An Exploratory Empirical Study of the Role of Manufacturing in Product Formulation

by

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Abstract

In recent years, a considerable amount of attention has been paid to improve new product introduction projects (Hayes and Pisano, 1994). Many companies are attempting to remodel their design-manufacturing interface to ensure their product designs are easier to manufacture thereby reducing development cycle time and cost. However, the window of opportunity for manufacturing function to maximize its impact is at the front end of the new product project, namely product formulation, because up to 80% of a product manufacturing cost depends on the decisions made at formulation (Gerwin, 1993; Smith and Reinertsen, 1991). This study explores the following research question: if the manufacturing function is represented in the product formulation of the new product introduction (NPI) project, what effective role can manufacturing play?

To answer this question, an exploratory empirical study was conducted to better understand such a role of manufacturing. Field data and findings were gathered from on-site interviews with five companies, one of which was the primary site where five NPI projects were studied in depth. This study found that the primary site and one of the four secondary sites had practiced manufacturing participation in product formulation since the late 1980s, and another secondary site since early 1990s. These sites expressed their opinions that such a practice added value in reducing development cycle time, and improving the quality of decisions made. At the studied two sites, the role of manufacturing was found to be especially vital where concurrent development of a

product design and a solution delivery process was an objective of the product formulation.

In terms of this role of manufacturing, this study found that an effective role is to assume an information provider role and become a contributor to product formulation, in the areas of opportunity identification and future problem avoidance. To facilitate information exchange between formulation teams and manufacturing, other than promoting reciprocal information flow (i.e., information pulling and pushing), manufacturing at formulation may offer foresight in advanced manufacturing process management through front end product planning (e.g., advanced information and insights that could drive manufacturing strategy, thereby rapid execution of manufacturing process planning).

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Dedications

To my parents and Imelda.

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Chapter One

Introduction

Successful new products continually excite the world and build businesses of all sizes (Deschamps and Nayak, 1995). The Sony Walkman revolutionized the audiophile's lifestyle by making it possible to privately listen to music almost everywhere. Gillette's Sensor razor was a major success in an already mature and saturated market (Wheelwright and Clark, 1992). Apple Computer experienced success with the Apple I and II in the late 1970s, the Macintosh in the mid 1980s and the Powerbook in the late 1980s (Hayes, Wheelwright, and Clark, 1988). Hewlett-Packard introduced an inexpensive laser quality ink jet printer for under US$1,000 in 1994, one that became the most successful product in its history (Hewlett-Packard Annual Reports, 1991, 1994). Kodak's Fun Saver single-use camera, captured 65% of the US single-use camera market in 1991, increased in sales by 50% and sold 22 million units in 1992 (Business Week, September 7, 1992).

A new product introduction (NPI) project is usually an intra-company endeavor that involves multi-disciplinary and cross functional teams (Page, 1993). The project can involve collaboration between business units, or companies. Depending on the scale of innovation, stakeholders contribute seed funding, specialized knowledge, staff time, technology knowledge, technology implementation, patents, intellectual property, and equipment. A product strategy that is tightly interwoven with corporate, functional and business strategies, has a higher probability of success.

We define a NPI project as consisting of three stages: formulation, development, and deployment. In the product formulation stage, a multi-disciplinary product formulation team must identify and evaluate a business worthy opportunity, and establish a business case (Bailetti and Guild, 1991b). In the product development stage, a larger multi-disciplinary product development team designs a physical prototype that seeks to be cost effective and is technologically feasible to make, that is, planning to "do the thing right" (Smith and Reinertsen, 1991). The product deployment stage is triggered by the completion and approval of the product prototype. Activities such as testing and verifying the product, material procurement, assembly, fabrication, and market launch are all part of the deployment stage (Urban and Hauser, 1993).

Manufacturing has two major responsibilities: manufacturing process management and manufacturing strategy. According to APICS Dictionary (1987) "manufacturing process management is a process which is part of the manufacturing strategy and involves a series of activities which are performed upon the material to produce the final product and create a greater product value, such as machining, packaging, assembly, equipment maintenance, testing, printing, and facility operation." According to the dictionary, manufacturing strategy is defined as "a collective pattern of decisions that act upon the formulation, that is, process innovation, and deployment of manufacturing resources, that is, manufacturing process." For many years, these two responsibilities have accurately described the nature of most manufacturing activities (Dertouzos, Lester, and Solow, 1989). The defined manufacturing responsibilities only represent a dimension of the role of manufacturing in NPI. Manufacturing may be necessary to take additional responsibilities above and beyond manufacturing process management and manufacturing strategy to ensure that the product design can have a smoother transition from the drawing board to the production floor[1]. A goal of this study is to re-define the role of manufacturing in NPI.

Recent studies have suggested that the formulation stage presents an opportunity for cost saving because decisions made at this stage may commit as much as 80% of product manufacturing cost (Gerwin, 1993; Smith and Reinertsen, 1991; Soderberg, 1989). Any cost saving at this stage is welcome news for companies because it improves profitability.

The purpose of this study is to investigate the emerging manufacturing role, based on field observation, in terms of manufacturing participation in the formulation stage. The research question of this study is as follows: if the manufacturing function is represented in the product formulation of the NPI project, what effective role can manufacturing play?

This question leads to three assumptions. First, manufacturing at product formulation will affect, either positively or negatively, the odds of success of a NPI project. Second, a multi-disciplinary and cross functional team (a product formulation

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[1] Gerwin (1995) discussed a case study of a leading North American telecommunication company in which a tight coupling between the manufacturing process management and the manufacturing process design would increase the value of the overall manufacturing operation.

team) is responsible for defining the product concept during product formulation. Third, the manufacturing function is represented in the new product formulation team.

This study aims at theory building instead of hypothesis testing. The research strategy used in this study follows the principle of grounded theory which is a method of inductive theory building for qualitative research (Glaser and Strauss, 1967; Strauss and Corbin, 1990). Qualitative research produces findings not arrived at by means of statistical procedures or other means of quantification. The data collection is by means of interviews and observations. Regarding the data collection methods, I choose participatory action research and case study method for phase one of the study and case study method for phase two (see Chapter Three for details). Participatory action research requires the researcher to become an active observer participant in the subject organization. Thus, the researcher can gain the full experience of a situation and its context. The essence of participatory action research is to develop an in-depth understanding of the problem issues with an insider's perspective (Whyte, 1989). Case study method is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident, and where multiple sources of evidence are used (Yin, 1982).

The field data were collected during my six-month tenure as a research intern at Company ABC, which is a major communication equipment manufacturer in North America. Four of Company ABC's managers and I formed an investigation team to study the research question. I observed from within, participated in a NPI process re-design team as well as on a NPI project. After studying five internal NPI projects, the team visited four other companies to understand their practices and how others deal with the issues at hand.

The remaining chapters are organized as follows: Chapter Two examines relevant background literature and summarizes major theoretical concepts; Chapter Three discusses the design of theory generation research, and describes the two data collection methods used; Chapters Four and Five discuss the first and second sets of empirical findings uncovered during the two phases of the study; Chapter Six provides concluding remarks as well as several tentative hypotheses emerging from this study.

Chapter Two

Literature Review

This chapter discusses the role of manufacturing in new product introduction project and product formulation.

Manufacturing Role in a New Product Introduction Project

Manufacturing, as a recipient of product design, traditionally has played a reactive role in a NPI project (Hill, 1989). Often, two important but perhaps false assumptions were made about how well manufacturing can respond to changes in the parameters of a new product. "The first is that manufacturing's role is to respond to ... changes, rather than make inputs to them ... The second is that manufacturing has the capability to respond flexibly and positively to these changing demands" (Hill, 1989, p. 17-18).

Dertouzos, Lester, and Solow (1989) stated that "product design groups neglect manufacturing considerations in their designs, and manufacturing managers are preoccupied with manufacturing operations; thus, process design tends to be an orphan" (p. 69). This is notwithstanding the fact that a very significant portion of total product cost is decided at product definition (Soderberg, 1989).

A gap between product design and manufacturing is evident (Wolff, 1985). This gap represents:

> "a focal point of total corporate interaction since within its bounds occurs the inevitable confrontation of human resistance to change, urgency to meet product schedules, new technology infusion into products, interdisciplinary language problems, continuing design alterations, and corporate cash commitments, to name a few" (p. 97).

Whitney (1988) suggested a term called "manufacturing by design":

> "Converting a concept into a complex product is an involved procedure consisting of many steps of refinement. The initial idea never quite works as intended or performs as well as desired, so designers make many modifications.... As design evolves, the choices become interdependent taking into the character of an interwoven, historical chain in which later decisions are conditioned by those made previously." (p. 83-84)

As the market launch deadline approaches, more of the product parameters become fixed; otherwise, engineering changes will be extremely costly (Smith and Reinertsen, 1991). Therefore, it is generally not feasible to make large number of changes to the product design or its performance parameters. Manufacturing process strategy must take place earlier to synchronize with NPI.

Rigid manufacturing process can restrain engineering changes in product designs. Existing manufacturing process may not be able to accommodate engineering changes while frequent changes intensify the pressure on the existing manufacturing procedures because any changes disturb the process. Therefore, advantages which should result from learning curves and economies of scale are diminished. As a result, both manufacturing quality and product cost suffer.

The "front end" of NPI is dominated by issues of marketing/product management and R&D/design engineering. Manufacturing is left a recipient of the "front end" decisions and is expected to deliver in the "back end". Perhaps the key to successful back end is to have manufacturing and other stakeholders participate at early key points, and much earlier than the usual back end of NPI.

Difficulty can result from the disparate performance measures used by design engineering, marketing and manufacturing; design engineering is usually measured by its ability to innovate; marketing is measured by how well market needs are fulfilled; and manufacturing measures production efficiency as the primary criteria of excellence (Calantone, Di Benedetto, and Haggblom, 1995). Mature products, often with a lesser degree of innovation but further along the learning curve, are likely to take greater advantage of economics of scale via machine efficiency. Thus, manufacturing may question its own role in the front end, especially if there is uncertainty as to whether or not a particular design concept will ever be commercialized. Similarly, design engineering and marketing may be unwilling to consider manufacturing issues which might constrain their idea exploration. Coordination of design engineering, marketing and manufacturing can result in the dilemma of product innovation versus production efficiency, a tension between creating the new and improving the existing.

If the role of manufacturing is confined to the deployment stage, then manufacturing is almost forced to be reactive. It does not have sufficient time to face the challenge demanded by a new product.

Design for Manufacturing and Concurrent Engineering

Manufacturing is taking on a larger role in NPI than it has before. Beginning with design for manufacturing (DFM), followed by concurrent engineering, DFM makes engineers aware of the producibility of the design. Concurrent engineering takes the concept one step further by simultaneously developing the product and manufacturing processes (For a discussion of the fundamental principles of concurrent engineering, see Smith, 1997).

According to Stoll (1991), design for manufacturing (DFM) is, "concerned with understanding how product design interacts with the other components of the manufacturing system and in defining product design alternatives which help facilitate global optimization of the manufacturing system as a whole" (p. 107). Some of the DFM principles, such as minimizing total number of parts, minimizing handling, avoiding separate fasteners, designing for multi-use, using standard components, and developing a modular design, contribute to the producibility of the product (Sanchez and Mahoney, 1996; Zirger and Hartley, 1996). However, a limitation of DFM is that it assumes pre-determined manufacturing parameters, that is, what has been used before will be used again.

Concurrent engineering relaxes this assumption and advocates product and manufacturing process co-development. The intent of concurrent engineering is to manage the linkage between product and process development so that the product can be manufactured more easily. This factor contributes to production volume flexibility, product quality and process reliability. The concept of concurrent engineering has two major objectives: [1] building up the team by breaking down barriers between the members, and [2] simplifying the product design and manufacturing process. By breaking down the barriers, the team can communicate their concerns as early as possible (Hauptman and Hirji, 1996). A simplified design could reduce the number of parts in the product and improve the manufacturing efficiency, and material purchasing and handling. Other factors, such as setting the process tolerance level, affect the overall product quality and are critical for promoting linkage in design and manufacturing (Dertouzos, Lester, and Solow, 1989; Shina, 1991; Smith and Reinertsen, 1992; Soderberg, 1989; Trygg, 1993; Turino, 1991; Vassey, 1991; Whitney, 1988).

Both design for manufacturing and concurrent engineering are critical in contributing to increasing the odds of success of a NPI. When implemented correctly, they provide coordinated capabilities in product design and manufacturing, that is, design-manufacturing integration (For different implementations of concurrent engineering see Ettlie, 1988; Ettlie and Trygg, 1995; Haddad, 1996; Hull, Collins, and Liker, 1996; Swink, Sandvig, and Mabert, 1996).

A disadvantage of simplifying the product design is that it increases the ease of "reverse engineering" the product (Ulrich and Tung, 1991). If a competitor can easily mimic a product design and replicate the manufacturing process, then the company's competitive advantage depletes. A challenge is to know how to sustain the competitive advantage gained from new products. An alternative may be to present a moving target by providing a continuous flow of new products. This alternative requires tight coupling between product innovation strategy with manufacturing process innovation strategy. This suggests that a product portfolio approach may enhance a continual success of a "new-to-the-world" product and its extensions. The downside of such an approach is that it is possible to become trapped in an endless stream of product extensions that customers do not want.

