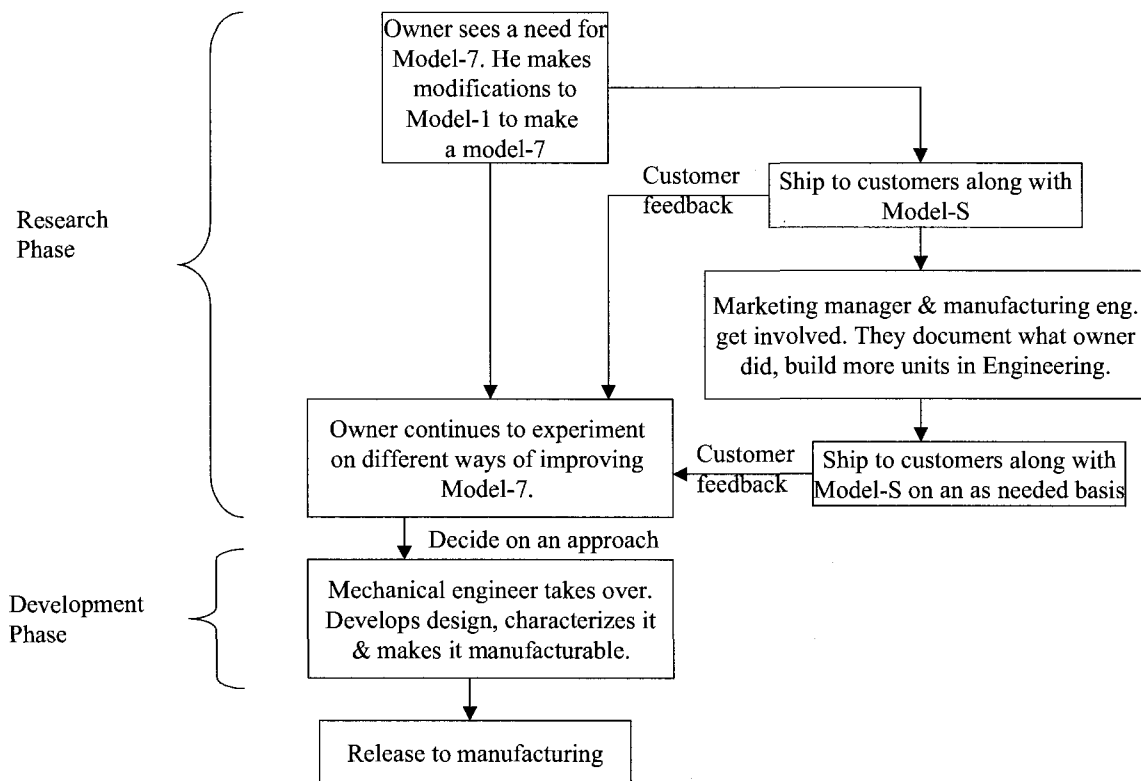


Figure 7 - Model-7 Development Elements

These practices have some advantages. The research phase was fast and did not require too many resources. It allowed feedback from customers to be incorporated into the product. The development phase then produced a machine that was consistent in function and manufacturable. Alone, Model-7 would not have been a product; it was developed to support Model-S. Precisely what motivated this separation of research and development is unclear, and may reflect Jim's role in the development or other factors.

More details about what happened to Model-7 are provided below.

Model-7 and Model-S

Model-7 and Model-S during fieldwork

The first few machines of Model-7 and Model-S that were now being built by Manufacturing were for design verification test. This is where the engineering test/design verification test department took some of the first units built by Manufacturing and tested them to simulate how a customer would use them. Everyone talked about this way of doing things as if it were the normal process, although it was not written anywhere. It seemed to be the next step for the product that everyone took for granted and agreed on. This design verification test was, in effect, the Quality Control portion of the process. As mentioned before, at SIC, this function was in Engineering and posed a certain conflict of interest. If and when problems were encountered in design verification test on the first few units built by Manufacturing, Engineering was responsible for correcting them; thus the conflict of interest.

Model-S and Model-7 were machines that were designed to work together. They were manufactured and shipped together from Engineering, but they were now built by Manufacturing. There appeared to be a different process for making a decision on whether these products should be shipped to the customer. There did not appear to be a formal process for making this decision; that is, no one was sure about what criteria would be used to determine if these products were ready for shipment. So even though these products had been shipped to customers as prototypes, since they were now built by Manufacturing, it appeared that a different set of criteria was needed to determine whether they should be shipped. As one individual noted, "In the absence of a quality person [i.e. a Quality Control individual], everyone needs to be able to make a decision.

It needs to be a decision owned by everyone.” This comment needs clarification. The person in charge of design verification test is also the Quality Control person. However, she reports to the head of Engineering and does not have the authority to determine if something should be shipped or not.

To decide whether Model-S and Model-7 should shipped, a meeting was called where everyone who was associated with the project in the functional groups of Marketing, Engineering, Manufacturing, and the CEO were invited to see the engineering test/design verification test manager describe in detail the results from numerous tests performed using Model-S and Model-7. The goal was to make a joint decision on whether or not the machines could be shipped. During this meeting, the tests and the test results were presented, as well as many details related to the machines. However, there were no specifications to compare the results with, so the numbers were difficult to interpret in isolation. As one individual indicated, “It’s unclear for me what we are using as metrics.” Problems were identified, but it was unclear what these meant in terms of shipment; that is, whether they were going to stop shipment. Who was responsible to make this decision was also unclear.

The standard that machine performance was compared with was not an explicit company specification, but some implicit standard and perhaps a standard based on experience that was not shared by everyone. There were disagreements on the test procedure, test results, and meaning of results. A meeting that took almost two hours left people confused and unable to make a decision.

The tests that were carried out were meant to be black box tests, meaning that the approach to testing was to simulate customer usage of the machines. It seemed that there

was confusion about their purpose among those at the meeting. One individual said, “We should be careful not to merge R&D testing with this type of black box testing...If these results are not good, then we should go back to Engineering and look to see what we need to do.” Some argued about the appropriate test, about interpreting the results, about how the test was conducted, and about whether the problems were significant or not.

One senior manager who attended the meeting remarked: “This is why we are all here. This is a qualitative decision. We need to look at the results and then decide.” The decision to ship was going to be made by consensus and by how the output looked, but not necessarily by the numbers that were shown in the test results. The numbers in the results were not compared to a standard defined by SIC, but by some metrics specified by the manufacturer of the test equipment. Furthermore, no one seemed to really understand how to interpret the results, except perhaps those involved in testing. One individual, frustrated, commented, “We need to look at the [test] data and understand it.”

Another interpretation of this scene is that perhaps this was to be a shared decision because the consequences of that decision needed to also be shared. It wasn’t about numbers, but about collectively discovering the criteria for shipping.

Someone mentioned problems with the consumables. This appeared to come as a surprise. The consumables that were used for testing were not within specification, even though they came from Manufacturing stock. Now there was the issue of the consumables to contend with, along with the known electronics, mechanical, and software issues, which the design verification test tests had also revealed.

Finally, someone recommended that everyone move into the conference room so that “we put all of this on a white board and decide what is a stop ship.” In the

conference room, someone commented, “We can’t make specification decisions. We need Ed [the owner] here.” So it was decided that they would not make any decisions on specifications. After two years of product development, there did not appear to be a written specification. The founder-owner appeared to be the one who had this knowledge and he was needed if a change in specification was to be made. However, when it came to determining criteria for shipment, a key individual in the group said, “We don’t have to push for performance because there is no competition that’s doing this. So we don’t have to be perfect. When we have a ‘spec’[specification] change, we need to write it out and say this team is recommending this ‘spec’ change.” This team included members from Engineering, Marketing, and Manufacturing. Someone said, “The problem is I don’t know what the spec is.” The response to this was, “The process is we put something out. If we don’t hear anything for 24 hours, then it becomes official.” Among many things, this appears to indicate ambiguity about what was acceptable quality and criteria for product shipment. It was an interpretive process in which how things were done was based on the person making the decision. At this point, people were negotiating what was acceptable and what was not.

A ‘stop shipment’ would affect the company’s income, so this was a difficult decision. The ambiguity of specifications, the individualistic manner in which development had proceeded, problems that didn’t make anyone in Engineering feel comfortable about shipping the next day, conflict between what is acceptable and what is not, the need for consensus, lack of a clear or agreed upon specification, a casualness about quality, and other factors made this a situation that was difficult to control or to shape. All the problems seemed to come out all at once. Lack of time and pressure to

ship put people on the defensive. It was decided to postpone shipping for a few days so specific issues could be resolved.

Simultaneously, a new director of product marketing was hired. The immediate, noticeable influence that she had was that she took notes at meetings, and shared them and matrices of action items or problems with others who attended the meeting. No one wrote down anything that happened in meetings, except the ethnographer. People would walk out of meetings and carry information in their heads. A consequence was, as one person commented, "We come out of [a]... meeting with no conclusions, no document, no outcome."

The next few days were spent battling various technical problems on both machines. The next meeting included only Marketing and Engineering. A decision had been made to stop shipment and fix some problems. There was a written list of problems that they were going through. This new habit of writing things down seemed to have caught on. Now, status and progress were being monitored in writing and everyone seemed to be working together. When the final corrections were done, the machines were shipped. But some of the revenue for the year was lost due to late shipment.

When asked what they thought could have been done differently, there were a number of different answers. One individual said, "The problem is leaving things to the 11th hour. A whole bunch of things could have been ordered and put together a long time ago so that we would have seen problems and resolved them." Another two individuals, from different departments, said that they had never seen the vice president of operations attend any design reviews, implying that this lack of coordination between Manufacturing and Engineering is what caused the delays in ordering and getting started earlier.

The process also affected support of the product after shipment to customers. When a product evolves like Model-S and Model-7, the different versions in the hands of the customers may require repair or technical support. Some of the versions have no or little documentation. So the question that many asked about providing technical support was, “Which version do you support?” The only answer that I heard was that this was not as yet required, because the products shipped did not have a problem.

Model-7 and Model-S summary

In the absence of a set of rules to follow, the PDP is fundamentally an interpretive endeavor. The criteria for decisions are negotiated and decisions made are at best consensual.

It seems that at SIC most practices, concerns, expectations, and knowledge were implicit and were expressed verbally. The explicitly written test results were also seen as ambiguous and were interpreted differently by different people. Even the seemingly explicit could be negotiated.

Model-Q

History of Model-Q

A project that had started shortly before this research began was Model-Q. The prototype, which was seen as having been “thrown together,” was a great success at a trade show in September. Model-Q was different from any other product that SIC offered. So, technically, this was a new challenge. It also required new consumables.

Model-Q during fieldwork

I attended the first meeting in early October, which all personnel from Engineering, Industrial Design, Marketing, and the CEO attended after the trade show.

Ed, the founder-owner said, "We need to offer congratulations on what you were able to pull off for the show." Apparently, this new prototype had been put together in a short six weeks. Paul, the vice president of Engineering asked, "Where do we go from here?" The answer to this question became the topic of this meeting. There was much discussion about what needed to be done technically on the machine and on the consumables, which special features needed to be preserved, the level of interest at the trade show, the target market, and the pricing strategy. While people who attended the trade show seemed very excited, others seemed cautious or anxious.

Ed, who was the product champion, clearly drove what was going to be done. He said "We want to do a redesign and target to build 20 units and get 15 or so into the field and have users use them and provide feedback." So, the extent of the redesign was being discussed. What was going to be done was not clear in anyone's mind because they lacked the time to analyze the machine and understand everything that needed to be changed. The extent of changes was also unclear and was going to take time to determine. Also, building 20 machines was going to require considerable time and resources, which was a concern among those in Engineering.

Bob, an engineer, said, "It is a lot of work. We are overloaded. Just want to make sure this is a good idea."

The CEO said, "It is not a question that this is a betting exercise."

Ed, the founder-owner said, "Talk to those who were at the show to see what they say," implying that there was no question that this was a great idea.

On one hand, there was excitement about the product and the positive reception it had received, while on the other hand there was concern about devoting resources to what

could be a big risk. The conflict was between those who looked outwardly and saw opportunities, which got them very excited, and those who looked at what lay ahead internally at the work required to get the job done. They saw a great deal of effort for what the CEO called a “betting exercise.”

Paul, the vice president of Engineering, said, “I am up to my eyeballs in things.”

One could see that this was causing a degree of concern and anxiety among those who were going to be possibly involved in doing this job.

The CEO: “If we could have the machine as is for the customer to look at?”

Ed: “They’ll come back and ask for more.”

The CEO: “Would you turn down an order for 200?”

Ed: “Yes. It needs to go through another iteration and solve some problems.”

The trade show acted as both market research and field trials for Model-Q machine and consumable. The market research showed positive results and the field trials point to what needed to be changed in the product design. Ed said that there was a good deal of engineering still to do on the project and perhaps some new resources could be sought from outside to perform it. Ultimately, Paul and Fred decided to look for a new mechanical engineer to fulfill this role.

Since these were going to be sent to customers for feedback, the product was expected to go through further iterations. So this was both the research phase and the development phase because problems that had been found were going to be corrected. Research and development phases were thus intertwined.

Finally, the meeting ended and nothing was written down: there were no action items, no next step, nor documentation of any decision on who would do what next.

The next meeting included personnel from Engineering, Industrial Design, Manufacturing, Product Marketing, the founder-owner, and the CEO. It began with discussions of how exciting it was to be at a prestigious show with such an impressive product. Those who had gone to the show were very excited.

Bob: "So one of the things that happens at these shows is market research. It's interesting to hear about the competition. Did anyone take pictures?" The founder-owner said "yes" and explained that they had seen many others who were trying to do this.

The perception at SIC was that trade shows, in general, allowed those attending to learn about the competition, evaluate how SIC's products measured up, and study the products of other companies. This is one of the ways market research was done at SIC.

In this Model-Q meeting, Ed, the founder-owner reiterated what he had said in the first meeting about what he thought should happen as the next step.

Ed: "We need to get a design that we can build 20 from... so that we can get it in the hands of customers."

Peter, an engineer, said, "We design for sale, then it's different."

CEO: "Why can't we sell prototypes?"

What Peter implied here was that if this was going to be a prototype, then the approach taken to get a design to build 20 would be different than if it was going to be a developed design that would be for sale. This is probably why the CEO responded as he did. The reason for the question that Peter asked may be the experience that Engineering had gone through for the past two years with the prototypes of Model-S and Model-7 being sold as part of the development process of these two products.

John, the manufacturing engineer, said, “We get locked into things that way. Once things get locked down, people always say there is no time afterwards. What we need to do is to start with a design spec.”

This is the familiar pattern of conflict between internal and external concerns. As defined previously (Quinn and Rohrbaugh 1983), the external concerns are about producing a product that will allow the company to enter a new and evolving market. This means that the product may evolve as the market evolves. To capture the market changes, prototypes are sold to customers, who then provide feedback. Their feedback is quickly integrated into the next revision of the prototype. This way of proceeding allows the development of machines and consumables through customer feedback. However, internally, the manufacturing engineer perceives that the product development cycle begins with a design specification, which contains more explicit design requirements. The concern that he is expressing is that the product won't be changed after the initial design. He sees this approach as one that locks in a design, which may not be optimum. His idea of the way things should be done is also tacit.

Paul: “Yes. We have that, but what we need is a cost spec.”

CEO: “At SIC, Ed gets an idea of a project and things like this happen. I was very impressed with the idea and a tremendous effort. This morning we had a customer from the show talking about this product. I walked him through this exercise to see what we can sell it for. This in turn has a constraint as well. That [trade show] is in March. [This meeting was taking place in mid-October] They [the customer representatives] want to pilot one of these machines with consumables... so that they can test and announce this product at the [trade show]. They don't need many machines. This is the good and bad news. Here we have a live evidence of market needs. This is just another data point, but an encouraging thing. Discouraging piece is that it is another new product when we have our hands full. What we need to do is to come up with an easy way to do this. We can use the people that are in this room or part of the group in this

room to do this. We are not in the business of making money on the machines per se. It's the consumables we make money on."

So, here, the CEO reiterates the business model that money is made on the consumables.

Paul: "How do we come up with a spec for market on the cost?"

Ed: "The driving force is the time to market. We need it to work well and have it fast."

CEO: "Cost reduction is for volume. You are talking about volumes we've not seen."

Ed: "Quality, cost, speed. We can't have all three."