To sustain long-term competitive advantage, there is increasing evidence that successful companies generate continual streams of products, supported by their versatile manufacturing strategy (Hayes, Wheelwright, and Clark, 1988). These companies attend to design quality standards, achieve reasonable cost targets and reduce time to achieve competitive advantage[2]. However, the literature seems to largely miss the role that manufacturing can and needs to play.

Synthesis of Product Innovation and Manufacturing Process Innovation

Utterback and Abernathy (1975) suggested synthesis of product innovation and manufacturing process innovation. They added a third element, competitive strategy, to the design-manufacturing interface. At the beginning of an innovation, the production process often appears uncoordinated and the best strategy generally aims at maximizing product performance. As an innovation progresses, the rate of product innovation

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[2] Meyer and Utterback (1995) argued that a shortened product development cycle time does not necessary contribute to commercial success of the product. However, the study was based on a case study of one company. No generalized conclusion is noted yet.

decreases, and the manufacturing process innovation becomes more systematic. The objective for the product is cost minimization. The rate of manufacturing process innovation is generally slow at the beginning and reaches the peak then gradually slows down again, until the product is phased out. In other words, the stages of product innovation directly influence the rate of manufacturing process innovation (Hayes and Wheelwright, and Clark, 1988).

Following their earlier work, Abernathy and Utterback (1978) proposed three patterns of innovation as changes progressed: fluid, transitional, and specific. Each pattern has a different emphasis on competitive strategy, predominant type of innovation, product line, and manufacturing process. For the fluid pattern, the product line is typically diversified and manufacturing process is flexible but relatively inefficient. The product becomes stable when at least one product design is at the transitional pattern. Corresponding manufacturing process often becomes more rigid and some sub-processes may become automated. At the specific stage, a product line is largely undifferentiated. Now manufacturing process is efficient, relatively rigid but capital intensive; the majority of the equipment is for specialized purposes. The authors assumed comparable rates of product and process innovation. This assumption would seem to be valid only if the product line is stable. More attention must be paid to situations where the product line changes rapidly and frequently.

Instead of illustrating the innovation process on a time line, Hayes, Wheelwright, and Clark (1988) characterized innovation through generational changes. The term "generation" is used to show that innovation consists of more than one wave. It also implies that product and process innovations are generational, i.e., changes occur before, during and after implementation of the new product or process technology. Changes can vary in degree and in extent. Thus to these authors, the essence of competitive advantage is how well the firm manages change.

Coordinating product innovation and manufacturing innovation is by no means trivial (Ettlie, 1988). For example, a formulation team in an electronics company had designed a way to delay the decision on the colour scheme for new products. Instead of directly injecting colour into the plastic cover, the team decided to apply a colour foil onto the colourless cover. Then, the team could use the latest customer colour preference on products. Thus, as the team imposed a constraint to the manufacturing process, additional machines were required. Depending on how such information is transmitted and received, manufacturing may feel they are either losing perceived control of the process or they are adding value to the product.

To have manufacturing participation in product innovation, coordination at the operational level of product design is necessary (Soderberg, 1989). In fact, at the strategic level, it is essential. But effective linkages from strategic decisions to the operational decisions are often missing. To resolve this, senior management must expend more effort to actively communicate priorities by translating them into concrete operational terms (Hamel and Prahalad, 1989, 1993, 1994; Kanter, 1990). How can we translate such strategic decisions? Consider manufacturing as a set of production skills instead of machinery. Manufacturing strategy defines the boundary of strategic choices of production skills. Because skills are dynamic and change over time, a well defined technological change program is essential. Yet, the direction of the program can be managed by having the strategic plan to realign the orientation of the strategic decisions. To distinguish strategic importance and thus appropriate resource allocation, some skills should be chartered as core competencies and some products should be chartered as core products (Prahalad and Hamel, 1990). Core competencies, through combined core product, define the long-term technological change program. Hence, core competence defines the trajectory of the skills development. Core products define the trajectory of the technological program.

Product innovations often result in multiple waves, i.e., radical innovation is generally followed by a series of incremental innovations. The initial source of innovation is often R&D (Sanderson, 1992). Yet, subsequent innovative improvements often originate from manufacturing or marketing. Thus, information flow concerning innovation should not be sequential and uni-directional, i.e., from R&D to manufacturing then to marketing, but non-sequential and bi-directional, i.e., from R&D to manufacturing, from manufacturing to R&D, and so on.

To operationalize such an information flow, Teece (1988) suggested a manufacturing gatekeeper function to "develop understanding of the real and hard-nosed environment of the manufacturing plant so as to keep R&D up to date on the realities of materials, of assembly processes, and to keep marketing and R&D up to date on the cost of doing things a different way" (p. 263).

The notion of functional participation in the innovation process is not a new idea (e.g., Hise, O'Neal, Parasuraman, and McNeal, 1990; Lewis and DeLancy, 1991; Nevens, Summe, and Uttal, 1990). Gold (1987) suggested interval reduction by integration between R&D and other functional areas. According to Gold, there was no consistent empirical finding to verify the assertion. Results varied due to factors like changing magnitude of the product design; urgency of change to gain or maintain competitiveness; and extent of management pressure for effective utilization. Gupta and Wilemon (1990) reported that 71% of their interviewees blamed poor definitions of product requirement as the major reason for product development delay. They suggested that integrating R&D, engineering, manufacturing, marketing, suppliers and the customer at an early stage of the process was necessary to develop sharp product requirements. Early integration of functional expertise would seem to contribute to: forecasting of product launch environment; understanding of customer requirements, technical feasibility, manufacturability, and marketability of the product; assessing of market potential of new products; communicating of changes in product requirements speedily; achieving trust and commitment from functional group members thus easing interface management; developing a sense of urgency within functional groups, thus reducing organizational response time; testing of product concepts early; enhancing of organizational learning. With regard to implementing integration, they suggested that formulation teams be used to share knowledge and common goals (Gupta and Wilemon, 1990).

van de Ven (1986) addressed a structural problem of managing part-whole relationships, which emerged from the life cycle of ideas, people and transaction as an innovation developed over time. He suggested simultaneous coupling of R&D, manufacturing, and marketing in the innovation process. The negotiation among the three functional groups begins when a manufacturing engineer joins the team and asks for engineering changes during the deployment stage. Often, changes are difficult, yet avoidable (Soderberg, 1989). In order to minimize the number of changes, Whitney (1988) suggested that the design team's charter should be broadened. Whitney showed that when design decisions were integrated, informed and balanced, it was important to involve manufacturing engineers, repair engineers, purchasing agents, and other knowledgeable people early in the process.

Functional area participation in innovation process seems to have been a practice in Japan. Gomory (1989) pointed out that Japanese design engineers typically start their careers in manufacturing plants. Almost intuitively they think about the control processes needed to maintain consistently high quality. The Japanese extend the participation to early supplier involvement (Clark and Fujimoto, 1991). Suppliers are encouraged to participate in the product development, even to jointly own the process. Intensive supplier communication contributes to lead time reduction according to Clark and Fujimoto (1989).

A study by Imai, Nonaka, and Takeuchi (1985) produced a sample of five Japanese product innovation projects to illustrate the practice of group dynamics in Japan.

They argued that overlapping innovation phases would ensure broadening of the goals and help to alleviate differences. Members of the teams are encouraged to share information and responsibility. Generally, members have diversified skills, and often carry out several tasks (Gomory, 1989). Because generally speaking a Japanese team is group oriented, tasks for individual members are not as systematically divided as they are in western teams. Within a group, members' skills often overlap. At all phases, ambiguity is tolerated and over-specification is intentionally avoided. The decision making is delayed to get the most up-to-date information on marketplace and technology. Timing and the extent of manufacturing participation in the innovation process are important considerations in product innovation.

To conclude, there are two types of coupling that need to be addressed. The first type is team coupling in which the manufacturing representative can maximize its contribution to NPI. The second type is innovation coupling which coordinates manufacturing process innovation with product innovation. The new manufacturing role must be examined under these two types of coupling.

A gap in understanding is evident. No studies have addressed the role of manufacturing participation in product formulation in terms of time and extent of participation.

Product Formulation

The premise of this section is as follows: managing product formulation is challenging because it is a pathfinding and a decision making process -- the process and the end point of the process is fuzzy; the process is highly iterative and; the result of the process depends on the collective contribution of the team. Any changes in the role of manufacturing in product formulation must recognize these characteristics and seek to improve the process.

Objective of Product Formulation

A formulation stage is situated at the front end of product creation to take on the task of formulating a product concept that seeks to create value for the customer (Bailetti and Guild, 1991b; Clark and Fujimoto, 1991; Soderberg, 1989). At this stage, the master product plan is developed, including an estimation of the product revenues and the manufacturing costs. A list of product features is drafted. Focus groups may be used to test acceptance of the new product concept.

An objective of the formulation stage is to identify business worthy product concepts: to do the right thing. These concepts must match new business opportunity with available technology or technology under development.

Product Strategy. Before deciding what the right thing to do is, it is necessary to know where the marketplace is headed. Just as a battle strategy defines the boundary of the battlefield, similarly, a good product strategy defines the set of market requirements the product will fulfill (Bailetti and Litva, 1995). The set of requirements reflects key parameters of the market, such as growth, size, risk and competition[3]. Furthermore, just as a successful battle strategy defines how to fight the battle, a successful product strategy should define the initial and subsequent product deployments through a product proliferation plan.

Formulating a comprehensive product strategy is typically highly complex and non-linear. However, the result of this step is critical to the success of the formulation stage. Rigor at this step must not be compromised.

Concept Exploration. Despite the stereotypes in the popular press about how a charismatic visionary or inventor inspires brilliant ideas, identifying business worthy opportunities and exploring new product concepts is not as glamorous as it might seem. More often, concept exploration can be a grind, a group process that involves a team of dedicated experts expending long and tedious effort to germinate a viable product concept (Smith and Reinertsen, 1991; Urban and Hauser, 1993).

To facilitate creative capacity under conditions of imperfect information, taking account of all pre-existing knowledge seems essential:

[3] Tellis and Golder (1996) argued that first-to-market advantage is not a necessary condition of enduring market leadership. Therefore, time-to-market may not be a sufficient condition of a successful NPI project. Timing is more important than time.

> in a setting in which there is uncertainty [emphasis added] about the knowledge domains from which potentially useful information may emerge, a diverse background provides a more robust basis for learning because it increases the prospect that incoming information will relate to what is already known (Cohen and Levinthal, 1990, p. 131).

The same logic makes it desirable to have a work group comprising multiple disciplines as the most likely to inspire creativity.

Opportunity Analysis. This is a "sanity test" to estimate market potential, user acceptance and technical feasibility of the new product concepts; this procedure should include consumer recognition, appraisal and subjective estimate of qualitative attributes. Sometimes, scenarios are developed to simulate market response (Smith and Reinertsen, 1991; Urban and Hauser, 1993). Product features are defined and tested to match the needs of identifiable customer groups. Such questions, as what kind of benefits the product will bring, are discussed and evaluated from many aspects. Numerous sessions are held ranging from peer discussion to formal management review meetings. A series of reports may be documented. They may include: New Business Opportunity; Commercial Specification; Product Specification; Project Management Plan; Strategic Investment Summary; and Feasibility Study Report[4].

The critical balance of high-level concept formulation versus detail-oriented design work is often difficult to achieve. Starting off, a concept should avoid being precisely defined, otherwise it risks being tied to a specific idea. At the outset, a concept

[4] The list of reports are adapted from the internal new product development manual of

should be deliberately vague and fuzzy. As such it conveys more connotations and triggers a broader range of innovative solutions by the recipients. These operational distinctions of concept and idea are crucial to product formulation, to exploring new product concepts that can then be developed, or materialized by the product development team in the later development stage.

Characteristics of Product Formulation

The center of discussion of this thesis is the product formulation stage, which is a pathfinding and decision making process. The three key characteristics are noted: [1] fuzziness; [2] highly iterative process; and [3] collectivity.

"Fuzziness" is defined as an attribute of the uncertainties embedded within almost any innovation project. Several major sources of uncertainty are noted, as follows:

- The product formulation team can only derive market estimates from perceived customer needs, which is a self-selection process (Ettlie, 1992). The major drawback is that the validity of the solution is subjectively provided by the team. Customer needs are only a projected experience by the team and even customers might not have full confidence to evaluate a product that does not actually exist (Wheelwright and Clark, 1992).
- The means to deliver the new product concept is fuzzy. Technology in development is often a potential solution. The technological risk associated with a new technology must be factored in.

Company ABC.

- The product concept generated in this stage tends to maintain a level of ambiguity, i.e., a lower level of specification and only an approximation of the new product. The product formulation team must maintain a broader perspective over the project. Sometimes, for domain-specific experts, tolerating much ambiguity is unacceptable. It is important for the product formulation team not to go the fine detail about the product design. This should be reserved for a larger team with very specific expertise.
- When a market situation is uncertain, instead of rushing into a decision, perhaps a team might choose to delay decision-making. However, the market window may elapse while the team delays its decision.
- No fool-proof approach to handling product formulation has been identified (Smith and Reinertsen, 1991). There is no established metric to measure the effectiveness of product formulation.