CEO: "I disagree. We can have all three. It's a matter of degree. A good team can have 80% of all three." There was no reaction out of Engineering on this comment. They were very quiet. Things felt uncomfortably tense in the room.

Ed: "At high volumes, you have [various processes] that push schedules out to 9 months. That's real price reduction. Three years ago, we would have gone and done the long range slow process of cost reduction. Today, we're going to do low volume, expensive techniques to get things out fast." This mention of three years may be significant. This is when the new business model was adopted and the CEO came on board SIC. An individual who had been at SIC at that time told me "Three years ago, the bank pulled our loan. We were all scrambling. There were major layoffs."

The CEO and Ed had spelled out the development process that supports the business model of selling machines and making a profit from the consumables. The founder-owner had expressed the requirements that the process should meet, that is, "We need it to work well and have it fast." So quality and speed were the two requirements, at least according to the founder-owner. But at the same time, the CEO had a different idea; he thought quality, speed, cost at 80% was what a "good team" can accomplish. These different views were both expressed at one meeting where the direction of product development was to be determined. These views have different implications for product development.

In the meeting, the conversation turned to what needed to be done next.

Paul: “We need a plan. Phase 1 is trade show, phase 2, is this or that?” There was no clear answer as to what needed to be done next or the expectations for the next phase so that Engineering could gear up for it.

CEO: “The thing that scares me is that we have a company to turn and we have this other product. I just want to remind the team that not everyone will be able to work on this project because we have other projects to run. It’s a tricky balancing act. If we don’t pay attention to the core business, we don’t have any money to run the show.”

What the CEO meant is that SIC had limited resources in Engineering, some of which were needed for manufacturing support. It was close to the end of the year and large orders needed to be shipped for the company to make money. Additionally, Engineering was also handing off new products to Manufacturing. The CEO was concerned that the significant effort required on Model-Q might cripple the company if it interfered with what they were doing now to keep the company going.

It seemed that even the founder-owner and the CEO were defining the work that needed to get done and the process that the project would follow. The founder-owner wanted to go through another iteration of the machine to implement lessons learned from the trade show so that the product could be sent out to the customers for more feedback. The CEO was concerned about balancing the need to keep the company alive by shipping products and the need to get done what the founder-owner wanted. The founder-owner’s focus was the product, while the CEO’s was balancing of resources.

Another meeting was scheduled to discuss the technical details of the changes. The engineer who had designed the prototype said, “I am not the right person to do the production design.” Paul explained, “We need to get feedback from customers. This is

an evaluation thing.” The meeting ended and again there were no decisions made about who was going to do what, if anything.

There appeared to be two groups in Engineering who were working on this product. One group involved Mark, the mechanical engineer, who had developed the first Model-Q under the direction of the founder-owner, while the other group was Greg, the electronics consultant, and Bob, the firmware engineer, who worked under the direction of Paul, the vice president of Engineering. There did not appear to be much communication between the two groups. Actually, the founder-owner was in charge of the mechanical design, while Paul was in charge of the electronics and the firmware. The decision made in the next meeting was to produce some 10 units for January first and order parts to build 100 in March.

Paul: “So, we are going for 100 pieces [that is for March]. So this design is going from zero to maturity in two months. Why do you think we can do that?”

Ed: “We are not talking about your kind of maturity.”

Paul: “What if the world goes gaga after the 100 and they want 1000 [Model-Q machines]. How are we going to handle that?”

Mark: “This is what we have to do anyway to start off now.”

Paul: “Do we need to talk about offshore manufacturing now if we are going to have high volumes? It takes time to set up these partnerships.”

Mark: “We can send these over to overseas for an evaluation and setting contacts.”

Paul: “It isn’t that simple. We need to set up relationships. Let’s have a strategy.”

There seemed to be a vast difference in approaches and expectations between Ed and Paul. Even the meanings of words were different for them. The order of 100 is what Paul considered mature. But the founder-owner said that this is not that kind of maturity, although it was not clear what the different levels of maturity were. There were tacit expectations, views and ways of doing things that were held by the founder-owner, which did not appear to have been communicated to Paul who had been at SIC for six months. I could see the look of confusion on Paul's face. He came from larger organizations with explicit processes that dictated the various steps in product development.

Paul: "For consumables, I know there is some work going on. How is that going? Are you comfortable about the consumables?"

Ed: "No, that's a big challenge. We can't throw it into [Vice president of Manufacturing's] department. There is a month or two of work required to do."

In this project, there were four components: electronics, firmware, mechanical, and consumables. The electronics and firmware were apparently under the vice president of Engineering, but the mechanical and consumable were under the founder-owner. There did not appear to be a concerted effort. This might be because there was no overall project coordination between these individuals or perhaps everyone was focused on figuring out his own piece. It could also be because the founder-owner was involved and was directing a large portion of the effort on this project (mechanical and consumables), which made the situation complicated.

In November, Mark, the mechanical engineer who had worked on the mechanical design, had gone through a number of design reviews on the Model-Q. However, now the founder-owner had also started to incorporate some design changes in areas where he

had seen weaknesses. People did not understand his motivations, but they were reluctant to ask him. They were not sure why he was the one heading the project. People were confused. One individual's comment describes some of the feelings: "Ed was second-guessing his engineers." When asked why he thought that was the case, he replied, "He is just not aware of it." There was uncertainty about what was going on and some had difficulty interpreting Ed's behavior. But no one dared to ask. It was difficult to understand why there was no one else to go to for answers, such as the CEO. It appeared that the tacit process that the founder-owner was following was not clear to anyone else. Furthermore, the fact that he was the founder-owner seemed to make it difficult for people to find out.

In the first week of December, another design review was called. This time, the design review was on a new implementation of the machine, which was done by the founder-owner. This was a different way of implementing the same idea. One individual explained it this way: "This design review is a shoot out [between the older version and this new version]. This isn't a public company so he [the owner] gets to have the final say." Another individual said, "It's the owner versus Mark [the mechanical engineer who designed the prototype]. If I had to bet my money, I know who I'll bet on for a winning design."

However, during the design review, the old design was also discussed and some problems that were being worked on were debated. There was much back and forth discussion on these problems and it seemed like everyone participated. There appeared two common themes: (1) let's make a logical decision based on data and (2) let's do a low risk design to get units into production fast. The first theme required further study,

while the second implied that they didn't have the time to do any more study. Each theme sounded logical, but they were contradictory and therefore the cause of debates.

The subject turned to design for manufacturability, which is a function that incorporates design features into a machine during the development phase to make it more manufacturable.

John (manufacturing engineer): "Where do we fit DFM [design for manufacturability]?"

Mark (mechanical engineer): "The more cooks you have to make soup, the longer it takes."

Ed (founder-owner): "We are trying to still understand if the concepts of what we are doing work. I don't think we know the validity of the design enough to do design for manufacturability." It seems that his previous message was lost. Clearly, he was saying that this was still the research phase.

Bob (engineer): "Where do we do this in the process?"

CEO: "At the moment we are trying to do proof of fundamentals of design."

John: "OK. It's important to acknowledge that we are not doing DFM [design for manufacturability]."

Ed: "I don't buy this that we are not doing DFM [design for manufacturability]. There is DFM [design for manufacturability] for two, for 20, etc. We get some of the obvious ones before we build this."

John: "We have 20 screws in a tiny little subassembly."

Ed: "So we'll remove some of the screws."

Bob: “I guess we don’t want to be too extreme and say we need design for manufacturability for this rev of the design.”

CEO: “I sure would like to see two models that work.”

What the CEO called proof of fundamentals was probably the same as proof of concept. This meant giving physical shape to the mental idea to see if the model could perform as envisioned. One unintended lesson was that not everyone saw the line between Research and Development the same way. For example, John wanted to do design for manufacturability in this stage, which the CEO called the “proof of fundamentals,” while Ed said that different levels of design for manufacturability could be done, depending on where things were. So this line between research and development was not just blurred, but was defined differently by different people.

Secondly, John was concerned that if he didn’t push for design for manufacturability now, he would never be able to get it. From their experience, once a product was built, even in quantities of one or two, there would not be another opportunity to change the design and the prototype would end up in Manufacturing. Design for manufacturability was an internal need and it was likely to be secondary to external needs.

The message that this was just a proof of concept was either not heard or ignored. Even those who acknowledged this was proof of concept were confused about what was going on, which stage the project was in, why the design reviews were conducted, and what was the logic behind it all. This confusion created a certain uncertainty and discomfort about the whole project.

In order to understand this uncertainty, we need to understand this concept of design review. “A formal design review constitutes a coordinated activity (including a meeting or series of meetings) directed to satisfy the interests of the design engineer and the technical discipline support areas (reliability, maintainability, human factors, logistics, manufacturing, industrial design, quality assurance, and program management). The purpose of the design review is to formally and logically cover the proposed design from the total system standpoint in the most effective and economical manner through a combined integrated review effort” (Blanchard and Fabrycky 1998:71).

A formal design review serves a number of purposes. It provides a formalized check of the design with respect to specification requirements. It also provides a common baseline for all project personnel by allowing the design engineers to explain the reasons behind their approach to representatives from various departments. It addresses interfaces to ensure that all system elements will be compatible. It provides a formalized record of what design decisions were made and allows others the opportunity to identify new ideas that might result in a simplified and cost effective product (Blanchard and Fabrycky 1998:71-72). At SIC, there were no specification requirements to check the design against and no record of design decisions was maintained. Nothing was written down that could be seen or called a system document that would allow others to understand what the machine should be expected to do. Instead, the engineer simply showed the mechanical drawings on his laptop. To really be able to understand what this design needed to achieve and have a design review of it would have required specifications against which the mechanical design could have been compared. However, these meetings did provide an opportunity for the designer to explain the

reasons behind his approach and some opportunity for others to provide ideas for a better approach. To call these design reviews confused people who defined them in other ways. The discussions that occurred reflected this confusion.

Having said this, it is possible that this was what a design review at SIC was about. They were simplified versions of a formal design review where a discussion of what the designer had done took place. The meaning of a design review might very well be different in the context of a product development where the research and development phases were so intertwined.

In one of these design review meetings, the founder-owner said, "I was an advocate of the previous design until about one and a half weeks ago." He described the problem that he saw with that design and the fundamental difference between his design and the old one. He showed a mockup, which opened the door for discussing other concepts. He then said, "As the market evolves we might have to come up with a different design." The atmosphere and rules changed from those of a design review to a brainstorming session. Now there were three separate conversations in the room. At the end of this session, no decisions were made, nor was anything documented.

The work of implementing a new version of Model-Q had begun. The founder-owner worked with, Dick and Joe, two junior people in Engineering, designing models of the parts that needed to go into this new machine. What the founder-owner was doing was putting together a design to test this new concept. He was also directing the effort. The more junior person, Joe, was making models on the computer and putting together the mechanical drawing of the machine as he was told by the founder-owner. The other, Dick, who was more experienced, was also working on making these models.

Joe: "Dick, I've made changes to the plate."

Dick: "I'm also working on the same thing. It makes it really tough when you go around modifying these parts. Now it messes me up."

Joe: "I think Ed had some vendors and just wanted to show them what was going on."

Dick: "This probably won't work. Now we have two designs that don't agree. I'm not beating up on you. You are wrong, way too much. As a designer, this is one thing you want to avoid."

Joe was not really a designer. He is the youngest member of the engineering team without any engineering background.

Dick: "For example, why did you do this like this?"

Joe: "I don't know. I just did what Ed told me."

Dick: "Wrong answer. Fundamentally, there is a problem with the design and if you see it, you should bring it up."

Joe: "I just did what I was told. That's why he likes me."

Dick: "There is a culture here that's top down driven. It's based on gut feel. Typically, the guy who does the model also puts it together, so we need to be sure that it works. If I see a problem, I point it out to him. So, Armineh, impartial observer, what do you think?"

Armineh: "I just want to know how you guys do things or get things done."

Dick: "We just talk to each other, that's how."

Armineh: "Is there a pattern to the way you talk to each other?"

Dick: "No. It's disorganized."

Dick dug into Joe further for doing things the way he did them. He was harshly critical of Joe who had done what he was told to do. Joe seemed to have had enough.

So, he got up and left. Somehow, this interaction doesn't look friendly any more.

Dick: "I am working on [the new version of Model-Q]. It's fortunate for me. It's good to be wanted."

This interaction captured a social aspect of the interpretive process: People behaved in ways that they perceived would put them in a favored position with those in authority.

After another design review for one of the versions of Model-Q held in mid-December an individual made the following comment: "What's amazing is that we had a spec change in the meeting from a lifespan of 10K [ten thousand] to 100K [one hundred

thousand]. For what reason, I don't know. Ed decided that 10K [ten thousand] would not do. So, it went to 100K [one hundred thousand]. This has significant ramifications. But no one asked any questions."

What this individual was implying was that such a change would affect the design and the price of the product. Therefore a change of specification that would have design ramifications should be carried out only with justification, which would be appropriately communicated so that people would understand it. The other matter that he brought up is that "no one asked any questions." He included himself. This may have been because the founder-owner was the one who made the change or perhaps people assumed that since the founder-owner was the person who had the ideas about the product he was also the person to specify it. Perhaps the founder-owner's tacit knowledge was shared among the others in the meeting and they agreed with this change. Typically, engineers prefer to 'over design' rather than 'under design'. Perhaps the fact that he went up in the specification of lifespan was considered a move in the right direction, without further examination.

The design review started.

Ed: "The plan in the next couple of days is to structurally stiffen the [old design] to see how we can structure it. We then build one [of the new design] to play with it.

Mark: "We can make two different bases, have the same tops, build two different machines and see how it works."

Peter: "Is it easier to build it on a computer or physically?"

Mark: "You've got to build it. It's too complex for simulation."

Dick: “Why not make the assumption that they both work. Then what would be the criteria for the company to chose one over the other?”

CEO: “Cost, ease of manufacture, technical support, cost, etc.”

The meeting finished suddenly. Everyone went away. There did not appear to be a firm decision as to what would be done. There were no action items or minutes to document what was said or done. However, the idea was to look at both designs (the older and the newer) and see which one was a better alternative. Although the criteria for selection were not clearly defined, the CEO casually suggested some.

At the end of December, I saw the founder-owner testing the original design of Model-Q. He was concerned about the safety of the machine and was trying to characterize the machine. He showed me the new design in the machine shop. The machinist had cut the parts for the machine. Jim, the mechanical engineer, who had recently learned how to weld, was going to weld the parts together. The founder-owner was doing what he had said in the meetings, that is, trying to characterize the old design and build a new design.

Armineh: “So you are pursuing both paths in parallel?”

Ed: “The idea is to get the [new design] built fast so that by the time Mark finishes the [old design], if the new design works and runs well, we won’t need to build the [old design]. If it doesn’t, we have the [old design] as a fall back position.”

So, Ed was trying to simultaneously do a new design and characterize it so that they could identify the best approach. He identified people in Engineering that he needed and they worked with him as needed. Although the changes to the mechanical parts were significant, the changes to the electronics and firmware were minimal at this point.

The one thing that was apparent is that the founder-owner was not married to one way of doing things and he liked to try different alternatives before he settled on something he felt was right. Even though he appeared to have communicated this at meetings, his message was still ambiguous. Perhaps what he was doing was based on a tacit understanding of what he thought was the way to do things next, but this understanding was not shared by others. Perhaps others didn't understand the purpose of what was taking place. Perhaps they didn't want to say anything because he was the founder-owner. Perhaps the fact that he was involved made people nervous. From observations and conversations, the only thing that could describe the mood is confusion and being unclear about the founder-owner's ultimate goal.

To capture who was working on what at this point sheds some light on how a project spreads. Since most of the work was on the mechanical aspect of this project, then this was to be the focus. Mark, who worked offsite, was working on the old design, trying to address weaknesses that had been identified. Dick and Joe had been working with the founder-owner to develop the new design. The machine shop was building the new design and Jim was going to weld the parts together. These resources were being used to pursue a parallel design path for developing the best approach to implement Model-Q. This took up half the engineering resources, and the firmware and electronics design had not yet been included. Since this work was still on the proof of concept, it could have been considered to be the research phase of the project. A lack of visible division between this phase and a development phase meant that these engineers could also have worked on the development phase of whichever design was chosen, with the exception of Mark who seemed to work only on proof of concept and building

prototypes. This allowed a seamless transfer of knowledge between research and development engineering. Generally, distinct activities are done in each phase that define the phase, but at SIC these phases were invisible or were not seen the same way by people; the research and development phases were blurred and sometimes took place at the same time.

An eighth design review was held. I asked one individual what they thought about these design reviews. He said, “They are not design reviews. They are design discussions. For design reviews, we should get a package ahead of time to review and prepare. There is nothing here... I am not sure what you think about what’s going on here, but these are not typical. I don’t know that they are typical. Some good design suggestions have come out, but this is not the way to conduct design reviews.” I asked if there was a pattern to these design discussions. He replied, “If you see one, let me know.”

The Model-Q project was in between research and development phases; it was neither research nor development. As discussed previously, the meaning of a design review at SIC may be different than a formal design review outside of SIC. Model-Q was not at a stage where formal design reviews could be carried out. What was carried out in the name of design reviews were design discussions or brainstorming, which allowed those interested to come together and discuss what was going on. So naming these meetings design reviews carried a different type of expectation, which was partly the reason for the confusion, conflict, and tension that developed at them. Those attending had different ideas of why they had come and what the outcome should have been.

Different people from different backgrounds attended these meetings. Some had formal engineering training, some had worked in larger organizations, some had been exposed to how things were done at SIC for a long time, and some were new. There were people from different technical backgrounds, different positions at SIC, and different functional groups. They all interpreted their experiences at these meetings differently.

I had been away from SIC for a month. I walked in wondering if anything had changed. The first thing I was told was that there was going to be a 10:00 o'clock Model-Q meeting and that I should not miss it. I had this mental image that this would be taking place in the large meeting room, much like the other meetings, but I soon discovered that was not the case. I noticed everyone had gathered for the meeting in Engineering around the desk of the vice president of Engineering. Paul sat behind his desk, while the director of product marketing, Mary, sat on the other side. Everyone else gathered around. This included the manufacturing engineer, engineers, industrial designer, and the founder-owner. Mary had a printout in her hand, which she went over.

This was done at 10:00 a.m. every day and appeared like a new ritual headed by Mary. The discussions were on the status of everyone's work. It was done very quickly. Issues were raised, people were designated to work on specific problems, and a list was written up with people's names on a piece of paper. People were tied to specific tasks and there was a paper trail to reflect what people were tasked to do and their progress. Questions such as "at what point are you going to be ready to test this?" were asked. It seemed like she was moving people along towards the next stage of what needed to happen on the project. If an issue came up, everyone got to put in his or her input. Decisions were written down. Everyone knew who was responsible for what. Everyone

had to talk about what they were doing and why. Mary made a list of what was discussed and distributed it to everyone. It seemed like “everyone was on the same page.”

This meeting took approximately twenty minutes. Everyone seemed content during the meeting. The difference between this and other meetings was that the meeting was documented and the notes distributed. When asked about why she held the meetings this way, Mary said that she had tried different ways to get status from everyone, but none of those worked well, “So, I decided we’ll do it like this where everyone gets together and talks about issues that affect everyone cross-functionally. So far, it seems to be working.” It seemed that she had started what might be her contribution to a process of communications at SIC. What she had done was, at least on a project level, “broken down the silos.”

After the meeting, one individual commented that the thinking was to go with the new design of Model-Q, that is, the founder-owner’s design. “It just came together a couple of days ago. It hasn’t been tested or even proved to work. It’s a real prototype phase and it would be ridiculous to actually manufacture it because it isn’t manufacturable.” When asked why one design was being chosen over the other, he replied, “There was no technical reason given. Mark addressed all the technical issues [of the older design]. He has a bill of materials to go and order from to start building the [older] version. But Ed said no. We live under a monarchy here. He wants to do the [new version], which isn’t ready yet. The [original design] is one of the most design reviewed products in this company.”

Another individual who was asked which model would be shipped responded “Ed decided that the [new design] would be the one. It was his edict...We haven’t yet tested

it. It doesn't have the electronics and software on it yet." Another commented, "Engineers don't have any confidence in this design," meaning the founder-owner's design.

The founder-owner showed me the prototype of this new design. He said, "We tested it manually. It did some things well, but when we tried it again, it didn't perform well. But this was all rough and manually done by churning up the power supply. It didn't have any real electronics and software in it. We'll have to test it this weekend."

These conversations reveal, at a minimum, a lack of communications concerning what the founder-owner was doing and wanting to achieve and the rest of the organization. From my previous conversation with the founder-owner, what he appeared to be looking for was a better alternative to the original design. If this alternative did not work, then the original design would be the backup design. The founder-owner acknowledged that the new design had only been out for a couple of days, and that it was not likely that sufficient testing had been done on it to make such a decision. However, some people seemed to think that the new version would be used. What the founder-owner said was different from what others were saying.

Another issue was the lack of a clear divide between research and development. While some believed that the original model was ready for manufacturing, it was still in the proof of concept phase according to the founder-owner. So, both models were in essence prototypes; the original model was an older and better-tested prototype, even if it was not the ideal implementation.

In February, there was another new design of Model-Q in progress. One individual commented, "We have all these different approaches, but no clear direction."

Another said, “People just can’t keep the same sense of urgency. People are stressed. They are sick of being asked to work weekends. Because nobody believes in the design, they think what they are doing is futile.”

In mid-March, it seemed that all other approaches were abandoned and the original design for Model-Q was pursued. The founder-owner had started making changes to the original design. It seemed as if this was the end of the research phase and the beginning of the development phase of the original design. However, once again, this effort was interpreted in such a way that surprised, confused, and made people anxious. However, the choice to use the original model refuted the assumption that if the founder-owner was coming up with a different design, then that was ultimately the design he was going to choose.

Some were wondering why the founder-owner was making these changes to the original design. The original design had gone to a show earlier in the month and had been very well received. One of the individuals put it this way: “Inside, it’s unbelievable chaos. Outside, an incredible success story.” This might have been reflective of the priority SIC placed on external concerns over internal ones.

When asked why they thought the founder-owner was making changes to the original model, someone said, “He hasn’t been comfortable with the [original design] concept...He is obsessed with the safety issue.” Another said, “The behavior of the CEO is disappointing. I believe the CEO has a good understanding of what’s going on, but he doesn’t redirect things. He made a public statement that he is temporarily turning the CEO reins over to the CFO so he can design another machine version himself. Now he is designing another machine. This is like science fiction. I’ve never seen this happen

before...It must be terrible for morale. This must be a sinking feeling.” A third person said, “People like the vice president of Engineering were brought in to change things. But no one can stop it.” A fourth person said, “[the CEO] is getting involved in all sorts of things. His title should be ‘Anything but CEO’.”

In May, the founder-owner said, “We’ve modified [the original] design. Hoping to build 50” I noticed that almost everyone in Engineering was working on Model-Q. I also found out that the vice president of Engineering was leaving in a couple of weeks.

Another individual outside of Engineering said, “Ed doesn’t believe in management or communication. He says people should just go do their work and they don’t need to be managed.” An organizational psychologist was hired to come in to define and create a role for the head of Engineering position.

Jim, the mechanical engineer, who had taken on the role of developing the [original] Model-Q, said, “It’s fun. But it’s crazy. We keep making changes, beefing it up, making things better so that they don’t break, making them more manufacturable.” Although there was no clear division between research and development, research was halted, albeit temporarily, and the development phase had begun. This was not visible to the others who were in the midst of all the pressures to complete this work.

At this stage the final development changes were being made to build more Model-Qs to ship to customers. As the founder-owner had previously said, it would be for the purpose of getting their feedback.

Model-Q summary

The founder-owner started model-Q, much like other projects. The prototype that was taken to the trade show was received very well and provided some ideas for improvement.

One of the high level employees at SIC had this to say about process: “This is a mature company. Product development process is not clearly defined. It is in the heads of people. There is an informal methodology in place. We are 120 people. What if we became [a] \$100 million company? How would we be today? We would then need to teach and educate people what our process is. Structurally, we are informal. The philosophy at the top is that we want to remain entrepreneurial, fast, helping customers, and meeting customer expectations. This principle is doing things fast, there is a lot of ramifications. Fast means we are not perfect.” He added, “We are struggling with execution. Why? Because we lack effective decision-making. We don’t have a behavioral framework that all employees understand...Another reason is clarity around accountability. Why would a senior executive not have the authority to make decisions? So we flounder and all decisions get pushed out. People are not empowered to make decisions.” At SIC there were many different vice presidents, but the perception of those I spoke to is that they did not have the authority to act without consulting the CEO or the founder-owner. Here the organic entrepreneurial image of SIC contrasted with this more hierarchical decision-making process.

There were no consistent rules to follow. Although an organizational chart existed, it was confidential and was not displayed anywhere. There were no mission statements or quality statements displayed anywhere.

It appears that the interpretive approach is the primary process that was used by those involved in this project to determine possibilities for the next step. Different backgrounds, expertises, focus areas, and interests guided the interpretation of people's experience, and therefore, what they thought the next step should be. So, a diversity of people generates different ideas about the development process. It is the combination of these ideas that leads to the construction of a PDP. Therefore, one of the positive aspects of the interpretive approach is that it allows the participation of people from different perspectives to contribute to how things are done. However, without an awareness of the nature of the process, people's different perspectives can conflict, leading to misunderstanding and confusion.

In this project, the founder-owner, who had a different background, experience, and expertise from the others, was by default the primary guide of the process. Although he was explicit about what he wanted to do, it wasn't heard or understood by others who did not share his experience. This is perhaps because others interpreted this approach in a way that did not fit their experiences and so it was meaningless for them. It appears that people working in such environments may need a set of non-technical skills to evaluate what is going on and act effectively.

Figure 8 summarized the process that the project followed. It seems that there was a separate research phase followed by a development phase. It is not clear what will come next, but considering what the founder-owner has said, the product would be put in the hands of customers for feedback. If this project follows the same pattern as Model-S, the next stage might be incorporation of customer feedback.

Model-Q consumable

The consumables for Model-Q were developed as described below by one of the designers: “[The owner] came up with an idea, then he sat and talked to us about it. He then made some samples to see what was possible. We all made some samples. We patented all the different thoughts that [the owner] had. Then did a series of experimentation with them and documented what we learned. We then went with what was the best approach.” After the best approach was decided, research was done into the materials and other requirements, and then recommendations were made to manufacturing.

The Model-Q consumables had been developed, but were still being improved. Manufacturing the consumables was yet another project. Different ways of manufacturing these consumables were being experimented with in the Industrial Design area under the directions of the founder-owner. Prototypes of different manufacturing concepts for Model-Q consumables were developed and tested. The most feasible version was to be presented to Manufacturing, which would then adopt a means of producing these consumables in volumes. However, Manufacturing did not have the necessary equipment to manufacture these consumables yet and was not involved in producing any of the Model-Q consumable prototypes. Figure 9 shows the process that Model-Q consumables appear to have followed.