Hence product formulation is a highly iterative process. It involves several design cycles of concept exploration and evaluation (Bacon, Beckman, Mowery, and Wilson, 1994; Beckman, 1992; Beckman, Mowery, and Wilson, 1992). However, the number of cycles, or the number of alternatives which might be considered simply cannot be pre-determined. Often, strong team discipline is necessary when going through these cycles to ensure the quality of product formulation.

Although recycled ideas are the most economical for downstreaming activities, American designers tend to design brand new concepts, rather than confining themselves to previous concepts (Sanderson, 1992). Japanese designers, however, prefers incremental innovations over breakthrough innovations (Tatsuno, 1990). The advantage to emphasizing recycled concepts is that the company has a higher level of continuity in organizing teams and design practices. Griffin (1991) argued that this practice enhances organizational learning and memory and eventually enhances product generation transitions.

Task partitioning, an aspect of team work often treated as a given, is a variable of the innovation process (von Hippel, 1990). Two approaches, namely the economics of specialization and traditional patterns of NPI, are used to manage the problem-solving interdependence of NPI tasks. Task specialization for reducing the need for problem-solving across task boundaries is more appropriate for incremental innovations. Conversely, reducing the cost of engaging in a given level of problem-solving across task boundaries is more appropriate for novel innovations, such as new product formulation (NPF). The point here is that different environmental factors may dictate how tasks should be partitioned even though two teams have similar tasks.

The third characteristic of a product formulation is collectivity. Collectivity is defined as an effort to develop a joint dimension of problem-solving and decision making among all members of the product formulation team.

Risk is an inevitable issue in many companies, including the information technology companies (Meldrum and Millman, 1991). Collectivity implies multi-stakeholder decision making with risk minimization. Functional diversification of expertise is necessary to balance the risk profiles of the product formulation project. According to a study by Curry (1992), the breadth of knowledge makes an individual flexible. Breadth of knowledge, states Curry, means "the set of subject areas in which the individual had attained at least the comprehensive level" (p. 459). This implies that a more flexible individual tends to have a greater number of responses to new problems or is more creative in decision-making.

Group decision making is different from individual decision making. Inevitably, stakeholders have a set of hidden agendas. With a multi-disciplinary team, each of the stakeholders excel in their own areas, therefore, demanding that members compromise their differences and be collectively creative is not an easy task.

Collectivity implies parallel thinking, which does not necessarily imply efficiency. Therefore, the team should develop a collective common goal that spans the common domains of all stakeholders. The model of value-focused thinking leads the team to first define the value of the project rather than to identify alternatives. Constraint of free thinking at the beginning of the project would serve the real need to brainstorm new product concepts (Keeney, 1992).

Collectivity implies an autonomous team in which a self-organizing information system is used. The system acts like a human perception system where only appropriate and selective information is retained.

The premise of this chapter is as follows: the literature indicates that manufacturing usually takes a reactive role in new product introduction projects. Attempts are made to ensure that the product design is easier to manufacture thereby reducing time-to-market and development cost. However, the window of opportunity for manufacturing to make an impact begins at the front end of the NPI project, namely product formulation. There are two types of coupling that manufacturing in which participate: in innovation coupling to synchronize product innovation and manufacturing process innovation and team coupling to set up a team environment during formulation to maximize the collective contribution of the team, which includes manufacturing. Research opportunity is evident to better understand the emerging manufacturing role.

Chapter Three

Research Methods

Introduction

To a certain degree, a study finding is affected by the nature of the research strategy and data collection methods used. Because this study is exploratory in nature, the research strategy is not to "[seek] degrees of freedom from a large standardized data set" (p. 249) but involves a few cases with in-depth understanding of issues (Leonard-Barton, 1990). The goal is to observe converging evidence through different methods. Questions remained as to what factors drive the choice from different methods and how best to combine their advantages and limit their disadvantages so as to establish validity.

The research strategy used in this study followed the principle of grounded theory (Glaser and Strauss, 1967). The data collection is by means of interview and observation. Regarding the data collection methods, participatory action research (PAR) for phase one of the study and case study method for the phase two are chosen.

Review of Research Methods

This section reviews four research methods used in this study, outlined in Table 1.

Table 1 Review of Four Research Methods

Research Method	Why
• Grounded theory -- the principle of qualitative research.	• Grounded theory gives the researcher an opportunity to formulate a construct of the phenomenon, and conduct a preliminary test of the construct.
• Outlier technique -- the underlying principle to investigate "outlying" companies.	• Outlier technique defines a process to investigate selective samples when the majority of the population is not ready to be tested.
• Participatory action research (PAR) -- the data collection method used in the first phase of this study.	• PAR gives the researcher an opportunity to obtain in-depth and rich understanding of the real life data within the organization.
• Case study method -- the data collection method used in the first and the second phases of this study.	• A phenomenon is bundled with its context.

Grounded theory and outlier techniques were used as the underlying research methods in this study. Respectively, they guide the exploratory process and sampling strategy. Whereas PAR and case study method are used as the actual data collection methods used in the phases one and two of this study.

Grounded Theory

An objective of this study is theory generation. In the context of this study, this objective implies the underlying research principle should satisfy the following criteria:

- Formulate a construct of the phenomenon, and conduct a preliminary test of the construct, as opposed to an exhaustive test;
- Observe arguments of what is and what is not perceived as important;

- Observe arguments between rival and complementary explanations; and
- Allow pattern-matching[5] and explanation building.[6]

These criteria call for qualitative research. Grounded theory is an implementation of qualitative research. Grounded theory is defined as

> "inductively derived from the study of the phenomenon it represents. That is, it is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to that phenomenon. Therefore, data collection, analysis, and theory stand in reciprocal relationship with each other. One does not begin with a theory, then prove it. Rather, one begins with an area of study and what is relevant to that area is allowed to emerge" (Strauss and Corbin, 1990, p. 23).

A grounded theory has three components. The first component is the data (as empirical data to be discussed in the next two chapters). The data collection procedures used are participatory action research and case study research. The data are collected through interviews and observations. The second component is the different interpretive procedures that are used to arrive at findings or theories. The objective here is to capture the insights derived from the data and to reduce the data and produce an empirically based summary. This could include how best to merge multiple perspectives, to report archival information, or to avoid investigator biases and errors. These procedures include the techniques for conceptualizing data. This process, called coding, varies by the

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[5] Pattern matching is defined as a continuous process of comparing the previous observed situations to the current situation.

[6] Explanation building is defined as a continuous process of building up the explanation power of proposed construct through converging evidence as exhibited in different phenomena.

training, experience, and purpose of the researcher. The coding procedures used in this study are diagramming, comparing and contrasting of conceptual relationships, as well as pattern matching and explanation building. The third component is the written or verbal report, which is this dissertation.

Outlier Techniques

Outlier techniques investigate selective samples when the majority of the population is not yet ready to be tested. There are at least two circumstances for using these techniques: [1] when the majority of the population is not experienced with a new concept or product, a very small scale test with a selective group might be more applicable; and [2] when the characteristics of the extreme subjects become the matter of investigation, either because these subjects are sparse, or the researchers hope to gain insights from them.

These two circumstances are often mutually influential. For example, this study was not initiated by simply structuring and testing hypotheses regarding manufacturing at formulation. First, I assume that the majority of the population does not have a sufficient understanding of the problem to provide meaningful answers. In other words, manufacturing at formulation is not yet a widespread concept or practice. Thus, it seems justifiable to investigate the "best practice" companies to gain a better qualitative understanding of the problem. Second, there are newsworthy innovators who have recently excelled in formulation. By interviewing them as outliers, one can better understand their success in the context of their particular innovations.

Using this to interpret management research, five applications of the outlier techniques are identified (Allen, 1977; Bailetti and Guild, 1991a,b; Nevens, Summe, and Uttal, 1990; Peters and Waterman, 1982; von Hippel, 1986; von Hippel, 1988). A generic process for outlier techniques is deduced from these five applications, as follows:

- Rationalizing: The first task of the researcher is to argue why the outlier technique is more applicable than conventional research methods such as a survey of a target market (Allen, 1977; Peters and Waterman, 1982; von Hippel, 1986, 1988; Nevens, Summe and Uttal, 1990; Bailetti and Guild, 1991a, b);
- Criterion setting: This crucial step is to set the selection criteria for defining outliers. The criteria should be precise and implementable (Peters and Waterman, 1982; von Hippel, 1986, 1988; Bailetti and Guild, 1991a, b);
- Identifying the outliers: By applying the criteria through some means of scanning, the researcher will generate a preliminary list of subjects (Allen, 1977; Peters and Waterman, 1982; von Hippel, 1986, 1988; Nevens, Summe and Uttal, 1990; Bailetti and Guild, 1991a, b);
- Implementing: Other factors will be used to address the practical issues of contacting outliers, such as locations of the firms (Peters and Waterman, 1982; Bailetti and Guild, 1991a, b);
- Contacting: Media used to contact outliers varies from interviews and mailings, to telephones and panel discussions (Allen, 1977; Peters and Waterman, 1982; von Hippel, 1986, 1988; Nevens, Summe and Uttal, 1990; Bailetti and Guild, 1991a, b); and

- Generalizing: This step considers how to generalize the results of the study to the majority of the population (von Hippel, 1986, 1988). This step is not always considered applicable (Bailetti and Guild, 1991a, b). For instance, the conclusion of this study cannot be generalized due to the limited sample[7].

Outlier techniques are not without their limitations and a carefully planned implementation is essential to address most caveats. The major challenge is the identification issue, followed by the issue of how to generalize the results to the majority of the population. The identification issue also leads to a reliability issue since replication may not obtain similar results.

These techniques do not adopt any cross-sectional sampling or clustering procedures. Thus, validity due to sampling should not be claimed. However, depending on the objective of a particular study, when extreme cases are the subject of investigation, a cross-sectional sampling might still be desirable (Peters and Waterman, 1982).

The characteristics of outlier techniques for exploratory study are as follows:

- In situations where the context is not separable from the phenomenon, it is difficult to eliminate the former and then partition the latter for analysis;
- By definition, outlier techniques have a strong bias of sampling; therefore, sampling validity should not be claimed. Rather, this technique should be considered a learning process to gain insight.

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[7] The implementation of the generic process is discussed in the later part of this chapter.

Participatory Action Research

Phase one of the research strategy used a research technique called participatory action research (PAR). As the name implies, this research method requires the researcher to become an active participant in the subject organization. Thus, the researcher can fully experience a situation and its context, i.e., will encounter the situation first hand and participate in the resolution of any issues that arise. The essence of this research method is to develop an in-depth understanding of the problem issues with an insider's perspective. To this end, I joined the primary research site (Company ABC) as a research intern during the data collection period.

One might argue that in order to understand a problem, one must "stand under" the problem. This principle summarizes the essence of PAR. PAR is an alternative research approach used by academic researchers and practitioners in a research collaboration (Whyte, 1989). According to Whyte, Greenwood, and Lazes, (1989), PAR requires that research be conducted from within an organization so as to understand processes from the organization's point of view. Essentially, the researcher is required to look at the research problem from within the organization.

The objective of PAR is knowledge advancement and organizational change. The research results should lead to actions which address the identified organization's issues. PAR is a type of applied research (Whyte, Greenwood, and Lazes, 1989). It is different from an organization contracting a researcher as professional expert to design and conduct a study. The term 'participatory' in PAR emphasizes involvement of practitioners from the subject organization. Their role is not limited to being interview subjects or filling out surveys. In PAR, the practitioners are expected to participate and take ownership "in the research process, from the initial design of the project, through data gathering and analysis, to final conclusions and actions arising out of the research" (Whyte, 1989, p. 502).

A major advantage of using PAR was becoming an insider. For example, I was able to better understand and appreciate some of the product formulation decision making dynamics because I was exposed to those decisions first-hand. This was particularly useful for a graduate student because it gave me the opportunity to achieve a very different perspective within a short period of time. The learning effect was rapid. A second advantage was having the company insiders guide the research process which increased the possibility that the research results would add value to the company. However a potential problem is the insiders' bias to drive toward their own agenda. Therefore, this study requires another research method, i.e., case study research with external companies, to balance some of the insiders' bias.

PAR is not a substitute for the experimental or quasi-experimental research method. PAR is a different research paradigm from the experimental research paradigm and different research paradigms serve different purposes. Both of the paradigms can be used to study a research question but they will have different starting points. Using the research paradigm of experimentation, the investigator should have a precise research question and be able to construct a hypothesis in an early stage of the study. The objective of experimental research is to isolate at least one variable related to the hypothesis so that it may be tested extensively.

An assumption of a PAR study is that the researcher does not have a precise research question or that he/she cannot construct a hypothesis based on his/her prior experience and literature review. The objective of PAR is to better understand the context of the research question. The PAR paradigm can be described as holistic and as providing a system perspective. It is holistic because "it encompasses a combination of technical, social, and economic aspects as well as relationships between the local and the external from the subject organization" (Deshler and Ewert, 1995, p.7). PAR provides more of a system perspective because the scope is broad and many variables are considered.