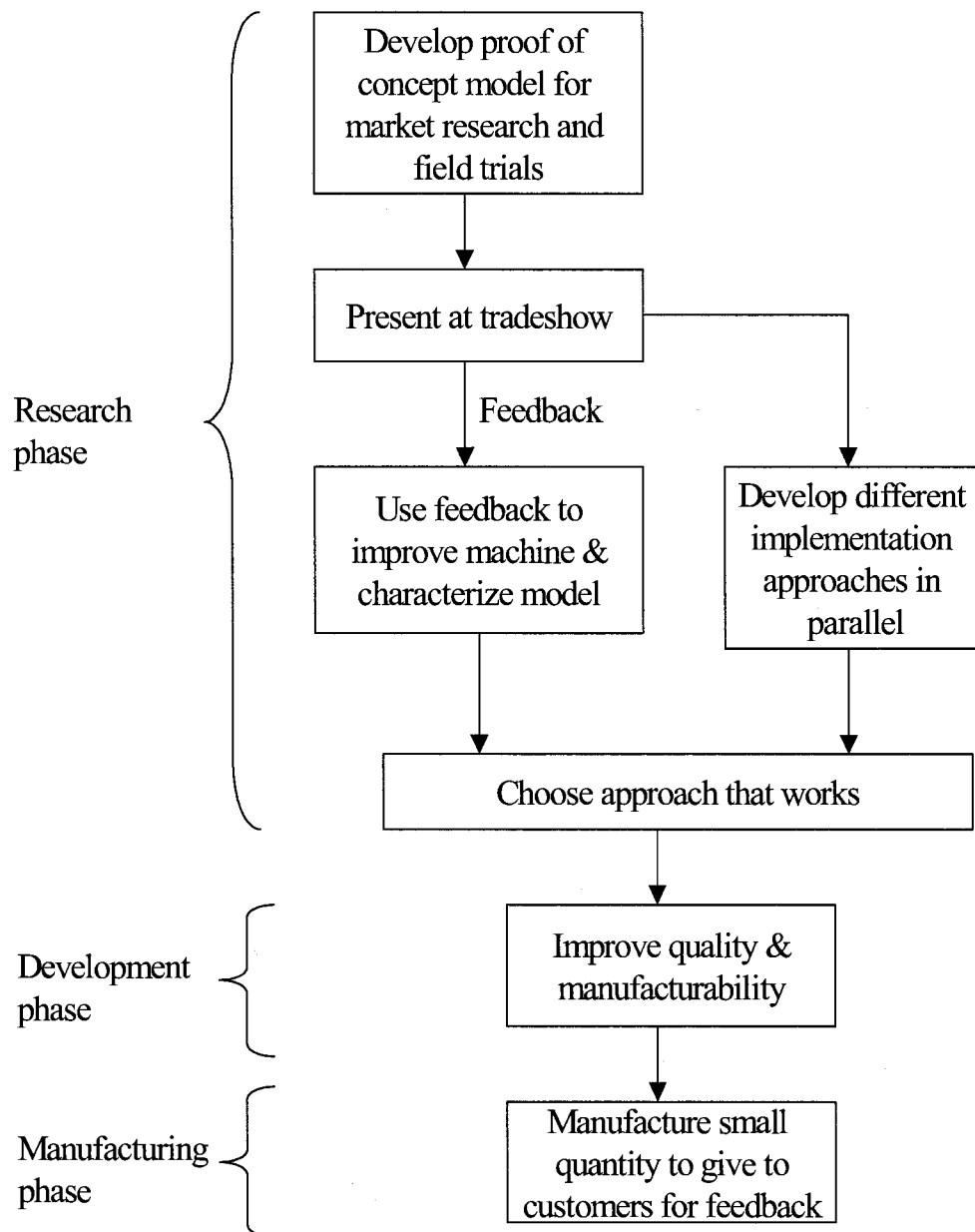


Figure 8- Model-Q Observed Elements

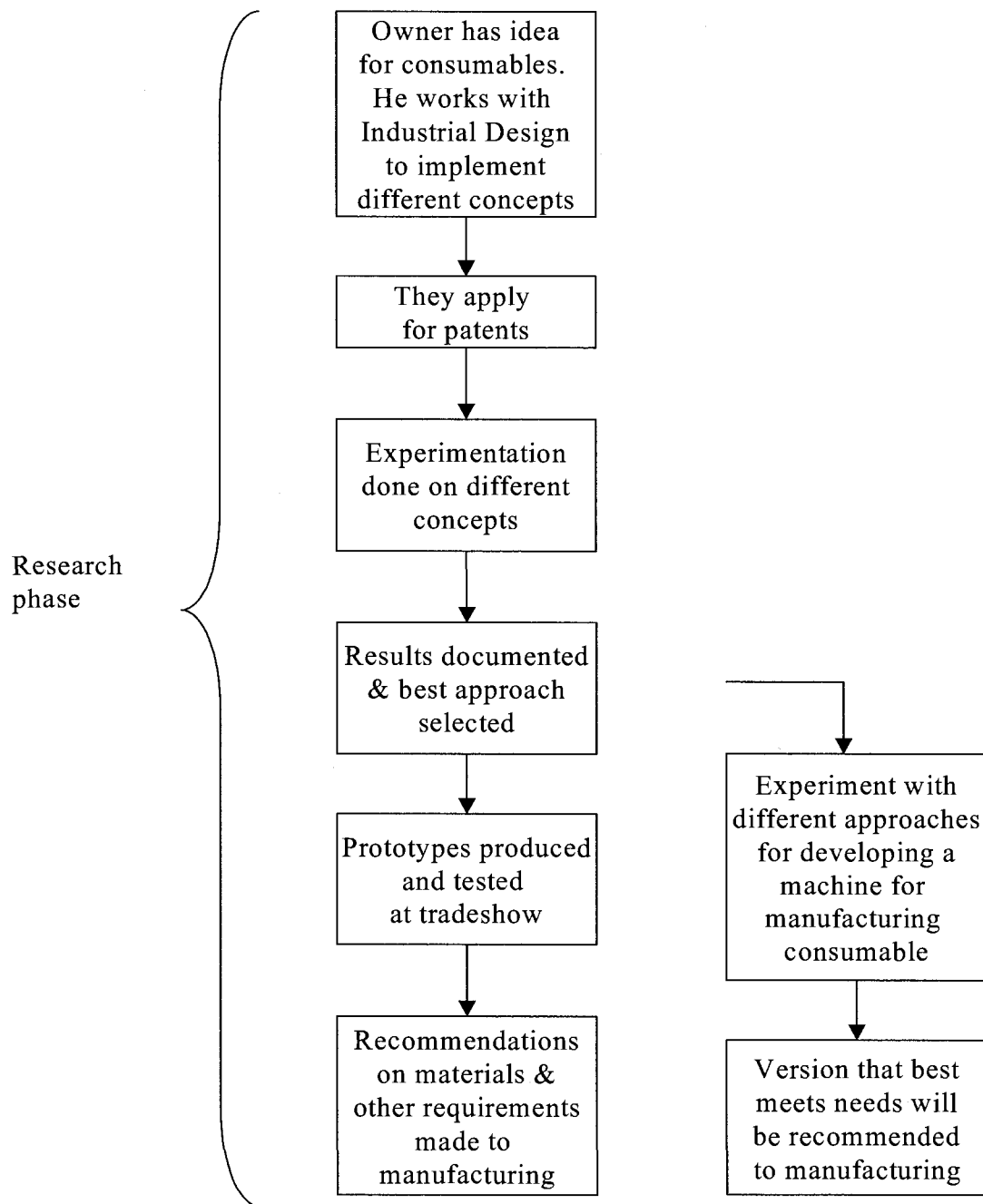


Figure 9 - Model-Q Consumable Development Elements

After observing Model-S, Model-7, and Model-Q I began to see that the organizational chart for Engineering was more complicated than I had previously assumed and so was the role of the vice president of Engineering. At the time that these two projects were taking place, there were other active projects in Engineering, which required different functional areas, one of which was called continuation engineering. The engineering test/design verification test area and technical services areas also reported to the head of Engineering. An organizational chart of Engineering is shown in Figure 10.

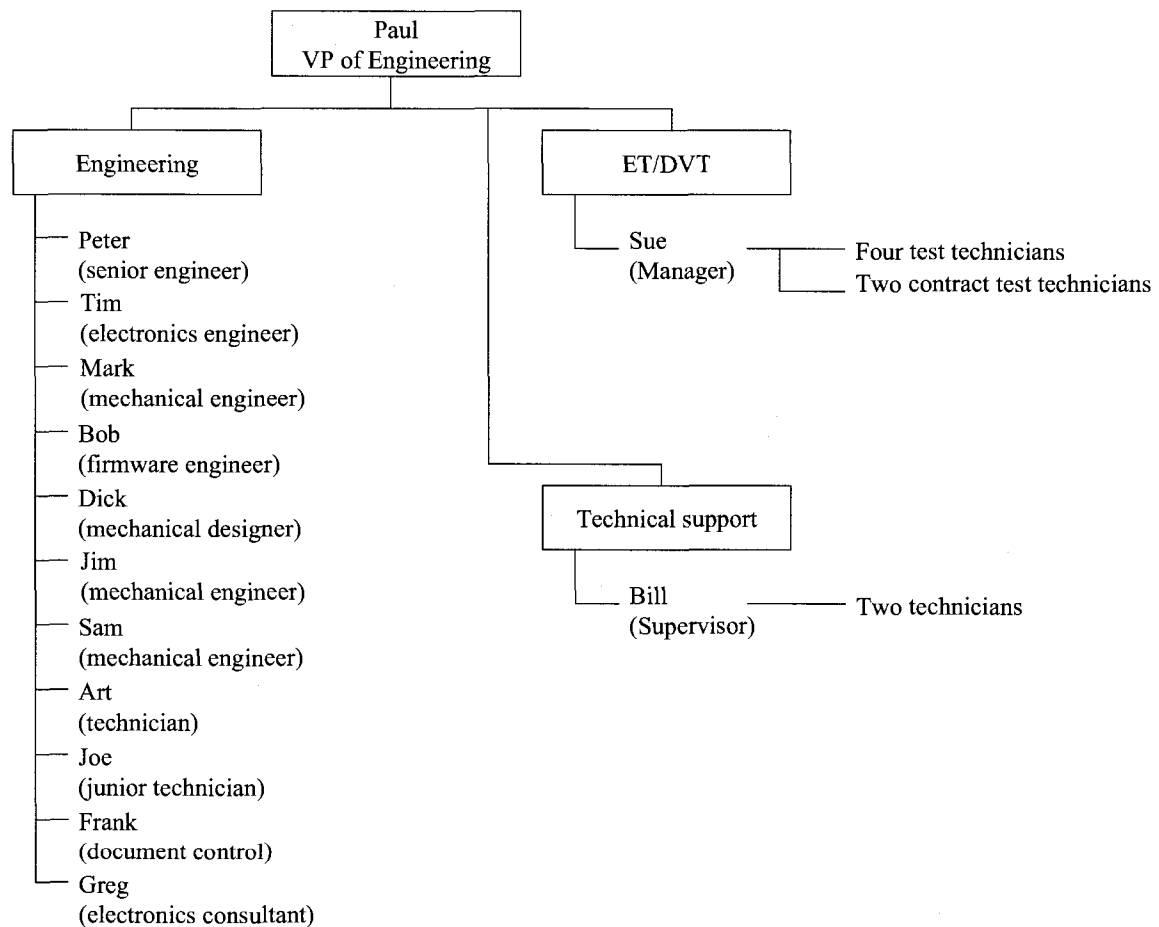


Figure 10 - Engineering Organizational Chart

The position of the vice president, director, or manager of Engineering is a difficult one for an organization such as SIC. First, there appeared to be many different areas that a person in this position would need to lead both administratively as well as technically. These included research, prototype building, development, sustaining, engineering test/design verification test, and technical support. Second, the founder-owner participated in product development, often as a technical lead and directed engineering activities. This made for a complex situation in an environment where a blurring of functions and responsibilities was perceived to be the way things get done. Third, the CEO also got involved and directed engineers. This made an already complex situation even more complex.

There was general consensus that the founder-owner decided what projects would be worked on in Engineering and that the CEO often directed engineers, without consulting the vice president of Engineering. This was frowned upon by the engineers and by various department heads and was considered to undermine the authority of the hired management. An individual in Engineering said, "Ed [the owner] just comes in here and tells people to stop working on what they are working on and do something else." The absence of a job definition for the founder-owner created some issues. An engineer voiced a common sentiment: "One thing that's been driving people crazy is the CEO getting involved in Engineering...I think that's wrong...is disrespectful, is sticking his nose in engineering to solve day-to-day problems." When asked why he thought the CEO did this, he responded, "What he does is create noise from information. It's not productive." He added, "He is business minded. Ed [the owner] enjoys the process of developing products and delivering a service. He doesn't think about business. It's more

emotional for him.” Although the blurred responsibilities and blurred functional lines were common occurrences at SIC, it seemed that in this case, there was an implicit understanding that this was wrong, particularly for the CEO.

Auto-consumable

History of Auto-consumable

One of the on-going consumable projects that had started three years ago was a special consumable that allowed automatic feeding into a machine. This was an important project because it helped SIC sell consumables in high volumes. This was being developed for a customer who was developing a machine that would use these consumables and which had very stringent reliability specifications

The engineer who was working on this project said the project started because “[the owner] had been thinking about doing this for a long time. He came up with the idea. We got our ideas together and applied for a patent on it. So, we developed it [the consumable] and sent it to them [the customer] to test it. We needed them to test the product because we didn’t have a machine. [You can manually work with it to see how it would work]. So we did limited testing here. While we were developing [this], they [the customer] were developing the machine. So when they got the machine developed, we got one [a machine]. So we now test using their machine. I developed the consumable and the machine that [makes this consumable at SIC].” He described the process of development further. “We would make some changes and send it back to them [the customer]. They would do some testing and give us feedback. We finally have it reliable now and tested their machine with our consumable and it’s very successful.”

Furthermore, the machine, which he had designed to make this consumable, was for low volume production, but now a new machine was needed to mass-produce them.

So, in this case, the customer was the one who was developing the machine that would use these consumables. Nevertheless, this process also required a synergistic relationship where feedback was received on the product (in this case consumables) that allowed SIC to carry out development according to the customer's requirements. This process of getting feedback from the customer on the consumables appears to be similar to that used for getting feedback on the machines. In this case, they could not do further development without feedback from the customer.

Auto-consumable during fieldwork

When this research began, the product had satisfied the customer's requirements and low volume shipments had started. One person, who was from manufacturing, was trained by the engineer on how to use the low volume manufacturing machine to make the consumable, and how to do quality checks and package the product for shipping to the customer. This part appeared to be totally under the direction of the engineer in Engineering, as opposed to Manufacturing.

Auto-consumable summary

Figure 11 shows the process that auto-consumable appears to have gone through. Like other products so far discussed, this product was also started by the founder-owner. The development phase appears to have included research and development in an intertwined fashion where the two phases seem blurred, much like Model-S. The development and building of low volume manufacturing equipment also took place in Engineering. Even when shipping the product to a customer, Manufacturing did not

seem involved, with the exception of providing an individual to do the work under the directions of the engineer in charge of the project. Therefore, research, development, and manufacturing phases all occurred in Engineering. In this case, besides the product development, the manufacturing equipment was also developed and built in Engineering.

The development process included the feedback from the customer, who was in the process of developing the equipment needed to work with this auto-consumable. The feedback was used to further develop the auto-consumable, so that eventually the auto-consumable was fine-tuned to the customer's machine and met the customer's specification for reliability. So, the process was similar to the Model-S machine process in that feedback was used to make adjustments to meet customer requirements.

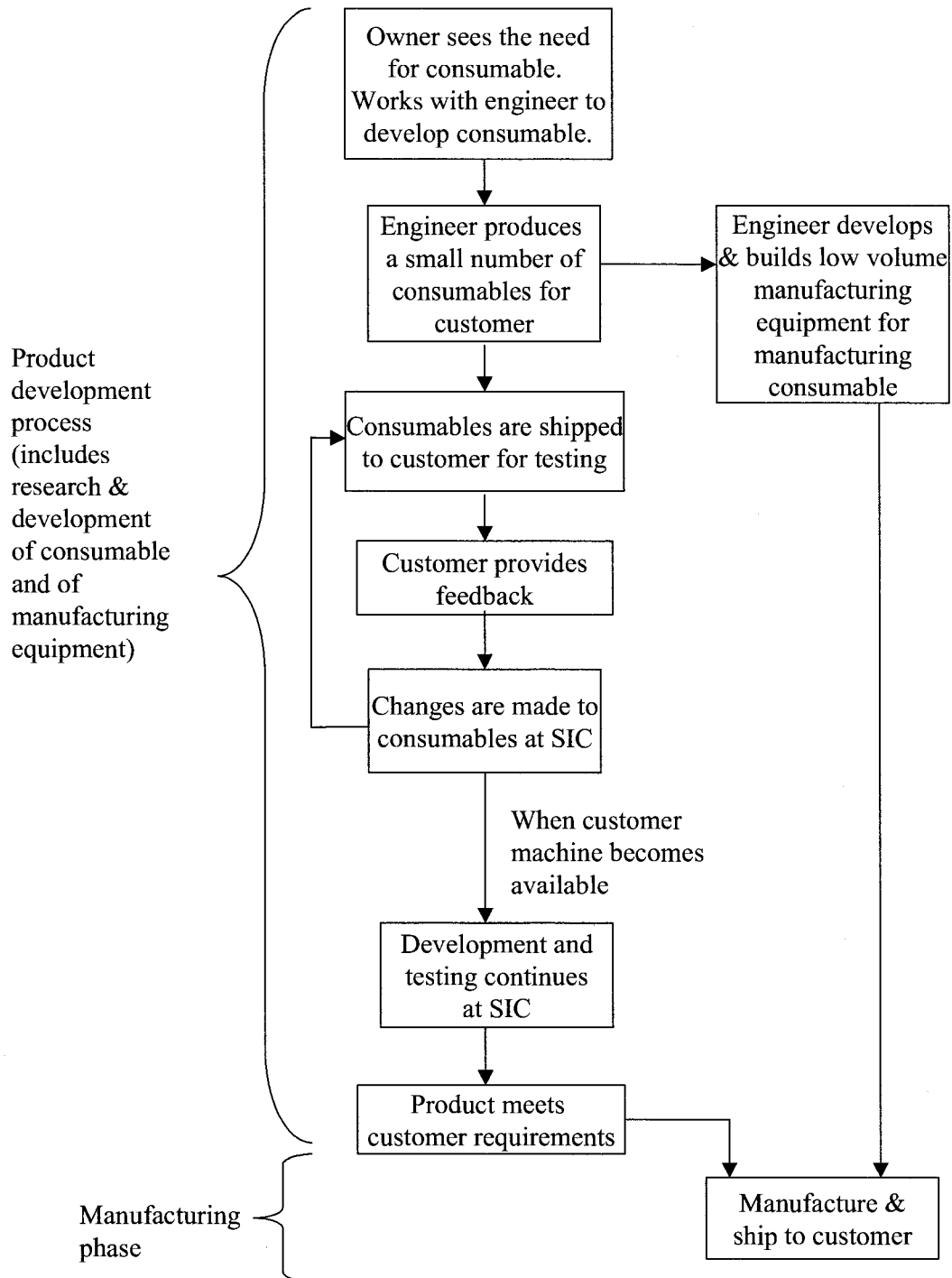


Figure 11 - Auto-Consumable Development Elements

CHAPTER 6: NEW PROJECTS

New projects include projects that began after this fieldwork. Table 4 shows the list of the projects in this category.

Table 4 - Projects in the New Projects Category

	New Projects
Machines	Model-B
Consumables	Special orders Model-Q-N

Model-B machine

One of the projects that started at SIC during this research was Model-B. This was a machine that incorporated the functions of Model-S and Model-7 in one. The project required mechanical, electronics, and firmware engineers and an industrial designer. It was intended to replace the Model-S and Model-7 pair. The engineer who was working on it explained that a new implementation of the function of Model-S had been developed and the idea was to join this new implementation and a modified Model-1 into one machine.

The theme throughout this project was a constant anxiety about what the expectations were. Was this something that was going to be shipped to the customer or was this a proof of the concept model only? The reason for this anxiety was the notion that as soon as a ‘breadboard’ was completed and tested, it might be shipped to the customer. A ‘breadboard’ is not a finished product by any means, but a rough model that is built to show that it can be done. In other words, it is a proof of concept model. It seemed that this fear was based on what was experienced with the Model-S.

Another question was how many prototypes could be made in the two weeks that they had allowed themselves. Model-B was a product that the founder-owner wanted to build and Engineering had agreed to come up with a prototype. Working on two prototypes was complicated because each machine required parts that were hand made and probably not fully documented, which meant that the engineers making the prototype had to do more work in an already shortened schedule. The other complication was that the parts were being designed and tested as the product was put together; design and testing was merged with research. There was a feeling of uncertainty as to why this project was being done and what its future was. This uncertainty bothered the engineers because the decisions they made depended on how Model-B was going to be used. If it was just a proof of concept for developing a prototype, then they could do what was needed to get the prototype done. But if it was to develop a machine, then more than two weeks were needed and the approach to development needed to be agreed on. In other words, how they interpreted their next steps depended on what their experiences told them was appropriate for the phase or purpose of the project, since there were no rules to follow. To add to the ambiguity, one of the key mechanical engineers was already working on another project that needed to be released to Manufacturing.

In this project, numerous and frequent meetings were held. During the kick-off meeting, one of the team members said, "A lot of coordination would be needed between people [in the team] and three brains have to coordinate." Another said, "I'm worried about coordination between people and I don't see how it's going to happen." The speed and the quantity of work in the project was one of the factors that made coordination a concern for all involved. The other factor was the project's unclear status. The decision

was thus made to have frequent meetings. The perception was that there was much to do, pieces of the system needed to be designed independently, coupling between pieces needed to be completed, and when all was put together, it had to fit, so that they could do integration.

One of the uncertainties that contributed to the low morale is expressed by an engineer's experience on a past project: "This was one of the most important projects in the company and it is now totally forgotten after it was finished. People are worried that Model-B would go the same way." He is referring to a prototype of another machine that was taken to a trade show after much work, but a decision was made to discontinue work because of lack of interest by potential customers.

Despite unanswered questions about the customers for Model-B, there was a real sense of urgency to get it done in two weeks. Technical discussions on key issues, such as whether one or two controllers should be used, were decided without much analysis. Each person was in charge of his own piece of the project, which was not really discussed, questioned, or scrutinized by others. The overall project plan was really defined by the two-week time frame that they had to complete the project. The interfacing between individuals and units was done to accommodate each other, and not to fully discuss optimal design choices. Each person only had control over his own part and interfacing between these parts was done to bring the whole product together. No written document was mentioned as a specification for a part or for an interface. Communication was by word of mouth and very fluid. It was not about designing an optimum machine, but a quickly-built one.

I observed people working in the lab on this machine. It literally looked like two separate machines being put together. There were two power supply cords and documentation was rudimentary. The mechanical engineer photographed the parts so that if the product were shipped, he would have an idea of what the parts were and how they were put together. This was what he had learned from working on Model-S where this had happened to him. The electronics were in different pieces. It was not one integrated printed circuit board, but different parts. Each person working on the project independently contributed to the making of the machine. The likelihood of another one being produced exactly the same way was low. It looked very much like a proof of concept model.

All the team members and the vice president of Engineering attended the follow-up meetings where the engineers would talk about what each one was doing. They would then adjust to meet each other's needs. The integration date had started slipping due to the autonomy of the groups; it was not a formal decision.

Every meeting followed a similar pattern. First, immediate concerns were addressed, i.e. what any individual needed to get done. Second, those who were affected by any of the events that were taking place on the project would talk about them. This allowed others to coordinate others' plans into their own ability to meet deadlines. Individual team members would use reactions from others as feedback. Third, adjustments by individuals would be made to accommodate to other engineers and the deadline for integration would be adjusted if necessary. As Sam, the lead mechanical engineer on this project, put it, "There are a lot of factors. There are requirements that are constantly changing. It's hard to plan day to day. What we do needs to help others.

You need to interact with others, need to be flexible, need to think of your part and your part interacts with other people's. Lots of coordination." Thus the meetings were for making adjustments and coordination to allow for productive interactions, under an aggressive schedule, among all the different members of the team. This allowed a number of people to work independently, yet as a team. It also seemed to provide a degree of support and reduce anxiety. These discussions and schedule adjustments provided support for individuals working feverishly to get their own parts done.

In one of the meetings, the tensions became high when the schedule slipped again. One of the engineers said, "We are not working to requirements. We are working to a deadline but we don't know the next step." Sam responded, "Next step is iteration of the product by testing it." Sam had been at SIC for a long time. But then the question of who was going to make another one or two, so that they could do more testing came up. Was it Engineering or Manufacturing? Another engineer said, "When are we going to see the big picture?" Yet another said, "The Model-1 should be redesigned for the final product because it's old technology."

Only Sam seemed certain of what the next step was. He said that this machine was being designed to sell consumables. If Model-1 were to be redesigned, they would miss the market opportunity. Sam had worked on Model-S and was comfortable with that process. He appeared to be looking at this project as taking the same route as Model-S.

The ambiguity of purpose was palpable in these meetings. No one seemed to know the goal. How was it that this project had been started without even a common

understanding of where they were going? There was much concern about the dead end aspect of this project; perhaps all this work was going to go nowhere.

Although Sam thought of this as just another SIC project where a machine was being designed to sell consumables, much the same way as Model-1 or Model-S, others thought that there should be a separate group outside of Engineering that would do these proof of concept projects. This is what Otto and Wood (2001) call the research phase. The contrasting perceptions were clearly worlds apart. One person saw this as the way machines are developed at SIC, while the other saw it as research and totally outside of development engineering. It was not clear how this had happened. They debated whether there would be further development on this machine or whether this was going to be the final product. Sam called this engineering with the next step being manufacturing, while another called this proof of concept with the next step being development. These were very different ways of looking at what they were doing. It was not clear why there were such different perceptions as to what was going on or even what phase the project was in. The invisible or blurred line between what looked like research and what looked like development appeared to be the cause of these conflicting views. At SIC, these two phases could be intertwined, as in Model-S, or separate, as in Model-7.

There did not appear to be a plan known to this level or it was too ambiguous to understand. There was unease about the ambiguity, but some people were more concerned about it than others. The perception that things were being done haphazardly and without planning troubled them. One of the engineers lamented, "If you don't believe in the product you are building, how can you get up and come to work everyday to kick ass." This obviously had an effect on the morale.

After a one week and two day slip, they started characterizing the machine. I attended another meeting at this time. The mood had changed. The team members were much more relaxed and were joking around. They were in a much better mood than in previous days. Their immediate task was to continue testing and tweaking. They decided that the next step was to alert the engineering test department that the unit was coming their way for testing. However, the discussion went back to concerns about what the next step would be. One of the main concerns was that the product contained the “guts” of Model-1, which required much tweaking. Someone commented that there was “a lot of voodoo” and that a clean design would save the company money. Another person asked what features needed to be demonstrated. There were no clear answers to these questions.

In the next few days, everyone continued tweaking the firmware, mechanicals, and the electronics. As one of the team members commented, “We have a great team. They take things seriously and are very responsive.” I asked, Sam, the mechanical engineer who worked on the project, what kept him at SIC. He just pointed to Model-B and said “this.” He explained the design of the machine, showed me his lab book, and talked about how he built some of the parts in the machine shop. I saw the pride with which he talked about the technology and what Model-B could do. As an engineer myself, those feelings resonated with me.

However, the project took an unexpected turn. When I asked one of the team members what was going on with Model-B, he replied, “Nothing at the moment. It’s just sitting there. We are busy on things that will make the company money soon. There are things that have gone into production, Model-S and Model-7. So no one is working on

Model-B at the moment.” I asked another team member what happened at their last Model-B meeting. “We didn’t really get anywhere. There was conflict between what the team thinks the product should be...Some [team members] think that we shouldn’t be putting an old Model-1 into this Model-B because it’s old technology and that we should redesign what we have to come up with a better product. But this will take a long time. Ed wants to develop something where we can keep our foot in the door with [the customer]. A quick turn around thing. A six month project. After that, we can then build a machine that’s got the modern processor...But for now, we need to get the product out so that we don’t lose the customer.” Another engineer said that the direction should come from the founder-owner and the CEO, and that Paul, the vice president of Engineering, was going to meet with them to find out. I looked at the area of the prototype. There was no activity. It was hard to believe that all the frantic activity had come to a sudden halt. People had been redirected to tasks required to release a product that needed to be shipped. But this was the way it had to be. For the Model-S and Model-7 to be started in manufacturing, a degree of engineering involvement was needed, as described previously.

The comment that was made about redesigning Model-1 with a new processor was something that some in Engineering were discussing. The processor in Model-1 was going to become more and more difficult to obtain. This was one of the main reasons for the push to do this. The other was that Model-1 was considered an old technology that was never designed to be manufacturable. These conversations reminded me of what I had heard about Model-2.

During the rest of the fieldwork, Model-B was put on hold. It was never restarted, because after Model-S and Model-7 were shipped, Model-Q became the new priority and consumed all the resources.

Model-B summary

The founder-owner started model-B much like the other products. The process described above, if continued, might have ended up like Model-S. According to Sam, it seemed that the founder-owner wanted to take this product in the same direction as Model-S, but for some reason, this was not being communicated.

The way the product came together was that each person worked separately, based on how they interpreted what needed to be done based on their own expertise and experiences. So, at a technical level, individuals worked on their own pieces without much technical discussion with the others. However, the coordination needed for integration of these different pieces was done at a team level in these frequent meetings. The team members were accommodating and cooperative. Project slips were justified in a way that did not point to any one person. The focus was on individual adjustments and creating an impression of cooperation. So, even though the technical aspect was performed independently, the overall coordination of the project was team oriented.

The skills seen here were more than just technical; they included the ability to work as a team, interact with others in a productive way in a stressful environment, and be flexible to deal with changing and ambiguous needs and events. There were some in the team that had a problem with this type of environment, but there were those like Sam, who thrived. However, everyone got his or her part of the job done.

The case of Model-B demonstrates the ambiguity and multiple perspectives that can underlie a seemingly holistic process like PDP. Those like Sam, who had been through a project such as Model-S, had different ideas of what was next compared to those who had not been at the company or had not been involved in Model-S. There were different views on *what* was next and what *should* be next. These different views came from individual interpretation of the project.

Special order consumables

Special order samples of consumables were made for the sales people or customers who had special requests. The person in charge of making these consumables, Anne, put together attractive samples either for SIC's sales people to show customers or for customers with special requests. She spoke to the customers who provided their requirements and she searched for materials that would meet them as much as possible. She then built trial samples by hand for the customer and awaited feedback. Once the customer requirements were fulfilled, Manufacturing produced the required orders in large volumes.

Model-Q-N consumables

Another new consumable was evolving from the consumable for Model-Q. The idea was conceived by the founder-owner and developed in the industrial design group. It was patented and was ready to be shown at a trade show. The designer shipped these to the founder-owner at the trade show and it was expected that the feedback from the show would determine the fate of this product. So after a week, based on the feedback from the trade show, it was decided that changes were needed. A few weeks later, I saw a number of different versions of this particular consumable. The product had evolved to

incorporate the feedback from the trade show. Figure 12 shows the process that Model-Q-N consumables appear to have followed.

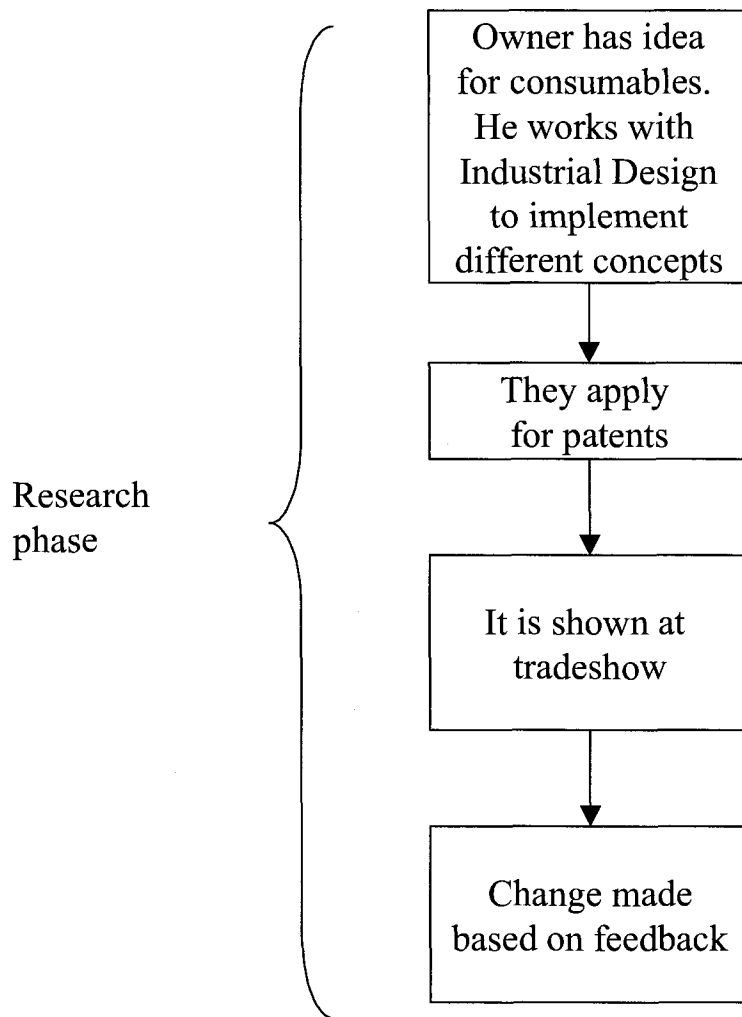


Figure 12 - Model-Q-N Consumable Development Elements

Consumables summary

The consumables are the profit makers for SIC. There appear to have been changes in the way consumables were developed in the past two or three years. Some engineers told me that Engineering used to develop and test the consumables, but now

this development took place in Manufacturing. However, from my observations, there are more people involved in the process of developing the consumables than just manufacturing. It seems that people in manufacturing engineering work on the development phase after the founder-owner and the industrial design group have had a chance to carry out the research phase and to generate recommendations. So the research and development phase are separate for consumables. Figure 13 shows the various phases of consumables development and the functional groups involved at each phase.

The consumables are also put through the process of getting feedback from either trade shows or customers and changes are made to the product to incorporate this feedback.

One individual, outside of Industrial Design, described the process for developing consumables as follows: “[The owner] comes up with the ideas and he tests his ideas and gives it to Manufacturing. It’s a manufacturing engineering kind of process, not a design engineering one... You just have to refine the manufacturing process by trying different settings on the [manufacturing machine].” Another individual said, “Basically, we go from design, what we want to do, to manufacturing, what we can do.” There appears to be an agreement as to how things are done for consumables, that is, the process that the idea goes through to become a shippable product.

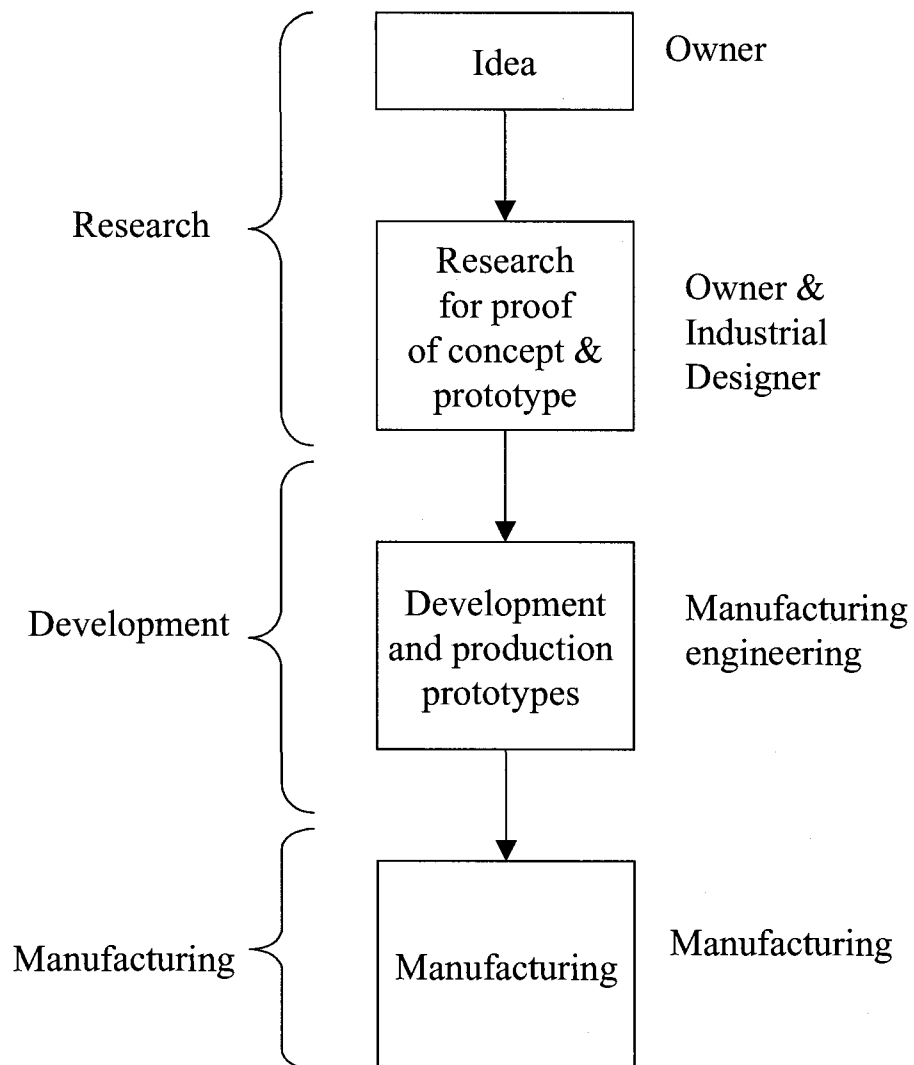


Figure 13 - Consumables Development Elements

It seems that although consumables are technically sophisticated, they are relatively simple compared to machines. There are many disciplines involved in the development of machines (mechanical, electronics, and firmware engineers, industrial designers, and manufacturing engineers) and their development takes more resources and

time. It takes many parts and steps to design and develop a machine, whereas it takes relatively fewer materials to develop consumables. The development of consumables is more of a manufacturing process, whereas the development of machines is an engineering process.