The boundary of PAR spans between the domain of rigorous normal science and practitioners' demands for usable knowledge (Argyris and Schon, 1989). The challenge of this study is to "define and meet standards of appropriate rigor without sacrificing relevance" (p. 612). This is a matter of tradeoff and balance, or simply put, choice of research design. However, this study does not try to draw a conclusion to the debate over which side yields better results. Nor does this study compromise scientific rigor for usable knowledge. PAR provides a middle ground for rigorous normal science and usable knowledge, especially at the front end of a research project. For instance, by using PAR, this study attempted to rapidly refine the research question and to identify major variables, which were then analyzed in stages two and three of this study.

PAR may seem to be less structured but by no means does it require less effort or less discipline. The time required to understand an organization is not trivial. Time is invested participating in daily activities and attending meetings. The researcher is required to have great flexibility in social skills. All of these activities take time.

PAR provides a research framework for theory building by observing real life phenomenon within the organization. Otherwise, the researcher relies on his/her prior experience and intuition to define the question and design an appropriate research strategy. Within the framework of PAR, the researcher is constantly challenged by events and different ideas, information, arguments and points of view (Whyte, Greenwood, and Lazes, 1989). From a learning process perspective, the researcher is gaining valuable insights to shape and reshape his perceived view of the question. Yin (1989) called this phenomenon "pattern matching", which is a form of theory building. Pattern matching is a process of cyclic critical checking and reflecting of the causal linkages of variables. Without cyclic reflection, the quality of research results using PAR may be substantially compromised. PAR leads the researcher to develop a preliminary hypothesis which is grounded with observed phenomenon.

PAR is not designed to claim any causal relation or causal explanation, such as preceding and non-spuriousness co-variation. This is because PAR cannot prove the relation. Yet, PAR may lead the researcher to recognize causal relation. In addition, PAR is not designed to provide the power of research generalization. This is because PAR generally has a wide research scope and a small sample size. One might debate about the validity of using PAR to advance knowledge. Indeed, the value added by a PAR study is through the process of knowledge creation. PAR contributes as a method of learning, i.e., the means, although not leading directly to conclusions. In other words, PAR is a tool which can help the researcher get to a credible conclusion and can contribute to the validity of the research result.

In order to motivate the task force or the investigation team of a PAR study, active participants should be encouraged to feel ownership of the research project (Master, 1995). At an early stage of the project, the team must agree on a common goal and on how to work together. This step is important to achieve because a team is often composed of experts from several disciplines and various functional areas. Due to the difference in training and experience, team members may have different problem solving styles. To highlight this issue, Master describes four elements of PAR (Master, 1995), as follows:

- Empowerment of participants to develop research questions and design research methods to achieve the common goal of the investigation team;
- Collaboration through participation to allow the participants to tradeoff between personal objectives and group objectives;
- Acquisition of knowledge through observing real life phenomenon and different arguments; and
- Social change through action.

These four elements describe an operational framework for the team to achieve cooperative collaboration for continuous mutual learning (Whyte, Greenwood, and Lazes, 1989).

In summary, PAR facilitates systematic and self-reflective inquiry into an issue of concern to an organization. Practitioners from the organization investigate the issue and take actions as a result of their investigation. I intend to show that this study has adhered to this principle.

Case Study Method

According to Yin (1989), "a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, when the boundaries between phenomenon and context are not clearly evident, and in which multiple sources of evidence are used" (p. 23). The premise of case study research is that the phenomenon and context are inseparable. In order to understand the phenomenon, the context must be well understood. Therefore, case study research fits in well with the objective of this stage. In addition, multiple sources of information were used in each of the "best practice" companies visited.

Case study research (Eisenhardt, 1989; Yin, 1989) calls for intensive analysis of a few data sources. This inductive process, i.e., building the explanation inductively, allows concurrent data collection and analysis. The purpose is to provide contrast, to compare, replicate, catalogue, and classify the subject of the study (Miles & Huberman, 1984).

There are two major disadvantages of a case study research. First, it takes a long time to contact the companies in order to gain access. Another disadvantage is that no generalization can be claimed.

The paradigm of hypothesis building from case study work, demands methodological rigor (as in theory testing) as well as replication and extension among individual cases (multiple cases). Because this approach does not rely on previous literature or prior empirical evidence, it is most appropriate in the early stage of research on a topic or to provide freshness in perspective to an already researched topic.

Synergy of Participatory Action Research and Case Study Method

The principle of dual methodology for data collection is proposed by Leonard-Barton (1990). In that study, Leonard-Barton combined a real-time longitudinal (three year) study with multiple retrospective case studies about the same phenomenon. Such a combination has two advantages: [1] longitudinal single site study will facilitate the researcher to identify cause and effect; and [2] dual methods facilitate pattern matching logic. This is similar to the rationale of using PAR along with multiple site case study in this research. That is to give deep learning and then to highlight cause and effect relationships which are observed during this study.

Because all methods have their merits and limitations, the intent is to apply them jointly in order to maximize the learning. The next question is how to integrate them so as to ensure that learning is accumulated and the validity of this study is strengthened.

The sequence of the two data collection methods helps enable the learning to be cumulative. The process of seeking convergence to a new paradigm was observed in the course of this study. In the context of exploratory research, cumulative learning is inductive in nature and eventually a new paradigm begins to appear.

Different attributes of two research methods are tabulated, as shown in Table 2.

Table 2 Different Attributes of Two Research Methods

Attributes	Participatory Action Research	Multiple-Site Case Study Research
Data sources	Direct observation, existing records and non-structured interviews	Literature search, existing records and semi-structured interviews
Data collection approach	Interviews several sources for each project, if possible	Interviews several data sources at the same time for each company
Who conducted	By the investigation team	Visit two companies with five members, and other two with three members
Access to information	Vast amount of insider information	Some background information
Time spent per case	Weeks	Hours
Credibility	Internal "best practice"	External "best practice"
Interpretation of information	Non-filtered	Filtered
Depth of data	High	Medium
Nature of data	Interpreted and contextually embedded	Factual and contextually embedded
Sample selection	Word of mouth and team consensus	"Best practice" with results
Sources of bias	Subjectivity, model and sampling	Sampling and model
Role of researcher	Observing participant -- inquiry from the inside	Onlooker -- inquiry from the outside
Keywords	Being there, and immersion	Detachment

The two-stage research strategy attempted to partially balance sources of bias due to subjectivity, model, sampling, and measurement. As mentioned, all data collection methods have limitations. Assume that if the team examined only the internal best practice projects, the subjectivity bias would be evident because the team's perspective would be based only on its previous working experience. By taking an insider view, the team would limit its ability to be objective when attempting to model an ideal situation. In the project they were working on, the team tended to focus on how to apply the learning instead of looking at optimal alternatives. Sampling bias is unavoidable in case study research because case study research calls for an intensive analysis of a few chosen data sources.

To operationalize the research strategy of this study, I chose an eight steps process suggested by Eisenhardt (1989) for building theory from case study research, as shown in Table 3.

Table 3 Eight Steps Process for Building Theory from Case Study Research

- Getting started: definition of research question; and possibly a priori constructs to provide better grounding of construct measures.
- Selecting cases: specified population; theoretical, not random sampling to focus efforts on theoretically useful cases;
- Crafting instruments and protocols: multiple data collection methods to strengthen grounding of theory by triangulation of evidence; qualitative and quantitative data combined; and multiple investigators to fosters divergent perspectives and strength grounding.
- Entering the field: overlap data collection and analysis, including field notes; and flexible and opportunistic data collection methods to allow investigator to take advantage of emergent themes and unique case features.
- Analyzing data: within-case analysis; and cross-case pattern search using divergent techniques.
- Shaping hypotheses: iterative tabulation of evidence for each construct; replication, not sampling, logic across cases; and search evidence for "why" behind relationships.
- Enfolding literature: comparison with conflicting literature to build internal validity, raises theoretical level, and sharpens construct definitions; comparison with similar literature to sharpen generalizability, improve construct definition, and raise theoretical level.
- Reaching closure: theoretical saturation when possible to end process when marginal improvement becomes small.

Furthermore, Eisenhardt suggests using between four to ten cases in order to achieve theoretical saturation. The final product may be concepts, a conceptual framework, or propositions. Regarding theoretical saturation, iterations between theory and data should continue until incremental knowledge is at a minimum.

Describe Primary Site -- Company ABC

Company ABC is a major global telecommunication manufacturing company with annual sales of tens of billions of dollars in the early 1990s[8]. It designs and manufactures various types of telecommunication equipment for residential and business markets. Its customers are telephone companies, large and small businesses, and mass consumers.

Company ABC has over one hundred years of experience in manufacturing process management and manufacturing strategy. Its product line spans from high volume terminal set manufacturing to low volume highly complex switching systems. In addition, its corporate product design is regarded as very successful. Company ABC was chosen as part of in this study because of its reputation as a world class manufacturing company. Some of Company ABC's manufacturing facilities are known to be among the most advanced in North America.[9]

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[8] Past studies of new product introduction have typically cut across industry lines. Barczak (1995) focused exclusively on companies in the telecommunications industry. The study found that no single NPI strategy stands out as being better than any other for the telecommunication industry.

[9] Company ABC won the Canada Awards for Business Excellence, and the Business Week Product Design Award.

I prepared a proposal to invite Company ABC to participate in this study. After Company ABC received my proposal, a meeting was arranged with a group of nine manufacturing managers to discuss the possibility. My research supervisor and I made an hour-long presentation and spent another hour answering questions. The reaction during the meeting was that the topic was very interesting to Company ABC but that the timing was not right. At that time, Company ABC had an initiative underway to redesign its gate review process (details in Chapter Three) and they preferred to integrate this proposal into the new initiative. Because a task force would be formed shortly, it was deemed to be better to wait until members of the task force could review the proposal again.

Three months after the initial meeting, we were asked to present the proposal again to the core members of the task force. After the presentation and question period, Company ABC felt that this study was of great interest to them and decided to endorse it. We were then invited to participate in a three-day off-site meeting with forty staff members of the task force. After that meeting, Company ABC approved the proposal and provided funding from its university interaction department. I was assigned to the department of New Product Manufacturing. The process from submitting the proposal to my first day at work took about five months.

I have signed a non-disclosure agreement with Company ABC. As a result, all sensitive and proprietary information has been handled in confidential manner. All companies and individual identities would remain confidential in any public reports that would be produced from the investigation. In addition, this thesis has been approved to be released as a public report by Company ABC using its internal information release request process.

My proposal asked that at least three experienced NPI project staff members be allowed to participate in this study. Although Company ABC had accepted our proposal, they could not allocate staff participation; instead, I was responsible for soliciting interest. Over the course of one month, I had face to face meetings with about twenty managers and engineers. The purpose of these meetings was to convince them to participate. In addition, I asked them to suggest internal NPI projects that the team might study. At the end, four full time staff members agreed to participate in this project. Some of them were members of another NPI project (Project Q which will be discussed in next chapter). They shared a goal to better understand the concurrent engineering and design for manufacturing issues. While Project Q's objective was focused on introducing a new product and this study focused on the business rationale and the process, nevertheless, it was felt that the two had sufficient synergy to share information between the project and this study.

An investigation team was formed with five members. I was the coordinator of the investigation team; the other four were all experienced product development project members -- in manufacturing operations and design engineering. The first member was a director of the physical design department and had been with the company for fifteen years. The second member, a product design manager, had worked for fifteen years. The third member, who was a manufacturing manager, had worked eight years at the company. The fourth member was a senior manufacturing engineer, who had worked for the company for ten years.

INVESTIGATION TEAM

Yin (1982) suggested training to the interviewers in order to assure uniformity during the data collection phase, as well as gaining agreement on research objective, design, procedure, deadline, and expectation. As a result, four meetings were held with the team members to discuss the following items:

- Problem definition and study objective;
- Terminology and basic concepts used in the study, such as formulation stage, development stage, and deployment stage, core competency, and performance measures, etc.;
- Research process design and implementation strategy;
- Selection process for the internal NPI projects and external sites;
- Preparation of the interviews for the internal pilot project, i.e., project M;
- Preparation of the visits for the external pilot site, i.e., Company R;
- Preparation of the strawman statement for interviews and visits;
- Roles during interviews and visits, and role assignment;
- Interview instrument and protocol development and refinement; and
- Field guide development and operating procedures development.

Samples

Following discussions with twenty plus managers and engineers, I compiled a list of ten internal NPI projects that the team should consider to study. The final list of five projects was selected by the team. Generally, the consensus was reached through discussion to highlight the pros and the cons of each of the alternatives. The criteria to remove names from the list included the result of these projects (generally failed projects were excluded), the impact of these projects, various stages of these projects, project primes left the company, locations of the project teams, or ability to get information and cooperation from the interviewees. In addition, the team suggested to include project Q because most of them were involved in the project. They would have advantages to gain "insider" information and cooperation from members of the project Q.

At the end of the selection process the investigation team studied five internal NPI projects (M, N, O, P and Q). Project M was a highly successful product, winning many internal and external awards. At that time, the four projects (N, O, P, Q) were projects in progress, and they were in different stages of NPI process. Three factors led the team to decide on these four projects. First, they were chosen because their potential positive impacts to the corporation. Second, the possibility of these NPI projects to be completed for market launch was comparatively higher than other alternatives. Third, they were projects from two of the three major product divisions.

A summary of the five internal projects are outlined in the next three tables (Table 4 to Table 6). Table 4 describes the product characteristics of the five internal projects.

Table 5 describes the project characteristics of the projects. Table 6 describes the sources and verification of the information received.

Table 4 Summary of Internal Projects -- Product Characteristics

Product Characteristics	Project M	Project N	Project O	Project P	Project Q
Product type	Private Branch Exchange System which is easy-to-install, use and maintain, with many useful features	An incremental cordless terminal from existing product lines	A new-to-the world terminal that is capable of interactive communication services, such as home shopping and banking	A new-to-the-world, greenfield wireless personal communicator with capability of interactive communication	A next generation greenfield central office switch
Product components	Three subsystems -- wall mounted unit, terminal, and software	A base station with LCD display and a handset with an LCD display -- radio on both components	A base station with changeable LCD modules	A base station and a handset with an LCD display -- radio on both components	Hardware (processors, controllers, & tape drives) and software loads
Product complexity	High	Medium	Medium	High	High
Origins of the product initiation	Early market indication from competitive analysis and market research	Requested by a Japanese manufacturer to co-develop a new product that both partners could market independently	Telephone companies requested a terminal set to increase the number of leased subscribers	Developed a next-generation product portfolio for wired line system for business use. Began only with user requirements as constraint.	An international product that was cost effective for deployment
Major product challenge(s)	Entire division survival depending on the success of the new product	Trade off between time-to-market and better design which would prolong the delivery schedule	Developed a feature-rich modular design terminal that subscribers really needed	Developed a product vision to sustain future product generations for the next 10 years	The success of this product line would eliminate the most profitable existing product line.
Target market	Small business	Residential and small business	Residential and business	Business	Telephone companies worldwide

Table 5 Summary of Internal Projects -- Project Characteristics

Project Characteristics	Project M	Project N	Project O	Project P	Project Q
Project status when interviewed	Completed and retrospective	Almost completed (passed Gate 2 and toward manufacturing and deployment)	In progress, passed Gate 1	Pre-Gate 0, i.e., in the formulation stage	Pre-Gate 0, i.e., in the formulation stage
Project Span	Three years	Sixteen months (expected)	One year so far	Eight months so far	Six months so far
Project responsibility	Design engineering, marketing, manufacturing, and R&D	Design engineering, component sourcing, and business planning	Design, engineering, marketing and manufacturing	R&D, design, engineering, marketing, and manufacturing	Design, engineering, manufacturing and R&D
Major project challenge(s)	Targeted with one design cycle	Managed time-to-market and respected delivery agreement with partners	Developed a product while maximizing the possibility of technology and components re-use for product extensions	Cross business units (wireless and business systems)	Redesigned a solution delivery and support process to procure and deploy new system.
Key value to this study	Manufacturing participated in NPF with significant contribution	Product was often generational and had multiple waves	Manufacturing could significantly contribute to a product that required modularity	No manufacturing participation is necessary when NPI is in knowledge building and concept development	Designed a system with the end point in mind

Table 6 Summary of Internal Projects – Information Sources and Verification

Information Sources and Verification	Project M	Project N	Project O	Project P	Project Q
How many interviews?	Five	Three	Three	Three	More than five
How many people have been interviewed?	Three	One	One	Five	More than ten
Who has been interviewed?	Former director of product design, mechanical design manager, and manufacturing engineer	Product design manager	Product design manager	Product design manager, senior design manager, behavior scientist, user interface designer, industrial designer	Director of manufacturing, director of manufacturing planning, director of physical design, product realization manager, and new product manufacturing engineer
Used other sources to verify information?	Case studies, internal documents, and presentation packages	Marketing brochures	Marketing brochures, internal documents, and presentation packages	Internal documents, and presentation packages	As an observer participant

Describe Secondary Research Sites

The purpose of this section of this chapter is to develop a comprehensive understanding of how a selected few "best practice" companies manage their product formulation projects.

Following are the criteria used to choose a "best practice" company:

- The company has recognized a need to improve its NPI process by reducing development lead time and improving the quality of investment decisions in process improvements;

- The company has recognized a need to achieve better coordination in functional areas and in managing part-whole relationships, especially among R&D, marketing and manufacturing;
- The company has obtained benefits through the participation of the role of manufacturing in the process; and
- The company has recently excelled at manufacturing, marketing or product design.

Selection of the "best practice" companies involved extensive company literature and database searches before an initial candidate list was prepared by me. I scanned thousands of articles from the past six months of both the popular press and trade journals to select an initial list of more than one hundred potential companies or business units. From these sources, I recorded how well each company performed, both from a product perspective and in financial terms, in terms of new products that were recently introduced to the marketplace. A partial list of the journal names included: Business Week, Fortune, Wall Street Journal, Globe and Mail, Boston Gazette, Electronic Business, Datamation, IEEE journals, Financial Post, and New York Times.

To narrow down the list of manufacturers, I compared companies and highlighted the outstanding "best practice" companies by benchmarking their financial and product successes. Because the number of companies was still too large, I then used winner lists of Canada Awards for Business Excellence, Malcolm Baldrige National Quality Award, and Business Week Product Design Award to further pare the list. The names of ten potential companies were then presented to the team. The team added and deleted names to prepare a list of the twelve "best practice" companies which seemed most appropriate -- one which would not jeopardize Company ABC's relationships with any companies. The team suggested to include a company in each of the industrial electronic, the consumer electronic and the service industries. If possible, an European based company and a Japanese based company should be included[10]. The team removed companies from the list with whom ABC competed, or whom were first tier suppliers to ABC. The final list had twelve companies. I then conducted a detailed database search of these twelve companies to prepare a two-inch background file on them. The entire selection process took about two person-months to complete.

When I contacted the "best practice" companies, I experienced less resistance to contact than I had anticipated. These companies generally gave my proposal serious consideration. The success rate (i.e., agreement to meet our team) was one-third.

The investigation team visited four companies[11]. The summary of the four companies is outlined in the next four tables (Table 7 to Table 10). Table 7 describes the product characteristics of the companies. Table 8 describes the project characteristics. Table 9 describes the sources and verification of the information received. Table 10 describes the criteria to select these companies. Companies R and U had chosen not to

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[10] One European company and one Japanese company were contacted but both declined participation.

[11] Although it is a telephone operating company, Company U was chosen by the investigation team because of its strong reputation in introducing new services in the telecommunication industry. Also the team felt that it is necessary to contrast observations from manufacturing companies to a service company.

talk about specific products. The meetings with Companies S and T were product specific.

Table 7 Summary of Four External Case Study Sites -- Company and Product Characteristics

Company and Product Characteristics	Company R	Company S, and Products S-1, S-2, and S-3	Company T, and Product T-1	Company U
Revenues in 1993	~$10 million	~$5 billion	~$20 billion	~$10 billion
Site Location	Southwestern Ontario	Southwestern Ontario	Northwestern US	Southwestern US
Ownership	Privately held	Public	Public	Public
Industry	Plant automation	Business computing manufacturing and service	Computing hardware manufacturing	Telecommunication service
Product type	Not available	Computing imaging system	Sub-notebook computer	Not available
Product components	Not available	Computer, image processing system	Display, CPU, and keyboard	Not available
Product complexity	Not available	High	High	Not available
Origins of the product idea	Not available	Market share driven with cost reduction and niche market	Gap in current product portfolio	Not available
Major product challenge(s)	Not available	Technology and component re-use	Modular design	Not available
Target Market(s)	Manufacturers	Financial institutions	Computer users	Business and residential subscribers

Table 8 Summary of Four External Case Study Sites -- Project Characteristics

Project Characteristics	Company R	Company S	Company T	Company U
Project status when interviewed	Not available	Completed	Completed	Not available
Project span	Not available	Two years	Eighteen months	Not available
Project responsibility	Not available	Design, engineering, manufacturing, marketing, and R&D	Design, engineering, manufacturing, marketing, and R&D	Not available
Major project challenge(s)	Not available	Time-to-market	Time-to-market and coordinated more than seventy suppliers	Not available
Key value to the study	The advantage of knowledge integration	The advantage of co-location	Developed solution delivery and support process	The service provider shared similar issue as Company ABC

Table 9 Summary of Four External Case Study Sites -- Information Sources and Verification

Information Sources and Verification	Company R	Company S	Company T	Company U
How many people have been interviewed?	One	Seven	Three	Two
Who has been interviewed?	CEO	Director of engineering, mechanical engineer, manufacturing engineering, engineering service manager, supplier manager, product manager, and material manager	Project manager, material manager, and industrial designer	Marketing manager, and new business opportunity manager
Used other sources to verify information?	Marketing brochures, and newspaper and magazine articles	Marketing brochures, newspaper and magazine articles, and discussion with former employees	Marketing brochures, newspaper and magazine articles, and discussion with former employees	Marketing brochures, newspaper and magazine articles, and discussion with current supplier

Table 10 Summary of Four External Case Study Sites -- Best Practice Criteria and Evidence

Best Practice Criteria and Evidence	Company R	Company S	Company T	Company U
Recognized a need to improve its NPI process	Not available	Yes	Yes	Yes
Recognized a need to achieve better functional coordination in NPI	Not available	Yes	Yes	Yes
Obtained benefits through the participation of the role of manufacturing in the process	Yes	Yes	Yes	Not available
Excelled at manufacturing, marketing or product design.	Yes, in manufacturing and product design	Yes, in manufacturing and product design	Yes, in manufacturing and product design	Yes, in marketing

The team felt strongly that the most effective way to communicate with these companies was in face to face meetings. The meetings were viewed as peer level technical discussions -- like exchanging ideas in conferences of professional associations. This proved to be effective since the investigation team collectively had much experience in product management, design engineering, and manufacturing. This approach emphasized sharing of learning among knowledgeable professionals. To foster open discussion at the visit sites, the team members were encouraged to share their experience with their counterparts in the "best practice" companies, within a comfort zone of non-proprietary information exchange.

Although it was costly to travel, visiting the "best practice" companies in person was deemed to be essential. The team tried to understand and identify the success factors of the "best practice" companies. They found that their diverse knowledge on the subject helped them to absorb the learning provided by the "best practice" companies in their own contexts. For example, when a success factor about design engineering was discussed, the team member who was a design manager could respond and understand the situation intelligently, expressing the necessary technical jargon to gain confidence among counterparts. This capture of unfiltered information allowed the team members to draw their own conclusions. The boundary spanning[12] experiences for the team members proved to be extremely effective. This was also important to maintain the interest of the team members. The direct contact with the "best practice" companies excited team members and enabled them to exchange their experiences with their technical peers. From a research point of view, the diverse knowledge of the team allowed the team to better absorb information from all perspectives.

A TYPICAL MEETING

A typical meeting at a "best practice" company lasted for about two to four hours. The team members were assigned responsibilities such as facilitating the meeting and scribing meeting notes. At the beginning, a Company ABC member presented a "strawman" statement[13] that represented the best understanding of the problem by the

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[12] See Glossary for a list of definitions of the key terms.

[13] A strawman statement included a product showcase based on one of Company ABC's retrospective products, Project M, and a ten minute presentation.

team. The statement was a terse summary of literature plus the issues, concerns, experiences and opportunities as viewed by the team. This served to define terms as well as to offer a "give-to-get" statement, constructively provoking lively discussion. The team also prepared a showcase of how project M, a highly successful Company ABC product, was developed. Actual products and literature were used to support our presentation. The format of the remainder of the meeting consisted of two-way open-ended questions. After the meeting, out investigation team met in private for an hour for a debriefing discussion.

According to follow up discussions, the team members all enjoyed the experience of discussion with their peers of the "best practice" companies. Not only did the discussion trigger insights, the meetings provided assurances as to whether Company ABC was on the right track in their approach to the problem.

At the beginning of each meeting, the team member who was designated the meeting facilitator would discuss the restrictions of discussing proprietary information. Because participants from both sides had not signed a non-disclosure agreement, proprietary information was not to be compromised. Instead, the objective of the meeting was to focus on how to manage product formulation. This issue, was agreed by both parties, was critical to ensure that the meeting was conducted in an open and friendly fashion.

Our investigation team had a learning advantage in this subject matter compared to the "best practice" companies. After several months of preparing for the meetings with the "best practice" companies, the team members had extensively studied each of these companies and their product lines whereas the "best practice" company members may not have had the same in depth knowledge of Company ABC. This advantage allowed the team to focus on the strengths and weaknesses of these "best practice" companies and to look for improvement in their organization.

The mode of inquiry was an essential point of contrast between stages one and two. Stage one involved a single site and I spent six months getting to "know" Company ABC from the inside. The idea of "being there" and "immersion" was critical to obtaining trust from the members of the investigation team. In addition, the information I obtained was subject to interpretation by Company ABC's technical staff and this provided me with additional information that was contextually embedded (Evered & Louis, 1981). As was pointed out by one of the members of the investigation team, this subjective experience of being within Company ABC allowed me to understand issues that might not have been possible with only my experience as a graduate student working at arm's length.[14]

When the team visited the "best practice" companies, the mode of inquiry became "inquiry from outside" (Evered & Louis, 1981). The team members and I had more or

[14] The bias due to being an insider was acknowledged. Therefore the study has included a second phase to visit other external companies for data collection.

less the same vantage point in terms of advanced knowledge of the "best practice" companies. Although we were all onlookers -- our role as learning agents was similar -- the learning was different since we had a different set of a priori knowledge, also called absorptive capacity (Cohen & Levinthal, 1990). For example, given a specific piece of information offered by one of the "best practice" companies, the product design manager, and the manufacturing manager at Company ABC, could absorb and interpret the information differently. This was important to provide grounds for the validity of this study.