Another difference is that consumables appear to have a distinct research and development phase. The founder-owner and the industrial design group do the research phase for consumables, while manufacturing engineering does the development phase. For machines these phases are intertwined, and include the founder-owner and the resources available in Engineering working to carry out research, development, and manufacturing of the prototypes. This complicates things because research, development, and manufacturing are different areas that require different sets of skills. So perhaps the separation of the phases for consumables brings clarity to the task at hand. Some of these factors contribute to the difference in the process of developing machines and consumables. Another factor may have to do with the attitude of people who work in Industrial Design and who shape the process for consumables. One of them said, "Smart companies have an advantage as times change. They don't have a baggage of people, way of doing things...They do things differently, that's what we do here a lot. You really have to. We do planning and follow through, but kind of do it in a different way. It's incredibly fluid."

We have seen that Engineering at SIC performs a number of functions (continuation engineering, research, development, and manufacturing), making it a company within a company; Engineering appears like a multi-functional organization that performs product development and manufactures prototypes, without explicit rules. The

external focus of SIC brings the ambiguities of the outside world into the inside world of this group called "Engineering." Although ambiguity is considered commonplace in the research phase, it is not normally the theme in the development phase, much less during manufacturing. At SIC, the intertwining of research and development spreads ambiguity into the development phase.

CHAPTER 7: DISCUSSION

This thesis has demonstrated that the need for interpretation is grounded in ambiguity. There are two facets of this ambiguity: first, the content of any step required in the transformation process, despite being thought of as clear by those involved, is not fully specified. Second, the iterative nature of the transformation of ideas into products leads to inputs passing repeatedly through the same functional “step.” Therefore, assigning actions to be taken upon an input is ambiguous and cannot be resolved simply through a process of technical trouble shooting. So interpretation is done by people interacting with each other, as multiple stakeholders try to make sense of what is going on and what needs to be done; the challenges are as much social as they are technical.

An ideal product development process, as described in engineering literature, is a specific sequence of prescribed phases, each defined by different functions. Resources required to perform these functions are specified and the engineers performing them have a clear idea of tasks and the sequence in which they need to be performed. This creates a methodology that is generalized, prescriptive, rule-based, and rational. This is the black box view of a product development process. It is “used by cyberneticians whenever a piece of machinery or a set of commands is too complex. In its place they draw a little black box about which they need to know nothing but its input and output” (Latour 1987:3). This is an outsider’s view of a product development process that is similar to Latour’s “ready made science” (Latour 1987:4). The idealized product development process is “ready made” engineering.

After nine months of ethnographic data collection on different product development projects at SIC, the process of transforming ideas into products appears different than the ideal. Much like what Latour calls “science in the making” (Latour 1987:4), at SIC one sees engineering in the making. Looking at how products take shape at SIC is looking into the black box before it’s closed. One sees the complexity and the mess, the ambiguity, the exploratory and incremental nature of engineering, and the interpretive nature of engineering work during product development. What happens cannot be put into clean boxes and labeled, with inputs and outputs nicely specified. The tasks that engineers perform, before closing this black box, are not rule based, but interpretive. Although some common functions can be inferred, these functions are not clearly bounded, specified, or sequenced. The inputs and outputs are not clearly defined, nor do all the products pass through the same set of functions. Because the tasks needed to perform these functions are not prescribed, the product development process at SIC is not generalized, prescriptive, or rule based. What happens is much more ambiguous.

The founder-owner performs what can be called the market research function. It includes attending trade shows or talking to distributors and customers, and yields many ideas for products. The development of these ideas is a complex process, which involves knowledge of the market and of the history of the product area, a passion for the product, and a constant search for niche market needs. In a conversation with the founder-owner, Ed, about where ideas come from, he said, “When it comes to ideas, different products have different events.” By events, he appeared to mean circumstances. “Customers will say we have some need, but I have to have an appreciation of it to see it. I love [SIC products], so I always think of things related to [these products]. I have about 20

different things going on. Some of them I have been working on for years. I wake up at 3:00 in the morning and I write down some ideas. I document them in this book with places for witnesses to sign.” This witness signature is for patent applications, because he considers these ideas to be the intellectual property of his company. When asked if he gets his ideas from customers or if he thinks about ideas and then a customer asks him for something that matches with one of his ideas, he said, “It works both ways. Sometimes, I look at a range of things and I think of a number of ideas that fit in different places. Sometimes the customer asks for things and I come up with a way of solving the problem.”

Trade shows or customers sites are also where products can be tested. One of the employees explained that Ed had gone to a trade show to demonstrate one of the prototypes that had recently been developed and added, “Ed said to me that we wouldn’t have any products if we didn’t have trade shows. We would keep working and going on to improve things forever. Trade shows are a deadline and we have to do our best and show it [SIC products that are in development] to get feedback.” So, trade shows allow Ed to get new ideas, show off new products, learn about the competitor or customer needs, receive feedback on the product idea, and a timeline for product readiness. Trade shows also determine if a product idea should become a product or if it should be abandoned. For instance, an example of success at the show launched Model-Q as a feasible product idea to pursue, whereas a lack of interest would have meant that it be abandoned forever. Aside from trade shows, customers are also a source of product ideas and a test site for SIC products. Problems reported by customers are corrected in the next revision of the product. Customer feedback on features is used as valuable input to the

design of the product. SIC customers use SIC machines and consumables to provide a service to their own customers. Based on their customer feedback and their own use of the product, they provide valuable feedback to SIC on features, which are then incorporated into the design. This collaborative effort incorporates end-customer needs into SIC products; the boundary between company and customer is ambiguous.

Therefore, the market research function is an exploratory interaction between Ed (SIC) and the outside world. This function is performed for different purposes and at different times and may involve other functions. Market research may be performed for an idea or for a product. It may involve Engineering or Industrial design. Its inputs and outputs vary, the tasks required to perform it vary, and the resources required vary.

The proof of concept/research function generally involves Ed working with Engineering or the Industrial Design group to develop a proof of concept model for his ideas. This might lead to the development of a prototype by one of these two groups. A prototype might either be sent to a customer or a trade show. An example of this was the Model-Q machine, which was shown at a trade show and was received enthusiastically. This prototype might then undergo further modification or development, based on customer feedback, or might be abandoned if no interest is shown. This process merges the proof of concept/research function with the market research function.

Customers who receive prototypes use them to sell new consumables, which blurs the line between a prototype and a finished product. They communicate feedback on how they use the product and the problems they see, among other messages. This feedback is often incorporated into the next version of the prototype at SIC. With each iteration, a certain degree of Design For Manufacturability is implemented, which is a

task clearly outside the research function. This merges the proof of concept/research function with the development function. An example of this is Model-S where twelve versions of the prototype were developed over a period of two years. What determines an acceptable output from this function is ambiguous.

So, the proof of concept/research function is not a concisely defined and limited set of tasks that is performed and set aside. It is intertwined with the market research and/or development functions. It is also performed iteratively, so it is performed at different times and for different reasons during the transformation of ideas into products. There is ambiguity as to where the inputs to this function might come from and where the outputs might go. The beginning and end of this function are also ambiguous. The engineers performing this function face much of this ambiguity and are constantly interpreting in order to transform the inputs they receive to what they perceive to be the required outputs. During this process, they might incorporate the history of the prototype, the new feedback from the field, Ed's ideas or a perception of what Ed may want, and resources available to them. Based on their own background and skills, they interpret what all these mean to them and what they should do next. This interpretive process is often a struggle.

The development function for machines is where "productization" is performed. This includes tasks such as making a product more manufacturable. This is not necessarily a separate function. The development can be intertwined with proof of concept/research and/or market research, such as in Model-S, or done separately, as in Model-7. For consumables, this function is performed in manufacturing engineering. Prototypes of consumables built in Industrial Design are transferred to Manufacturing,

where a process for the production of consumables is developed. The output from this function can be used to perform market research or to enter the manufacturing function.

Therefore, much like the research function, the development function is an iterative process, intertwined with other functions, with ambiguous inputs and outputs. Similar to the proof of concept/research function, this ambiguity results in engineers using the interpretive process to decide what they should do next.

Generally, the manufacturing function is not considered part of the product development process, but at SIC, it is an integral part of how an idea is transformed into a product within Engineering. Other such functions are continuation engineering and technical support. At SIC, these functions consume a large number of engineering resources, addressing problems on the production line or from the field.

The manufacturing function is just as ambiguous as the research and development functions. It can take place in Engineering, Industrial Design, or Manufacturing. For instance, 40 Model-S and Model-7 machines had been built by Engineering and shipped to customers over a two-year period. In this case, the manufacturing function was intertwined with proof of concept/research, development, and market research. Engineers were manufacturing the machines that were shipped to customers.

Products are also manufactured in Manufacturing. What determines the release of a product to be manufactured by Manufacturing is sometimes unclear. When handoff between Engineering and Manufacturing takes place, the knowledge needed to make the product is transferred between the two groups in a different way for each different machine. Examples of this were observed for Model-7 and Model-S. In the case of Model-7, people in Manufacturing knew its predecessor machine and they incorporated

the necessary changes to manufacture a new model with relative ease. On the other hand, for Model-S, this was a complicated and highly ambiguous task, and required much interpretive work for Manufacturing and Engineering people involved. Therefore, even the manufacturing function at SIC is interpretive work. Furthermore, the boundaries between Manufacturing and Engineering are porous.

Unlike the idealized product development models addressed in engineering literature, the product development process at SIC is not sequential, rule based, prescriptive, or performed the same way for all products. Nor are any of the functions performed in the process of development clearly defined or sub-divided into separate tasks. Each function is a combination of other functions, a combination that can vary according to product or other factors. Inputs and outputs to these functions are not clearly specified and sometimes not predictable. The beginning or the end of these functions and what determines them is based on different factors that are often tacit. Thus the specific activities required to perform these functions are ambiguous. To determine what should be done, the engineers involved in these transformational activities are constantly interpreting to transform inputs into outputs, based on what the specific situation means to them.

One factor that may drive this type of product development model is the new or constantly-changing niche market that SIC products satisfy. This makes developing products a risky business. The exploratory and incremental development approach allows incremental investment in development, which can be discontinued at any time if the market needs change or the product is not deemed viable. This minimizes risk, which is important for any small company with limited resources. This approach to product

development has consequences for the way Engineering is organized and managed, for the skills required by engineers who work in such an environment, and in general, for engineering education.

Engineering at SIC encompasses many functions, which are ordinarily performed by different groups in a company. These functions include market research, proof of concept/research, development, prototype manufacturing, technical support, engineering test/design verification test, document control, and continuation engineering. Different skills and focus are needed to perform these varied functions. One consequence of this type of organization is that it requires people with different skills who can perform in more than one functional area. However, it is unusual for any engineer to comfortably stretch over these functions in any depth.

Therefore, a broader and more generalized knowledge is required to be able to function in this type of environment. The majority of engineers working at SIC did not have a university degree in engineering, which likely allowed them a broader base of knowledge needed to perform over such a range of functions. Another consequence of this type of organization is the complexity that it brings to the management of Engineering across this range of activities; the position of any Engineering manager is made even more difficult by the undefined roles the founder-owner and even the CEO play in running Engineering. This accounts for some of the misunderstandings among those involved in product development. Since the position of the vice president of engineering is currently open, the possibility for an alternative management structure in Engineering could be explored.

This type of structure also blurs job responsibilities. This can be problematic, particularly when the individuals include the CEO and the founder-owner. Their participation in Engineering causes concern because different people interpret their responsibilities differently. Sometimes they have conflicting ideas about product development, which causes some confusion. On the other hand, it allows those from outside of Engineering to contribute to product development in ways that might not have otherwise been possible. One example of this was the product-marketing manager whose mechanical engineering background allowed him to work on documenting design changes and assembling Model-7. This task was outside of his official duties and outside the Product-Marketing department.

Engineering is therefore not just a department in this organization. It is more like a company located within a company and the boundary between these entities is permeable. This merging of a variety of functions in engineering contrasts with the official structure that one perceives initially, based on the various heads of departments. This contradiction creates confusion and conflict. Therefore, the official structure of the organization is inconsistent with its functioning.

One of the positive consequences of these merged functions under Engineering is that it allows a seamless transfer of knowledge between different functions. This is mostly because the work is done by the same people or by people sitting very close to each other. On the other hand, it causes delays and stress.

Merging the market research function into engineering product development brings a heavy external focus into Engineering. For instance, the management and engineering work done for an exploratory function requires a different focus and skills

than implementing a product that would be fit for Manufacturing. This adds complexity, which, combined with the blurred functions and job responsibilities, causes much stress, conflict, and various other problems. The question that arises here is how can one manage work that may require a variety of functions, which are intertwined, but need different skills and foci? This is a challenge that needs to be addressed in such an engineering organization.

Another consequence of this external focus is that it consumes the majority of resources in Engineering, leaving none for internal needs such as documentation or product improvement. This is perceived to be the reason behind the high level of continuation engineering, which takes resources away from new product development, and causes much frustration because it is interpreted as leaving the job unfinished or improperly done. It may be possible to accommodate some of the internal needs through more resources, but it appears that continuation engineering is an integral part of how products are developed at SIC.

The blurring of functions makes the development of explicit rules difficult. A positive consequence of this is that each product undergoes a custom development model; in other words, the same formula is not applied to all the problems and the combination of functions that are performed is based on the engineer's interpretation of the project needs. Even simple tasks, which could be routinized for efficiency, sometimes require rethinking. This creates inefficiencies and delays. It also causes confusion among engineers who are operating under different interpretations of the project and therefore on the nature of reasonable expectations.

The founder-owner has an extensive tacit knowledge of the product and the market. His history with the company provides him with a unique perspective. He is therefore an important asset to the company. His distinct experiences and skills, combined with reliance on the interpretive process in product development, sometimes causes others to misinterpret what he says or misunderstand his interpretation of what is going on. This causes confusion, misunderstandings, and frustrations among those who are involved in product development. A better definition of his role in product development and communication of his vision with engineers might reduce this problem.

In contrast to machine development, consumables have a separate proof of concept/research and development pattern. The proof of concept/research is done in the Industrial Design group, while the development is performed in Manufacturing. Individuals involved in research make recommendation to those involved in the development group. The consumables also go through the process of getting feedback from customers and incorporating this feedback in the design during research. The development phase produces a manufacturing model and refines the process of manufacturing.

So, one of the main differences between the machine and consumable development is that the proof of concept/research and development phases are not intertwined for consumables as they are for machines. Another difference is the development of consumables is more of a manufacturing process, whereas the development of machines is an engineering process. The issues encountered in machine development are not encountered in the development of consumables.

Overall, the transformation of ideas into products at SIC is considered successful and has allowed the company to grow. Beyond the challenges and needs discussed above, the manner in which this transformation occurs is not something that is taught in engineering schools, in the undergraduate or graduate programs. Much like the literature on PDPs, the process of learning how to apply engineering knowledge is theoretical, generalized, and prescriptive. A systematic approach is generally encouraged and considered appropriate. Most engineers become trained as product development engineers with a specific technical focus. They are trained to apply their technical skills within the constraints of a specific set of procedures in the environment they work in. An interpretive approach requires something more than this; it requires that the engineer explores and negotiates the environment within which his technical skills can be applied. To refer back to Latour's black box, engineering schools teach the engineering product development process as a black box. Besides technical skills, what engineers need to learn is what takes place inside the black box and the skills needed to effectively cope with life on the inside to get their jobs done.

The systematic approach to engineering development is an approach that assumes low levels of ambiguity and high levels of definition. At the development stage, the assumption is that much of the product has already been defined and the unknowns are minimized; what is left is implementation. At companies such as SIC, project definitions are generally fluid. The external focus of the company brings the ambiguities of the outside world into the inside world of Engineering. The merging of functions spreads these ambiguities throughout the entire product development. Dealing with a high level of ambiguity is therefore a necessary part of an engineer's job at companies like SIC. If

these ambiguities are not resolved at the organizational level, engineers will be expected to resolve them at the level of individual projects.