The process of deciding what are the appropriate research methods used in this study was not a trivial matter. In the end, a decision was made to combine grounded theory research with outlier techniques as the underlying research methods. As with any other research methods, these two research methods have limitations. Most noticeably, generalization was constrained by small samples and, hence, the low power of statistics which require a large number of observations. Although this study was an exploratory study, this limitation is observed and acknowledged.

Regarding the data collection methods, this study combined case study research with participatory action research. Both methods derive strength from improved understanding of the context of the phenomenon and the phenomenon itself. The limitation, of course, is the low power of generalization.

Thus, the result of this study is by no means definitive and should be considered as research-in-progress. It can be regarded as a milestone in a longer learning journey of trying to better understanding manufacturing role at the formulation stage.

Chapter Four

Empirical Findings from the Primary Site

The purpose of this chapter is to develop a comprehensive understanding, based on empirical observation and as an observer participant, of how a leader in the telecommunication equipment industry manages product formulation projects. Some jargon of the industry is preserved to illustrate the industrial context of the case studies. Following the project descriptions are the point-form summary statements as concluded by team members.

Case Study

Case studies are compiled from both internal and external documents and interviews with participants of the projects and are described in the following section.

Project M

The purpose of project M was to develop a private branch exchange system used in customer premises to handle internal and external telephone calls. A typical system included one or many wall mounted units, many terminals and software. The project was considered very successful, both in financial terms and market share gained, in the history of Company ABC and was one of the often quoted success stories. The impact of the exchange system was tremendously important because it transformed the company from an insignificant player in that market segment into a market and technology leader with substantial gains in market share and profitability.

Project M was the first project at the company to use an executive gate review process to manage a new product introduction (NPI) project. The gate process divided the NPI project, from conceptualization to implementation, into four major stages -- definition, development, verification, and manufacture and deployment. Each stage was separated by a gate and a major project review was held at each of the three gates. A review panel acted as a sounding board and source of unbiased advice. For members of the project's team, the gate review provided an opportunity to assess their work and receive the panel's independent input. The investment decision of each of the gate meetings was either a go or no-go result. If go, more resources were assigned to the team. Otherwise, the team would go back to the drawing board, or the team would be disbanded.

Based on extensive market and competitive analyses, a market gap was identified in the 3 to 100 phone lines small business market. The value factor for this market was cost and hence the market requirement was calling for a cost effective system. As a result, at the beginning of the project, the general manager had a vision of delivering a cost effective system, rather than a technologically superior system. He set three targets that affected the project direction. First, the company traditionally focused on providing technologically superior products, which translated to feature-rich products but with high cost and difficulty of installation. Therefore, the existing line was not popular in the small business market segment because the customers could not afford high installation and maintenance costs. The product challenges were set as, in decreasing priority order, product engineering, manufacturing, marketing and R&D. These challenges were chosen because Company ABC's tradition of focusing on R&D, rather than on engineering and manufacturing.

The second target was to reduce the number of design cycles before market acceptance. A lesson learned from the previous projects was not to reduce time spent on the early NPI phases. This would simply increase the total project span by forcing more design cycles, because the system was not properly designed the first time. The result was longer development lead time, higher development cost, and poorer design decisions being made.

The third target was manufacturing involvement at the front end to ensure the system was cost effective even for the small business market. Project M had not only manufacturing participation at the front end but also had manufacturing-related targets at the front end, such as reducing the number of components, and designing an easy to manufacture product. The product engineering team recognized that early and active manufacturing participation was advantageous to meeting the critical targets of Project M. Initially marketing, engineering, and manufacturing had difficulty working together because of different performance measures. A changing point came about when the general manger emphasized a new target of one design cycle effort.

Three planned design attributes contributed to the overall success of the system: [1] high performance and reliability; [2] feature rich, easy-to-use, and low cost; and [3] rapid delivery, easy installation, and readily upgradable. Many of these attributes were achieved because of the manufacturing participation since project inception.

An instance to illustrate the compromise made by manufacturing was evident. At one point in the project, the project team proposed to complete a production pilot test. However, the production of the current product caused a delay in developing the manufacturing and test plan. The production team needed to tradeoff between testing new product and keeping on producing existing product.

Projects N, O and P

The formulation stage of projects N, O, and P were initiated by the corporate design group in Company ABC. This group was one of the corporate primes of new business definitions[15]. It owned the product formulation stage until the product concept was accepted and subsequently owned by other product divisions. The group felt that a major source of inspiration came from end-user communication requirements. Hence the group was largely driven by customer value and had expertise in user value assessment[16]. According to its internal document, the division was chartered to increase "the cascade of design intent and early value qualification to the business units by developing designs."

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[15] The corporate design group is one of two corporate primes in new business opportunities. The other group is the system engineering division. Its mandate is to provide knowledge integration expertise in technology and business analysis to identify new business opportunities. The major source of inspiration comes from a system perspective and synthesis of business and technology.

[16] The concept of user-centered product design is discussed in March (1994).

The challenge for the group was on how to improve the management of product formulation and at what area the group believed that value of the product was defined.

This co-located group had four functional disciplines -- industrial design, mechanical design, user needs assessment and user interface. Use of cross functional teams was a common practice for all projects. The team worked closely together because they recognized that future product opportunity came from crossing functional boundaries. The experts in the group were behavioral scientists, ergonomic specialists, graphic designers, industrial designers, mechanical designers, electrical engineers, hardware designers, software designers, manufacturing engineers, business development specialists, market specialists, project managers, product managers, and system architects.

Project N was a major modified cordless telephone set from the existing line. The new set had a base unit with LCD display and a handset with another LCD display both of which had radio components. It was a joint development project with a major Japanese consumer electronics manufacturer, Company DEF.

Company DEF used a product development feedback process to update their product lines. The process worked as follows: in the spring of year one all of Company DEF's global marketing primes, who had at least one year of field experience, gathered in Japan for two weeks. The primes requested new products based on their perceived customer requirement. During the two-week period, high level business plans were developed and negotiation sessions between the marketing primes and the manufacturing primes were held until agreement was reached. The key challenge was time. In January of year two, the North American marketing primes of Company DEF would show their prototypes of new products, at the largest North American consumer electronics trade show, to potential buyers, who would place the bulk of their annual orders for the coming Christmas season. The time-to-market was about sixteen months (from April of year one to October of year two), from concept to market launch. The order-to-deliver lead time was about ten months. A firm product development schedule was critical to the overall success of any products because any delays would damage the company's reputation and profit. In addition, the company was committed to introducing an incrementally improved version to the existing product every twelve months.

A joint venture between Company ABC and Company DEF began about two years ago. One of the DEF's North American primes uncovered a market demand for a cordless phone with caller ID and directory features. Because ABC had substantial experience in industrial design, user interface, access to a specific radio technology, and firmware expertise, DEF proposed to ABC that they enter into a joint venture to co-develop the phone. The proposal was accepted and a joint venture team from Company ABC was assigned. The joint venture team included a product design manager, a user interface engineer, an industrial designer, a product manager, and a project manager.

The sixteen months development lead time was externally determined and hence not negotiable. Therefore, conflict could arise at every major product decision because decisions had to tradeoff against its impact to the development lead time. In one instance, after a product specification had been frozen so that the development team could verify the specification, Company ABC proposed a delayed design change. A rather elaborate process followed and vice presidents of both companies became involved (in contrast to DEF's practice, such a design change might frequently occur at Company ABC and usually no formal process was required). The vice president of the Japanese company asked for a written commitment from his counterpart for not changing the design specification again. Any further changes had to be delayed until the next product iteration. This incident showed that the Japanese team ranked development time as one of the highest priorities, even above product performance. On other occasions, even though a component was not the best alternative and the product performance might suffer if the component was used, because of the lead time restriction, the Japanese team would rather use the less than perfect alternative. The next incrementally improved version, which was to come in the next twelve months anyway, would then use the better alternative.

Project O was proposed to Company ABC by another telephone service company, which was ABC's largest customer. The telephone company's lease base, that is, the number of terminals leased to subscribers, had been falling for the last ten years, from 100% to 33% of its total subscriber base. This had motivated the telephone company to find a solution to reverse the trend and regain the lease base. Through market research, it found that the residential subscribers were asking for more value from the telephone company. The challenge of the product was to introduce a feature rich product so that subscribers would again consider leasing terminal sets.

A proposal by ABC was to develop a "new-to-the-world" wired line terminal with the concept of modularity built into the product vision. The product had two parts: the base unit with a handset, a speaker phone and a numeric keypad; and an interchangeable module geared to different interactive telephone service applications, such as interactive communication. The subscribers could lease different modules from the telephone company, thereby increasing the number of leased subscribers. As needs changed, the subscriber could pick up different modules from the telephone company.

The product formulation team had substantial manufacturing representation to take ownership of the product manufacturing cost and design for manufacturing issues. The cross functional team had two product managers, one manufacturing engineer, one mechanical designer, one user interface designer, one electrical engineer, one user needs assessment specialist, and one hardware designer. The manufacturing engineer was also the manufacturing representative of the team and had day-to-day interaction with the manufacturing facility. The mechanical designer had experience with manufacturing cost issues, as well as the responsibility of design for manfacturability. The manufacturing representatives in the team were not only responsible for all the action items associated with manufacturing issues, they were full members of the team and were accountable to the product concept.

Project O was a specific example which illustrates the difficulty in designing a product for its initial release and subsequent extensions. Firmware was referred to as an application-specific integrated circuit (ASIC) and was the brain of a terminal set. The software to operate the product was embedded in a microprocessor, which has limited memory sizes such as 16, 32 or 64 kilobytes. Firmware was often a bottleneck, delaying project completion because the design and engineering specification was often changing. Ideally, a modular design of firmware would make it easier to implement subsequent product changes. The current "brute force"[17] approach was used to squeeze all of the required functions within the specific memory size. As a result, the design of the firmware could not be re-used. A new manufacturing process might result.

Hampered by requirements for backward compatibility, the firmware of other line extensions still had to be redesigned because the platform was not modular in design. This problem became acute when more and more line extensions were to be introduced with shorter lead times. If a more robust software architecture, such as modular design, was implemented in the platform, then the line extensions should be easier to manage.

In early 1993, a product design manager in the corporate design group was assigned to develop a next generation product portfolio for the business communication for wired line system. The initial project P team had three other members (two user interface designers and one industrial designer). After a few months of intensive team effort, an initial product concept for an in-building personal communicator was developed. After a review meeting with management, the team concluded that the

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[17] Brute force refers to an extreme effort to meet an immediate objective. Often the resultant solution is difficult to maintain and improve. Therefore, the solution is not "future proof". Even a small alteration may require a completely new design and new manufacturing process. Minimum learning from the initial solution can be retained.

product concept had potential as a wireless terminal. In addition, the team concluded that the product concept was about three generation leaps away from the current ABC's wireless terminal and wireless switching system. As a result, the concept was reclassified as a visionary concept, as an end point, to guide the development path of other products. Therefore, there was no manufacturing participation because no plans for the manufacturing process and strategy were required.

After further modification and verification, the concept was evaluated by more than fifty focus groups of potential users in North America and the UK. In addition, the designers were asked to present in these focus groups and make direct contact with participants to understand their emotional responses to the concept. This approach was believed to create "high level energy" (motivation) in the designers because they were often excited and inspired by the interaction with subscribers.

The product concept began with "values to user needs" as the primary consideration. For example, the concept addressed user control, aesthetics, and time management. The terminal allowed the user to control who would have access at a certain time. It also served as a pager which was very popular among teenagers and gave the users the greater ability to manage their time.

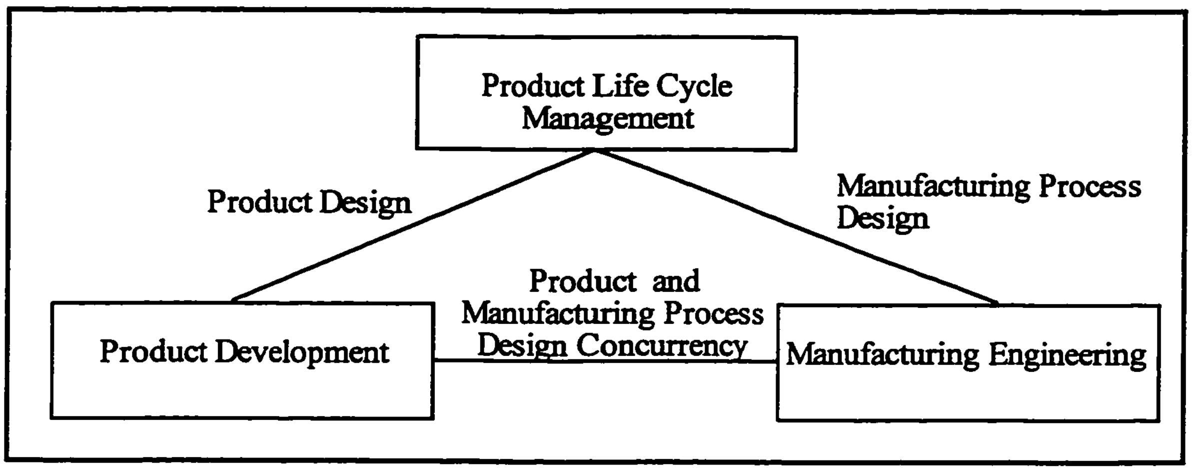
The product would have cross-division product impact. If the concept was accepted, it would have impact on the wireless division, the enterprise customer division, and the switching division (about three of the five major product divisions would be involved). Therefore it was critical to have buy-in from these divisions. To "socialize the concept", the team developed a 3-dimensional model and a video to share their view of the futuristic phone. The video was shown to other telephone companies to demonstrate Company ABC's vision to other customers.

Project Q

Company ABC realized that its most profitable switching product line had a limited growth potential. Although the existing switching system had a very significant North American market share, its international market share was less than a few percentage points. The main reason was because the feature rich system was relatively expensive, in comparison with its competitors. In order to gain a substantial international presence, a cost effective next generation system was needed for the markets outside North America.

After an internal operation audit, the recommendation was to redesign a number of business processes to support the new system. A "productization process" was to manage concurrent product development and manufacturing process (see Figure 1, more discussion to come). A marketing process established new business opportunities that led to sales of the system. An order management process was to realize customer requirement from sales initiation to system in service. An order fulfillment process was to manage all customer orders placed, and its procurement process. A customer operation support process was to establish and maintain the customer operation for the product and service the company had supplied. These processes were viewed as a cost effective and efficient solution delivery and support process to procure and deploy the system internationally. Therefore, the end point of the system was strategically determined by senior executives before the first formulation team meeting. The "key driver" and challenge of the product formulation team was the design of the "productization process", rather than only developing and deploying the latest technology.

Figure 1 Key Components of a Productization Process -- Concurrent Product and Manufacturing Process Development



The "productization process" was the result of the product development process re-engineering taskforce, which was completed just before Project Q. The recommendation of the task force was to develop a new "productization process", also called "integrated design and delivery", to better reflect the coordination of product innovation and manufacturing process innovation. Project Q was the first project to follow the recommendation. The principle findings of the taskforce were summarized as follows:

- There was a urgent need to change the serial nature of the current design and manufacturing processes, and to eliminate many hand-off and decision points by substituting a unified process that permitted a much greater degree of parallelism. The serial gate process should be obsolete and eliminated;
- This multi-functional team should have an unchanging core of membership cognizant of all functional disciplines involved throughout the project life cycle;
- There should be a single design document;
- To function efficiently and concurrently, all required information should be available to all members of the team as required; and
- New competitive technologies should be essential, but their development must be independent of product development. Product development should use only application-ready technologies. Re-use and OEM sourcing of technologies should be the norm[18].

Company ABC was concerned about product portfolio renewal of Project Q. While Project Q was still at the product formulation stage, the management team decided the subsequent extension of Project Q would be introduced in the German market in twenty-four months. After this initiative, another extension would be made twelve months later for the Chinese market, and another one to follow in the Mexican market six months after that. Therefore, the executives chose product life cycle management as one

[18] This claim is not necessary universally true. Iansiti (1995) studied 27 R&D projects from different companies in the mainframe computing industry. These projects focused on the development of advanced and novel technologies for specific product applications.

of the key drivers for both product and manufacturing process development (see Figure 2). At ABC, it was unconventional for the NPI team to design a solution productization process before the product concept was finalized and approved by the executives. The team had to decide and then make a recommendation as to whether ABC should customize a design configuration for a country, or coordinate a sophisticated supply network.

Because Project Q started with a "greenfield" development, the formulation team had options in choosing what components should be outsourced -- for example, to use either a generic IEEE standard circuit pack or application specific design processors. If the standard packs were chosen, the manufacturing costs would be lower but more time and effort would be spent in system integration. Application specific processors were expensive to design and manufacture; however, if they were custom designed in-house, they could be expected to perform better.

Problems were further complicated because various countries had different non-negotiable tariff regulations. Ideally, it would have been best if Project Q was designed generically to be able to meet all country requirements, but this seemed impossible. For example, the Chinese government would allow Project Q to be sold in China only if it could be made in China with Chinese joint venture companies. For the Mexican market, the regulations were different again to reflect that country's interests.

What Was Learned?

Listed below are the key points of understanding articulated by the investigation team members. The point form statements were used because this is how the statements were generated and can be most easily shared:

A growing awareness of new product introduction and product formulation as obtained to this stage from perception of the team members in Company ABC

- New product formulation is important strategically.
- Product portfolio renewal is an important strategic consideration. A product is often generational and consists of multiple waves. It is quite feasible for a product to sustain more than one product generation.
- Reduced time and effort spent in the formulation stage may increase the number of design iterations because the team tends to not design right the first time.
- "New-to-the-world" products that are substantially different from the existing product require a formulation stage to define the novel product concept. It is easier to design with a clean sheet of paper, i.e., greenfield development.
- Given the time-to-market pressure, it is necessary to make tradeoff decisions.
- A new product may require cross-division, or even cross-company coordination. As this happens, it becomes more challenging to the team to communicate their product concept to their counterparts.
- Gate process is a way to formalize the process of innovation thereby helping to control the quality of investment decisions.

- A product concept is the major output of product formulation and a prototype is the major output of product development.
- It is possible to define the end-point of a NPI project even before the formulation process begins.
- A single specification for the entire NPI project can serve as a single repository of information to the formulation team.

A growing awareness of the role of manufacturing in product formulation

- Manufacturing's participation in product formulation has been accepted in projects.
- Company ABC is convinced of the value of manufacturing participation in product formulation.
- Manufacturing tradeoff between carrying out production pilot tests and producing existing products is evident.
- Not all projects require manufacturing participation, especially a visionary project, particularly when the project does not need an assessment the manufacturing feasibility of the product concept.
- Company ABC is taking steps to formalize an integrated design and delivery process to monitor new product introduction projects.

Team members expand the definition of the role of manufacturing for product formulation

- Maximizing technology and component re-use is important to the role of manufacturing.

- There are many types of manufacturing interfaces such as hardware designer, mechanical designer, mechanical engineer, and new product manufacturing engineer (i.e., the functional title of two members of the investigation team).
- The new product manufacturing engineer is the key interface between designer and production engineer.
- Manufacturing representatives should be treated as full members of the product formulation team, with accountability for the delivery of the product concept. Indeed, in the case studies that we have observed, all members, including the manufacturing representatives, were treated as equal partners in the formulation team.

<u>Product formulation team characterized</u>

- Cross functional teaming is very common although initially various functions encounter difficulty in working together.
- Team members have different types of objective performance measures. However, one common goal for all members is to minimize the number of design iterations.
- The team should feel ownership of the recommendations.
- Co-locating the product formulation team is advantageous but often impossible. Co-location facilitates instant and immediate design feedback loops between members.
- Product concept should be socialized using some kind of stimulus, such as 3-dimensional model and video.

This concludes the summary of team members' opinion derived from the primary site.

Chapter Five

Empirical Findings from Secondary Sites

Building on the findings and observations from five internal projects (Projects M, N, O, P and Q), the investigation team set out to further validate and extend its learning by studying external companies. The purpose of the visits to companies R, S, T and U was to compare and contrast the observations from internal projects with the observations derived from external companies. The team was not only interested in why the "best practice" companies succeeded in product formulation, but also in how these companies came up with good ideas. The "why" and "how" questions that pertained to the contextual factors of the phenomenon have driven the research strategy toward case study research (Yin, 1989). Multiple site case study involved more than one company, each of which was perceived to have a set of common characteristics, but each was examined in its own context. Some jargon of the industry is preserved. Following the project descriptions are the point-form summary statements as concluded by team members.

Case Study

Case studies are compiled from interviews with participants of the projects and are described as follows:

Company R

Company R, founded by its CEO and his family, was established in the early 1970s and gained its reputation in design, production, installation and service of plant automation systems. Located in Southwestern Ontario, the company had a workforce of seventy and annual sales of 10 million dollars in 1992. Because of its small size, the CEO knew all aspects of the company from current production schedule to future work. Because of its limited number of major clients, the CEO handled all of the major clients' requests. He maintained a close relationship with his clients and had a good knowledge of the conveyer belt configurations in their facilities.

Over the last twenty years, Company R evolved from a machine shop to an engineering shop, to a customized shop. As a machine shop the company took orders from their customers who would provide the product specification. The company then produced as per the specification, and its value added was its craftsmanship. As the company's reputation built up, the client would consult the company for an expert opinion regarding the design and engineering of the product before the specification was defined. Its value added went beyond craftsmanship and the company became a domain expert in conveyer belt systems. As a customized shop, the client would rely on the company and requested the company to provide design, engineering, installation and service of all major components of the conveyer belt system. Its value added was solution integration. Essentially, the client treated the company as a well-trusted supplier who had access to the client's production system parameter, which was proprietary information for a high volume production system. The evolution of the company reflected its philosophy -- speed and flexibility. Therefore, Company R's production system could maintain a lot size of one. In return, the customer was the key source of innovation and inspiration for changes within the company.

"Necessity is the mother of invention", as quoted by the CEO, reflected the operating guideline of the company adeptness at improvising. It developed its own software for product design and simplified machinery, supported by one computing system for engineering, drafting, post-processing and manufacturing. The fully automated system had virtually no inventory but had concurrent product design and development. In addition, the CEO had the knowledge integration to support concurrency. The company demonstrated the advantage of knowledge integration over centralized decision making, centralized expertise, and centralized system.

Company S

Company S was a large computing equipment company with sales in excess of seven billion dollars in 1993. Its imaging division, located in Southwestern Ontario, had a workforce of five hundred and provided specialized computing imaging systems for financial institutions.

In the mid 1980s, the division had communication problems among different functional groups. Product development projects were largely a sequential effort that segregated mechanical and electrical engineers, production engineers, and suppliers. The result was missing development schedules, lower quality products and reduced market share.

After a reorganization at the corporate level in the late 1980s, the division acquired a corporate charter of imaging product portfolio in one centralized location. The division had the profit and loss accountability and within-site research, development, and engineering, which represented one-fourth of the revenues for a sales volume of about four thousand systems. The result was satisfactory, the cost, quality and reliability improvement factor was two to three times from 1986 to 1992. Time-to-market reduced from a three to four year period to a two year period, with one month deviation. The team was confident that they had conquered "doing the thing right".

The area that required improvement at the time of interviewing was how to defend the current 50-80% market share the company commended in their product lines. That is, how to develop products that customers valued while maintaining the manufacturing and design engineering excellence. They needed to conquer "doing the right thing". They viewed that the major opportunity was focused at the formulation stage.

Currently, the company used a three-phase product development process. Phase A, which was similar to product formulation, was to develop a concept. Phase B included development activities, and phase C was for deployment activities. However, the process was not always followed. For example, if a project was low risk, then the team would skip phase A and go directly to phases B and C.

The goal of phase A was to develop a product concept before commercial, product, functional and system specifications were prepared. The challenge of phase A was how to evaluate technology before embracing the products. At the time of interview, neither the division nor the company had a formal formulation process.

A parallel team structure was used in the past. A primary resource team, which was comprised of customers, sales and marketing, was run by the corporate staff. A secondary resource team, primed in this site, was made up of product management, production engineering, and design. The secondary team was concerned with product requirements and functional specification. They viewed that the structure maintained separation between the marketing side and the operation side. The production engineering was one of the key stakeholders in any NPI project, and this practice dated back to the late 1980s.

The corporation had studied the quality function deployment (QFD) model in detail[19]. It planned to adopt and formed a QFD team early, to replace the two parallel teams. The advantage of the QFD was realized in the ability to gather collective opinion and to know how to capture exact market requirements. The company had tried to experiment with customer involvement in the development process. They felt that the QFD team should be a cross-functional team, which was headed by senior management, with customer service, product management and manufacturing as focal points. The output of the QFD would be a business plan, a house of quality analysis and functional specification.

The division firmly believed in the value of listening to the customer, or the so called "voice of customers". As an example, one of its products had a 60% market share

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[19] For discussion on quality function deployment, see Griffin (1992) and Griffin and Hauser (1993, 1996).

in 1989. After listening to customers and changing the product accordingly, the replacement unit achieved in 80-90% market share. Subsequently, the division conducted in-depth customer surveys twice a year about their product and service, and collected product features suggested by the customers to drive new product ideas.

The division carefully managed its product portfolio to encourage part re-use, which was measured from one version to the next. For example, product S-1 had 60% part re-use from the previous version, product S-2 had 20% re-use from S-1, and product S-3 had 50% re-use from S-2. In addition, the overlap time from one version to the next was carefully managed. The target overlap was one year, given that a time-to-market target was two years.