Furthermore, a systematic approach leads to the expectation that projects have a beginning with a clear problem definition and the engineer implements a solution, verifies it, and with some modifications, the project comes to an end. The engineer is rewarded or gets a sense of satisfaction on a job well done. The approach at SIC is much more exploratory and incremental, where the beginning is not so clear and neither is the ending. With continuation engineering as one of the functions performed in Engineering, it almost appears as if projects never end. There are also frequent sudden changes of direction. This aspect of product development leaves engineers very dissatisfied, for they are not able to see the results of their work; they feel “yanked around.” This lowers morale and causes conflict. Engineering is exploratory and sometimes incremental work, where the participating engineer learns and grows regardless of the outcome.

The new skills and expertise need to be recognized and rewarded as they are passed along to the next project. The engineer should be made aware that he can perform product development better as a result of what he has learned and how he has grown within the organization. As Bovy and Vinck tell us (2003:74), “The identity of the designer does not remain unchanged at the end of the design process. The designer progressively discovers more about society as he is in the process of transforming it and is thereby led to modify his actions and their results. The designer’s identity is therefore affected.”

This systematic approach also makes engineering product development appear rational and sanitized. Transformation of ideas into products is not just a technical

process, but also a highly social one. Technical knowledge is applied and technical decisions are made and debated within a social context. There are also emotions involved in product development; these can be pride for a job well done, jealousy, fear of losing one's job, anger for feeling ignored, indignation at perceiving that one's opinion is not respected, and so on. Recognizing the social and emotional aspects of product development would allow better social interactions and possibly lead to different types of technical decisions and solutions.

A systematic approach can also lead to a focus on the process needs as opposed to a focus on customers needs. This means that *how* things are done becomes more important than *what* is done. This could also imply a focus on internal needs as opposed to external needs. A focus on process can take the customer out of the picture for a period of time. In a fast changing market or an evolving market, this could be detrimental. A focus on customer needs creates a product that meets the customers' short-term needs as well as provides clues for their long-term needs. Although it seems that a balance between internal and external needs may be difficult to maintain at a company like SIC, it is possible that a degree of internal needs can be satisfied if they can be incorporated into a process that is not linear or sequential, but incremental and feedback-based.

Although most engineers work on a broad range of problems, there is often specific technical knowledge for which an engineer is hired and a specific set of functions within Engineering that he is expected to perform. At companies such as SIC, it appears that a much broader range of skills, outside of those learned in engineering schools, allows the engineers to stretch over the various functions that are needed to get a job done

within Engineering. For instance, the engineer working on Model-Q, who had a degree in aerospace engineering, had taken a course in welding and was welding the prototype for Model-Q in the machine shop. So, engineering knowledge, augmented with other types of skills and knowledge in different functional areas, and an attitude that allows this type of undertaking, is necessary for working in organizations such as SIC.

Most engineering schools also tout the ability to teach innovation. Consider, for example, the San Jose State University vision and mission page of the Engineering school website. Under Innovative Applications, it reads, "In addition to learning engineering theory and skills, our students must have opportunities to learn innovation--a capability highly valued in today's global economy. Given its close ties to Silicon Valley industry, the College is in a unique position to focus its efforts on developing innovative applications of technologies. Innovation, defined as the development and exercise of creative processes to "see" beyond limits and boundaries, has the entrepreneurial quality of understanding and meeting customers' needs. It often occurs across disciplinary boundaries with contributing members having various functional expertises. Further, the ability to innovate contributes directly to the success of enterprises" (SJSU 2007).

At companies such as SIC, there are no explicit rules for product development in Engineering. In the absence of rules, people rely on the interpretive process to decide what their next step should be. Individual characteristics, history, and the social processes by which they interact lead to different interpretations. It is possible that it is the interpretive process that allows contributions from a diverse set of people in constructing a PDP, technically and procedurally, which contributes to the innovative nature of products that are developed at SIC. If this were the case, then the interpretive

system in determining a PDP, as opposed to a rule-based system, generally taught in engineering schools, would be more conducive to innovative product development. Learning to negotiate could also help develop engineers who would more comfortably work in such an environment.

Engineering managers and engineers in organizations such as SIC have to be able to perform and develop products through this interpretive process. Engineering schools could better prepare them for this environment by moving away from a systematic (black-box) approach in favor of an interpretive approach and by teaching that the product development process is the integrated application of technical skills and social skills.

In conclusion, there are challenges in organizations where the product development process is interpretive, engineering functions are merged, resources are limited, and engineering is a combination of different functional groups. However, these challenges can be overcome if a model that supports an interpretive approach, rather than the idealized model, is used to organize and manage Engineering, and to perform product development. In the area of engineering education, the focus should be turned towards an interpretive model, as opposed to the prescriptive and rule based model. A broad range of technical and negotiation skills are needed to perform product development effectively in such an environment. Given the increasingly important role of small, innovative companies in creating economic growth, the issues addressed here will likely be of continued importance. In particular, the type of development process described in this thesis and its capacity to meet the changing demands of niche markets may be both a strength of smaller companies, as well as a challenge to their organizational structure and

processes. The implications for the skills of the engineers within them and for engineering education are significant.

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APPENDIX A: GRAND TOUR

Functional layout

The general functional layout of the organization is shown in Figure 14. All the functional groups are located on the first floor, with the exception of the industrial design group and the owner/president's office, which are on the second floor.

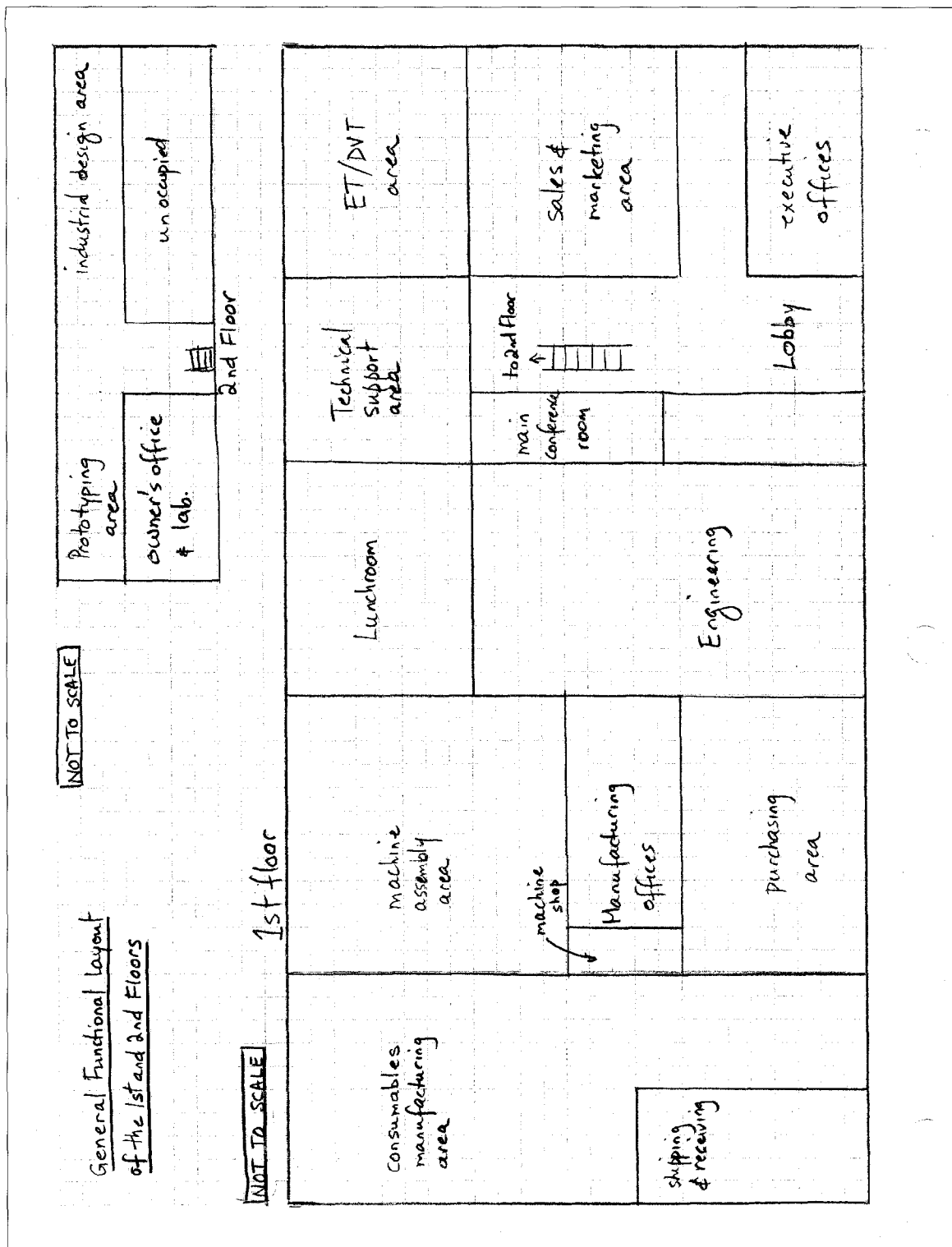


Figure 14- Functional Layout of the First and Second Floors

The lobby and the surrounding areas

Figure 15 provides a detail drawing of the lobby entrance and areas connected to the lobby. As you enter the lobby, you see the receptionist on the right, the visitor's area on the left, and the stairway that takes you to the second floor ahead. On the reception table there is a sign-in book for visitors. The receptionist gives each visitor, who signs in, a visitor's badge and notifies the person whom the visitor has come to see. Visitors are not allowed to go in unaccompanied. On the left of the entrance, there is one sofa, two seats and a coffee table with copies of METROPOLIS on it. Some of the products that are made with SIC machines and consumables are exhibited in a display unit, near the sitting area, presumably so that visitors will see them. Immediately past this point, you can see the stairs that take you up to the second floor. On both sides of the stairs there is a display of SIC products that show the evolution of SIC machines from the time that the founder-owner was a 13-year old teenager, until now. It tells the history of SIC, from the beginning until now. The display is in temporal order. On the left side of the stairs, the first object is an old machine that the founder-owner found in his parent's basement. This was apparently what got him interested in this business. This is followed by some of the experiments and prototypes that he built of the first SIC machine. Above these, along the wall, are a number of patents that SIC holds. There are also photos of people working on these first machines at SIC back then. The founder-owner and one of the engineers, Peter, are in one of the photos. They look to be in their twenties.

As you move to the right side of the stairs the current products are displayed. You see a big change. The current products don't look like prototypes, but completed

and professional looking machines. The name of the company, which one sees on the front door of the building and on the machines, is also the name of the founder-owner.

Just past the receptionist, on the right, is a hallway. On the right side of the hallway are the windowed offices of the executives, including the CEO. This is the power corridor. The Engineering and the Operations executives do not have offices here. There is a small conference room on the left side of the hallway. The hallway ends in a wide-open space, with a high ceiling, which is populated with a number of desks occupied by the sales and marketing personnel. This area feels open and airy.

In the lobby area, immediately to the left of the sofa and chairs, there are two doors. The left most door opens into a large room. One of the walls of this room is dedicated to the photos of all the people who work at SIC. The person who occupies this room is a customer support person who works with consumables. The right-most door in the lobby opens into the large conference room where most of the meetings are held.

There is a hallway below the stairs. Across the hallway is the technical support group. Going to the right takes you to the engineering test/design verification test area, while going to the left takes you to the Engineering and Manufacturing areas.

The engineering test/design verification test area is a large area. There are many lab benches, each of which has various machines or consumables that are being tested and characterized. The test technicians, who report to the manager of engineering test/design verification test, work in this area. The manager's workspace is in the Engineering area. You can see machines and consumables that are being tested, either by technicians or running on their own with some test firmware, any time you enter this lab.

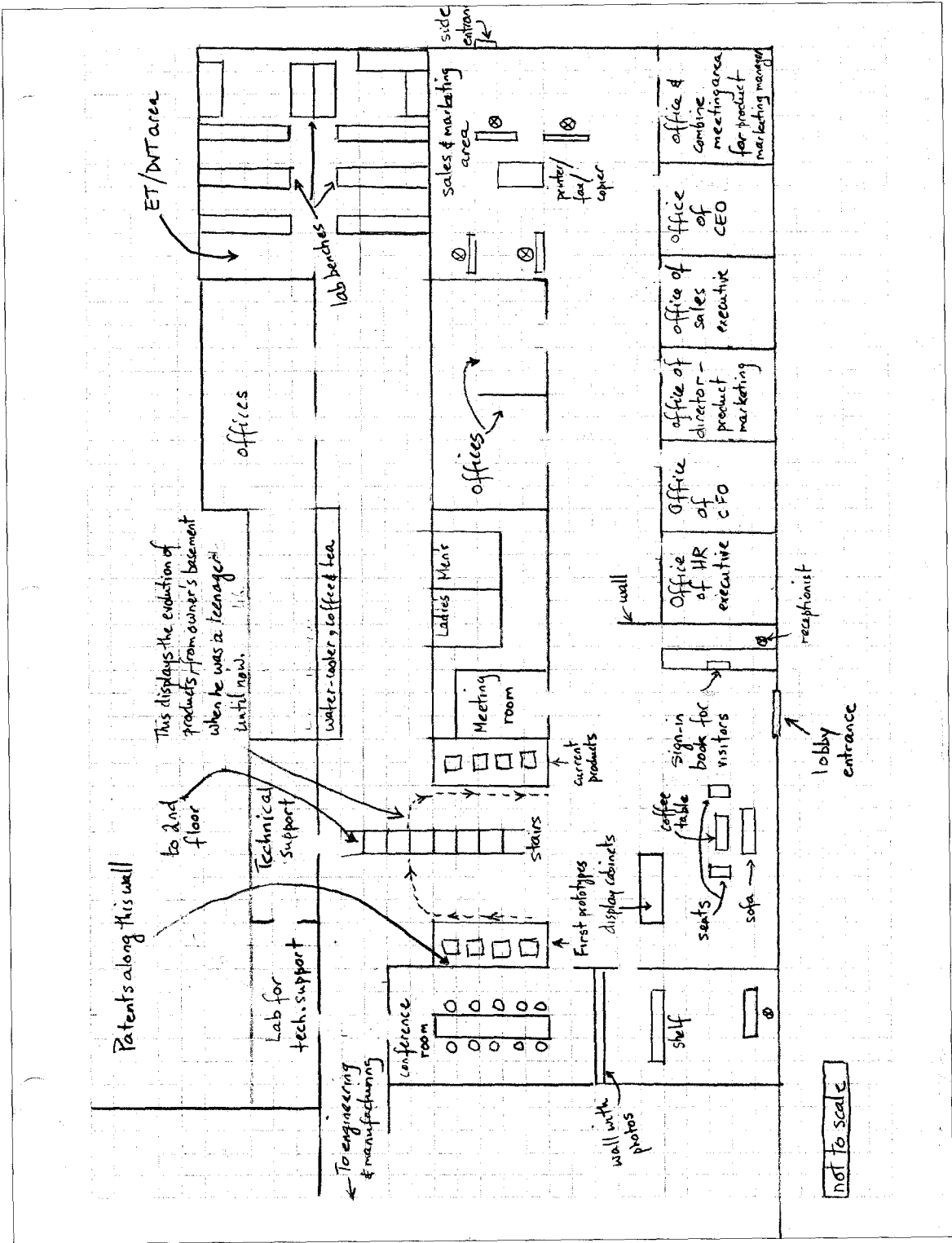


Figure 15 - Lobby and Surrounding Areas

The technical support group occupies two rooms. One of these rooms is a laboratory where repairs of the equipment take place. It has two large tables in the middle and shelves on the sides that hold various test equipment and parts. The other is an office shared by the supervisor of technical support and two technicians. This room has three desks, with a phone and a computer per desk. The supervisor and his technicians talk to customers by phone and sometimes visit customer sites. Products are shipped to this group for repairs or replacement. There are returned equipment or consumables usually lying around in this room.

The second floor

The stairs take you to the second floor, which is occupied by the founder-owner and the industrial design group. See Figure 16. This is the power floor. The founder-owner's office is on the left and the Industrial Design group area is on the right. The founder-owner's office and his lab are connected. The first room one enters is his office, which leads into the second room, his laboratory. The laboratory has tables in the middle and shelves with storage containers along the walls. This is a place where he can make prototypes of his ideas. His office has a desk, a table with two chairs and a visitor's seat. The partition at the front of the office provides some privacy. There is a shelf at the back of the office, behind his chair. It carries what look to be souvenirs and his child's drawings. From where he sits, he can see and be seen through the window at the front of his office. Standing in the lobby, one can see if he is sitting at his desk and he can see who comes in.

On the right side of the second floor is the Industrial Design area. This is the most colorful area in the whole of SIC. There is a nook behind the founder-owner's

office that is used as the prototyping area by the designers and by the founder-owner.

When I visited this area, there was a prototype for a consumable and a machine for making the consumable that was being tested. The actual Industrial Design area has three people. One of them is Anne, who works with a variety of materials to design consumables for the sales people and prototypes of custom products requested by the customer. Her area is located at the beginning of a large open space that is Industrial Design. Shelves that hold colorful materials that she uses for making consumable prototypes separate her space from others. The table in the middle of the shelves holds the products that she makes. She also has the SIC machines needed to make these consumables on the tables along the walls. The other two industrial designers, Steve and Luke, have desks for their computers, but also many different workspaces where they build their prototypes of materials and do experiments.

Back on the first floor, going left along the hallway below the stairs leads you to Engineering and Manufacturing.

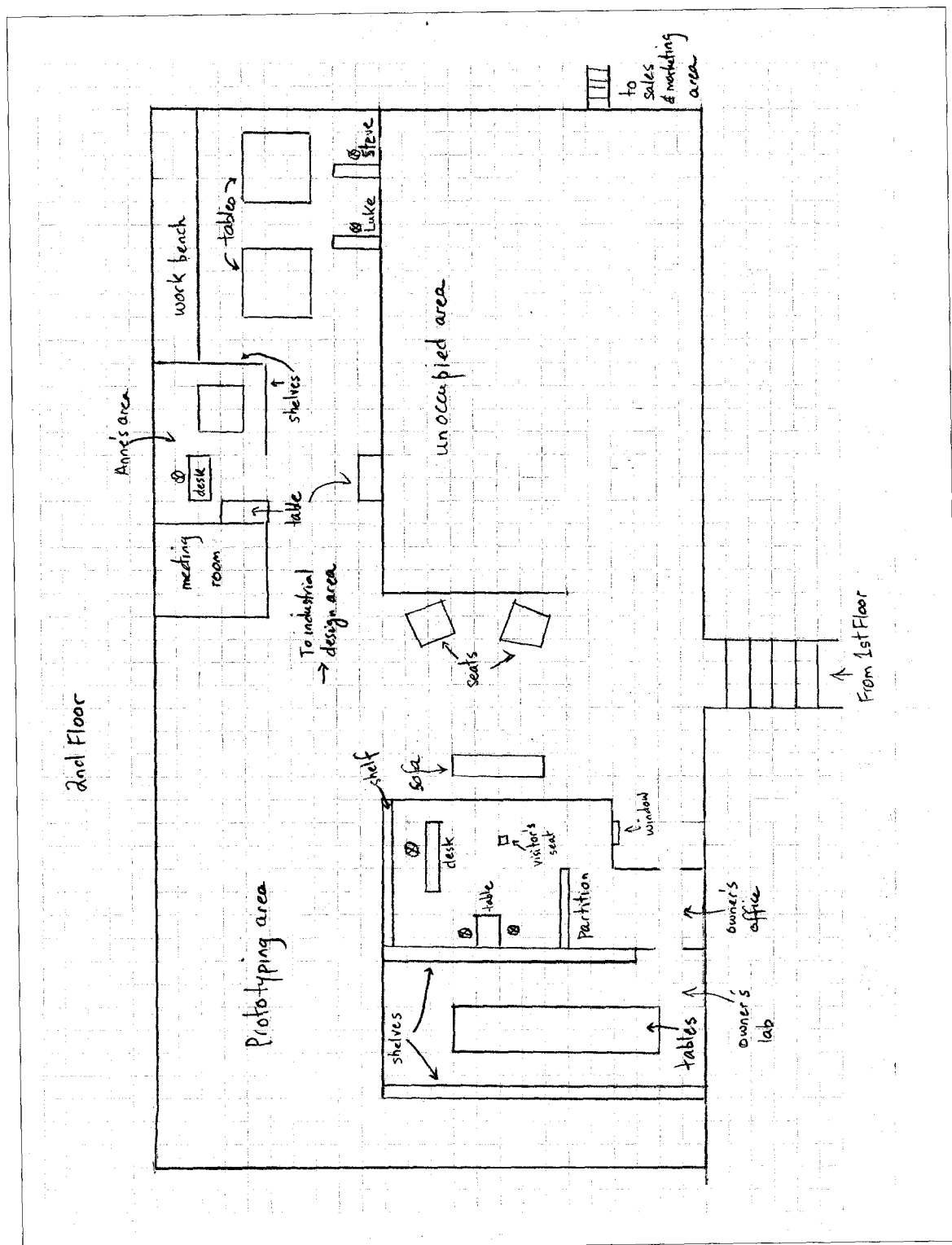


Figure 16 - Second Floor

Engineering

Figure 17 shows some of the details of the various things that can be seen as one goes along this hallway. On the right there is an open area that is used by Engineering for testing or prototype building. This area is an extension of the engineering laboratory. This area ends with the door to the lunchroom.

On the left of the hallway, directly across from the door of the lunchroom is the entrance to the place officially known as Engineering, occupied by twelve people who are not all functionally part of Engineering. The Engineering people include the Vice President of Engineering (VPE), two mechanical engineers, two electronics engineers, one firmware engineer, one mechanical designer and two engineering technicians. It also includes the manager of engineering test/design verification test, a manufacturing engineer, and a document control person. The area is open, large, and quiet, with only a few partitions. Each person occupies a laboratory and office combination type of workspace. Each workspace is personalized with a couple of desks or tables, bookshelves, and photographs. There are equipment, parts, tools and/or drawings related to what each person is working on. On the bookshelves there are data books that contain the specifications of the parts that they are using, textbooks, specifications, binders that hold patents, or even parts. Some of the workspaces have what look to be items related to one project. This may include the machine, consumables, or parts. Others areas appear to have layers of different papers, drawings, specifications, and other documentation related to a number of different projects. This may be because the engineer is working on these all in parallel. The VPE sits in his space located in the

middle of Engineering. The engineering lab, which is part of this space, is walled off and shared by all the engineers. People either work in their own workspace or in the lab.

People work on their own computers or on the machines that they are designing, testing, or debugging. The only woman in this area is the manager of engineering test/design verification test. The rest are all males.

The second entrance to Engineering leads to Purchasing and Manufacturing offices. The Purchasing offices are three cubicles in a row. The Manufacturing personnel sit in cubes that are located in a walled off space in front of another large conference room, which the Vice President of Operations seems to use as his private office.

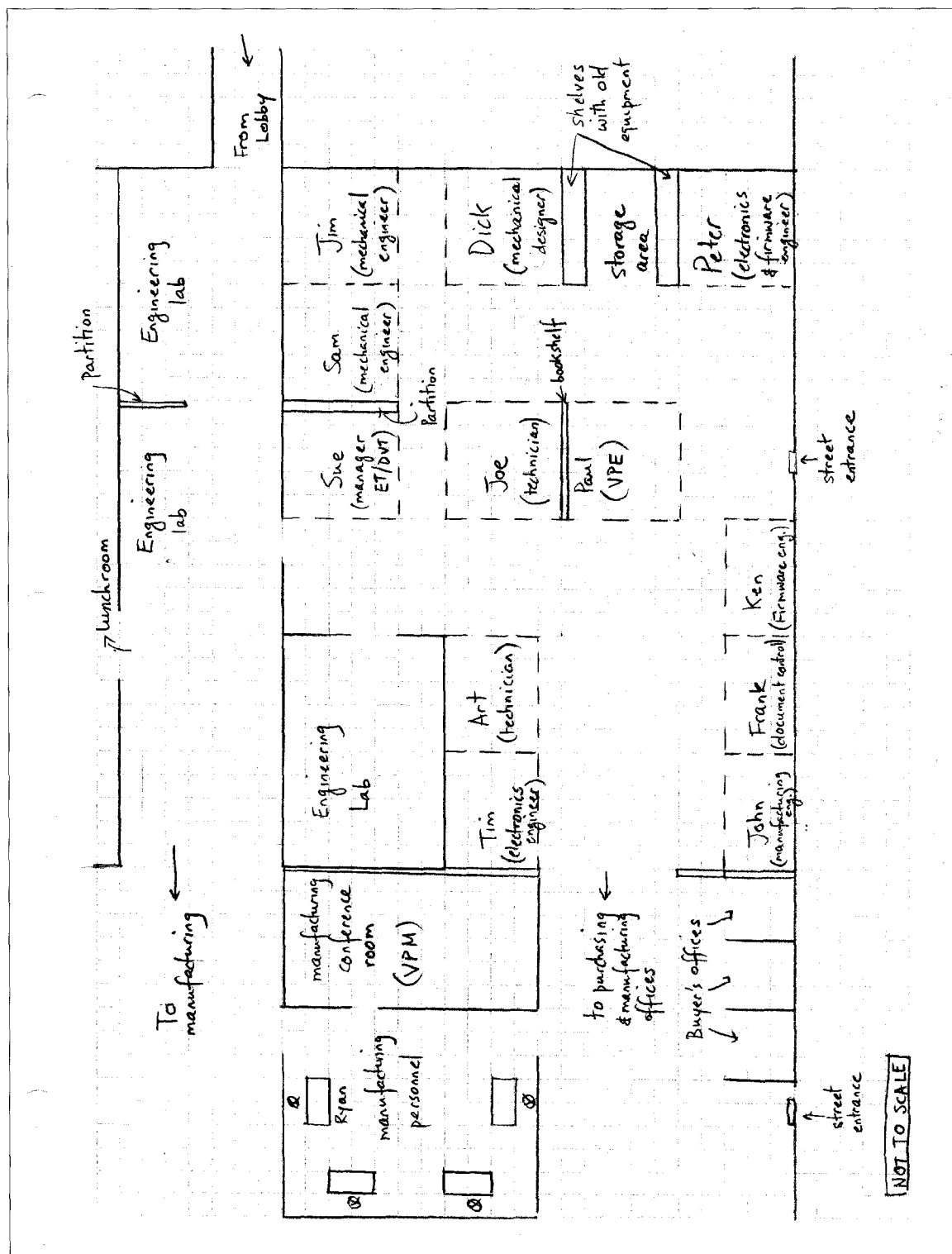


Figure 17 - Engineering

Machine assembly and lunch room

The lunchroom, shown in Figure 18 is a large L-shaped area. One section is actually used as a lunchroom. It has a counter with a sink, a microwave, and a refrigerator. There are a couple of coin operated dispensing machines for candy and drinks. A number of tables are set in the middle of this area. One sees different people have lunch here together. This includes the assembly line workers and supervisors, sales and marketing people, engineers, industrial designers, executives, and the founder-owner. This is the one area that people sit together, but don't necessarily speak to each other. The other area of this lunchroom is a flexible expansion area for a variety of things, such as temporary storage space, test area, ping-pong playing area and so on.

Past the lunchroom, along the hallway, is the beginning of the Manufacturing area. The first Manufacturing area is the assembly area for the machines. This area is literally the continuation of the hallway that leads to the lunchroom on one side and Engineering on the other. The assembly area is also an open space that is walled off by shelves that carry parts for the various machines that are being assembled. The middle of the walled off space is a number of rows of tables that have rollers on them, which allow assembly workers to roll partly assembled machines from one workstation to another. Different areas are used for different machines that are being assembled. The end of the assembly line is where the products are tested post assembly and then packaged.

Across from this machine assembly area is the machine shop, which contains a variety of machining equipment. The machinist is the person who is officially in charge of this area, although others, such as mechanical engineers and the manufacturing engineer also use this shop.

This section of the building ends with a wall that opens into another much larger assembly area for the consumables, where prototypes of the consumables are built for testing and manufactured for shipping. There are a number of large machines that are used for these tasks and a number of different technicians that operate these machines. There are piles of materials sitting on the floor, which are fed into these machines. There is also a lot of noise when the machines are operating. This whole area has the look and feel of a real factory, where raw materials go into the machines and products come out.

At the far end of the building is the shipping/receiving section. There are large door at the loading docks, where trucks pull in and out and load or unload their goods. This is where raw materials flow in and products flow out of SIC.

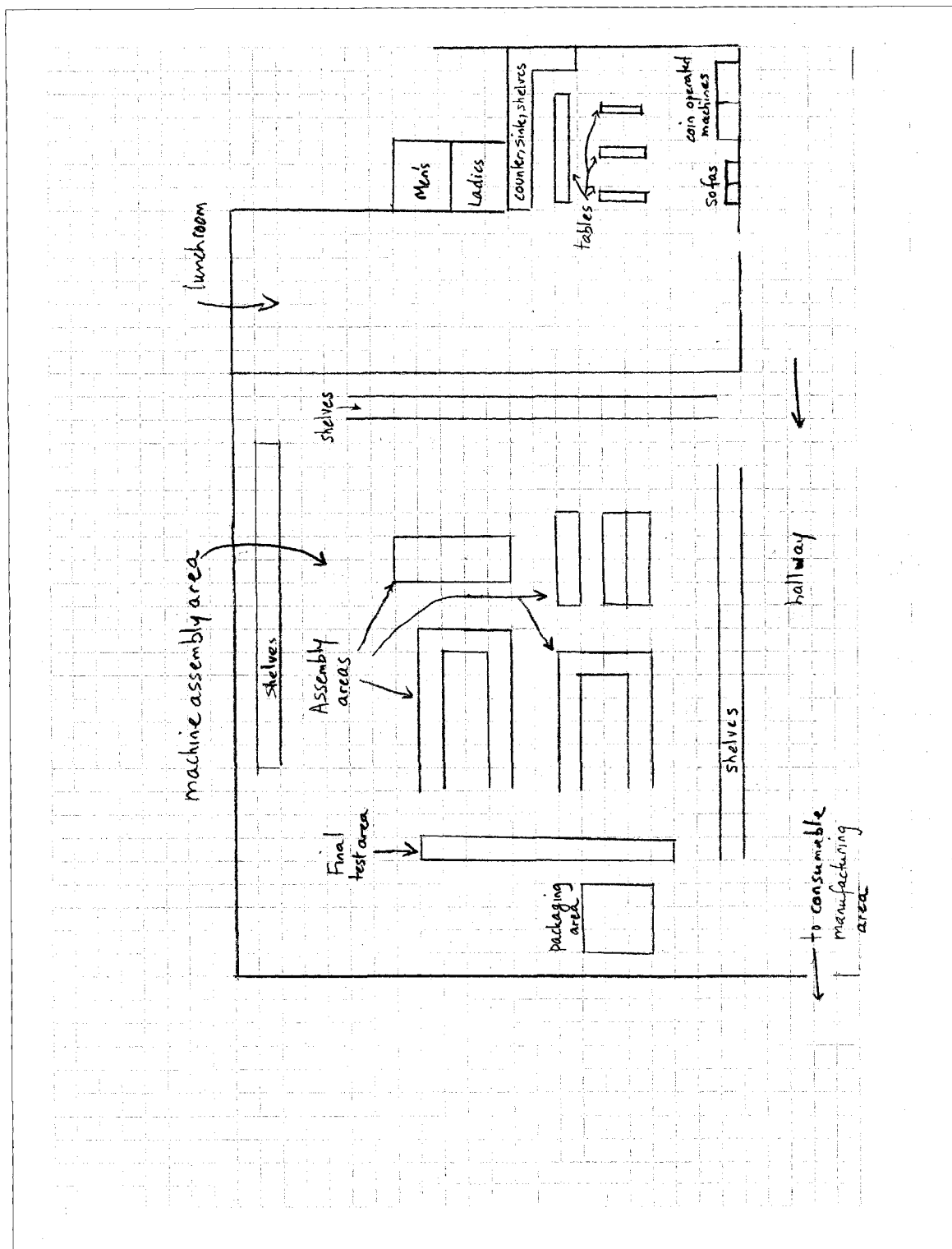


Figure 18 - Machine Assembly Area and Lunchroom