The division had the entire mandate and accountability in design, engineering and manufacturing and service within the site. For example, for the last three major products, S-1 had a time-to-market of twenty-two months, including a three month delay to incorporate one technology. Product S-2 was completed in nineteen months but lost one to two months because of one technical problem. Product S-3, completed in twenty-nine months, lost five to seven months because of four technical problems. The lesson learned from these projects was to separate advanced product development from advanced technology. At the time of interview, these areas of the company were viewed as separated activities. They tried to solve their advanced technology development problem through alliances and use of long-term academic research programs to reduce the advanced technology risk. This practice was substantially different from Company ABC because it often experimented by bringing new technology to the shop floor with new products. In addition, Company S's direction was to use more off-the-shelf products. In one of Company S's sites in the UK, as much as 80% of the components used off-the-shelf technology. This was a cost effective approach to reduce time-to-market. The division viewed that figure as a benchmark.

In terms of the organization to manage advanced technology risk, this division had an advanced product development group, an advanced technology group, and advanced manufacturing engineering in the same location who were working together with testing, manufacturing, assembly, and supply manufacturing.

Company T

Company T was a large computing and communications company located in the Northwest region of US with annual sales in excess of tens of billion dollars. The company had about 95,000 employees worldwide and 50% of the sales was from overseas markets.

The company culture had a strong bias toward product innovation. Forty-five percent of its annual orders came from products less than 2 years old in 1989. In 1990 this rose to 60%. In addition, the company strongly encouraged exploring synthesis of existing technology. Its innovation philosophy was not in re-inventing technology but in re-using technology. The company viewed that the implementation of existing technology was as significant as creating new technology. The visited site had a reputation for innovation; internally the site was referred to as “the mother of divisions”. Its charter was in very small computing systems, and computing peripherals. It wanted to participate in the sub-notebook computer business.

The sub-notebook computer market was tough to penetrate and at that time, Company T had no existing product in the sub-notebook market. In addition, the market was crowded by giant manufacturers such as IBM and Compaq, and lower cost manufacturers such as Dell and AST. For Company T, its strengths were in modular design and established relationships with many outsourcing partners. To take advantage of the company strengths, the division executives decided its differentiation strategy was to deploy a product generation. As a result, components had to be able to be re-used in several product releases in order to take advantage of the learning curve effect and volume discount. A team of two engineers was assigned by the division's executives to work on this project for a year. This was essentially a skunk works activity.

The product strategy was to take a portfolio view. The team viewed that it would be difficult to establish a substantial market presence in the highly competitive market. In addition, because of new computing technology emerging all the time, it was difficult to get the right product in the first version. It was necessary to advance with incremental improvement, and apply with parallel technology development, product development and process development, with extensive use of suppliers. In order to be able to sustain long-term continuous success, a portfolio product view was important.

To win and sustain a major market presence in the cut-throat competitive sub-notebook computer industry, the mandate of T-1 product generation was simple -- to try to introduce a new best-in-class (at time offered) product line extension every four to six months. In order to sustain the rapid stream of product changes, Company T decided not to make the most of the components in house; instead its responsibility was focused on product architecture.

The project started with a very demanding list that customers would value and that would truly differentiate the product. The incumbent market was very time-to-market oriented. The product has to be truly different and bring value to customers. For example, the product had to be low in weight, include a feature called "always on" (i.e., no system re-booting time) with a battery that could last for a eight hour working day.

Company T had a reputation of working across divisions and across companies. Product T-1 had a high degree of partnership within the corporation. This product involved the joint efforts of five divisions: micro-processing division, printer head division, service division to provide single point of service help line, a software division and the computation unit division. The sales channel was through the existing corporate channel.

Product T-1 was under time-to-market pressure. In order to expedite the development lead time, the formulation team decided to have parallel development activities, where some of them were done by their suppliers. This strategy had another advantage because the product strategy was calling for a portfolio. The team claimed that benefits included time-to-market, development time, and tooling cost. The team believed that by using best-in-class suppliers so as to secure superior resources for each product component, such as the LCD displays, power supply, and communication modules. Over seventy suppliers agreed to foster a long term partnership for the entire product generation. This all happened even before the prototype of the first version was ready. Essentially, this was the strategy used by Company T to share its technology risk with its strategic partners. The challenge was how to manage different technology directions, as well as to manage information exchange for overlapping activity.

Project T-1 was innovative in terms of procurement and material engineering. It re-defined the role of manufacturing above and beyond the traditional definition. Their manufacturing function was asked to take ownership of all aspects of supply management, as well as procurement and material engineering. Because of this accountability and primeship, manufacturing was able to consider factors such as design for manufacturability.

The corporate purchasing group provided database support by providing benchmarking and pre-qualifying suppliers worldwide (e.g. support part library and database for parts). The group, which had regional offices in Singapore, France and the US, used a supplier evaluation matrix to measure technology, quality, responsiveness, delivery, cost, environment, and business. The terms were defined as follows:

- technology: is the supplier willing to work with engineering to develop new technologies for T's products?
- quality: how do suppliers measure against specific part defect per million goals?
- responsiveness: how flexible is the supplier to T's changing production schedules? how quickly does the supplier react to quality problems?
- delivery: how often do supplier's deliveries make T's window -- three days early, 0 days late?
- cost: did the supplier meet cost targets set for the commodity?
- environment: do the parts or how they are produced cause any environmental liability?
- business: how is the supplier doing financially?

Our investigation team asked Project T-1 to list their product formulation team membership. Their eight product formulation members were as follows, in descending order of importance: customers, service / customer satisfaction, manufacturing operations, project management, consumer / marketing research, marketing / product management, industrial design / ergonomics, and R&D. Project management function was identified as one of the key members in the formulation team.

Company U

Company U was a telephone company in Southwestern US offering telephone services to resident and business subscribers -- sales exceeded tens of billions of dollars in 1993.

Company U had a process to capture evolving customer requirements and to incorporate them into new services. It had specialized teams, which consisted of marketing and sales functions, to develop new service ideas. At the time of interview, the company used a nine-step process for screening and evaluating new ideas. The process was considered to have too many steps and proved to be bureaucratic. A consulting firm was currently redesigning an improved process which would have better evaluation criteria.

Company U felt that the voice of the customer gave critical input to new services. It conducted annual extensive surveys, such as telephone interviews, questionnaires and focus groups. The output was a customer value model. Customer value is paramount for any new business opportunity's decision making. They perceived that they understood their customer values well. The challenge was how to implement new ideas.

Generally speaking, the model showed three types of service opportunity: [1] service innovation; [2] niche identification; and [3] cost cutting. A service innovation introduced a "new-to-the-world" service, such as call forward and call waiting features. Niche identification explored the changing requirements of the current customer base. For example, as a small business grew in sales, it would require higher bandwidth data service. Cost cutting would be an opportunistic effort to identify cost saving for the customer or to the company. An example would be calling card service where the customer would realize immediate cost saving over collect calls. Both niche identification and cost cutting could be considered extensions of the existing service portfolio.

In addition to the customer value model, Company U relied on external input as sources of innovation. From the technology side, it relied on Bellcore to supply innovative ideas. The company used lead user techniques to identify new business opportunities.

What Was Learned?

Listed below are the key points of understanding as articulated by the team members in Company ABC:

A growing awareness of new product introduction and product formulation within the team

- Product life cycle management is an important consideration in new product introduction, especially for next-generation product.
- Designing the first version of a product generation is considerably different from designing an extension to an existing product, or an "one-off" product.
- Product portfolio renewal is an important consideration for some companies.
- Sources of innovation can be external or internal to the team.
- The customer is a great source of inspiration for new product ideas. Some customers are eager to provide information to their vendors.

- Some companies use process to manage their new product development projects. However, not all companies have a formal process to manage their product formulation.
- Separating technological innovation from new product development is considered as a strategy to reduce time-to-market.
- Technology risk can be minimized through alliances and suppliers.
- Blending technology and creative implementation of technology may be advantageous for some companies.
- NPI is a cross-division, or even a cross-company effort.
- Some companies explore their current customer evolving needs to decide what products to introduce in order to capture market niches.
- Voice of customer is difficult to identify and implement.
- At least one company visited takes advantage of the centralized decision making. If possible, the team should try to replicate this phenomenon by having the team co-location and acting in unison.

A growing awareness of the role of manufacturing at product formulation

- Manufacturing has an greater role in minimizing the technology risk.
- Synchronize tool investment in the new product development.
- Separate advanced development from incremental development.

Team members expand the definition of manufacturing role for product formulation

- The manufacturing function assumes greater responsibility for coordinating product development with suppliers. For example, using more off-the-shelf products from supplier would reduce time-to-market.
- Design for manufacturing also means designing parts and specifying parts that are easier for the supplier's to deliver.
- An effective manufacturing role in product formulation includes coupling effectively with suppliers. Manufacturing needs support from their corporate purchasing agents through pre-qualified supplier database to find their potential suppliers.
- Manufacturing is necessary to contribute and take ownership of solution delivery and support process.
- Some companies are coupling product development with manufacturing process development.

Product formulation team, as characterized

- There is a clear advantage from achieving knowledge integration among a few people. However in a large organization it might not be possible to have integration of centralized decision making, centralized expertise and centralized decision support system. A product formulation team was trying to replicate these advantages.
- Co-location will contribute to team communications.

This concludes the summary of team members opinion as initially formed from experience at the primary (internal) site and then as modified by experiences at the secondary (external) sites. What remains is a task of synthesis and integration of the team's learning with emerging perspectives from the field of "management of technological innovation and change". The researcher's task is to achieve this integration and to generate hypotheses for more formal examination at some point in the future.

Chapter Six

Discussion

The purpose of this chapter is threefold: [1] summarizing and interpreting learning from the data collection phases; [2] shaping and generating hypotheses; [3] enfolding literature by comparing related literature.

Interpretation of Findings

The Observed Phenomenon

Following are the summarized findings of this study:

- We observed three companies have increasing interest in manufacturing participating in product formulation. It has been a practice for Company ABC and Company S since the late 1980s, and Company T since the early 1990s.
- Because a product formulation stage consists of many overlapping activities which rely on the use of partial information, the value of information exchange is especially important (Smith and Reinertsen, 1992). The value of information exchange between formulation team and manufacturing is noted in the study, as follows: other than promoting reciprocal information flow between formulation team and manufacturing (i.e., simple information pulling and pushing), manufacturing at formulation may offer foresight in advanced manufacturing process management through front end product planning (e.g., advanced information and insights that could drive manufacturing strategy, thereby rapid execution of manufacturing process planning). This study found that the effective

manufacturing role is to assume an information provider role and become a contributor to product formulation, in the areas of opportunity identification and problem avoidance.

- In two of the cases (Project Q and Company T) that this study has investigated, the role of manufacturing was especially vital where concurrent development of a product design and a productization process was an objective of the product formulation.
- Most of the products that this study has investigated are not "one-off", but are the first release of a next-generation product. This study found that managing a product formulation for a next-generation product is significantly different from an "one-off" product. Product portfolio renewal was often mentioned as an objective in next-generation NPI projects.
- We observed that to institutionalize product formulation, a product formulation process that is similar to a gate review process is needed to prevent unnecessary delay and to ensure the project remained focus. While the formulation team focuses on developing the content (i.e., the product concept), a dedicated project manager may be needed to focus on managing the formulation process.
- Multi-disciplinary cross functional product formulation teams are observed at all sites. In terms of team composition, three major functional areas are observed: R&D/design engineering, marketing/product management, and manufacturing. The challenges to the formulation team are how to socialize their product vision, and how to remain focused with the problem at hand.

Early Manufacturing Participation

This section will provide an answer to the research question regarding the role of manufacturing in product formulation.

Manufacturing is an essential function in the development and deployment stages of NPI. In this study I observed that the manufacturing function is critical to the entire NPI process, including the formulation stage. This is because manufacturing has competencies that contribute to a successful new product. To implement this understanding, a company may simply assign an experienced manufacturing representative to the formulation team at project inception. The manufacturing representative should be incorporated as a full partner of the formulation team. A full partner implies the representative shares the responsibility and accountability for the success of the entire product.

Based on the observations, the proposed concept is called Early Manufacturing Participation (EMP). The term "early" refers to the timing of manufacturing participation in the NPI project; the term "manufacturing" refers to the functional representation of manufacturing and skill set of the representative in the team; and the term "participation" refers to the extent of involvement in the team. Following sections of this chapter discuss EMP in greater details.

In addition to the promotion of reciprocal information flow between formulation team and manufacturing, EMP may offer foresight in manufacturing process planning through front end product planning. In addition, EMP may promote a concurrent and cooperative relationship among all stakeholders during NPI. With manufacturing participation since project inception, EMP may address future problem avoidance, opportunity identification and evaluation during formulation.

EMP extends the role of manufacturing in NPI. EMP aims at improving the efficiency and effectiveness of the NPI process. EMP may offer foresight in manufacturing process planning by anticipating future product requirements. The ultimate goal of EMP is to improve the competitiveness of a company through early and active manufacturing participation.

Three levels of early manufacturing participation (EMP) are observed as follows:

- Minimum extent: early information sharing, and coordinating multi-function activities; this is usually insufficient and below the threshold of involvement;
- Medium extent: acceptance as a full member of the formulation team, and participation in all of the formulation activities; this provides the first effective contribution, as we have observed in Projects M and O, and Company S;
- Maximum extent: changes in philosophy and mentality regarding the role of manufacturing, and changes in manufacturing skill sets in order to productively participate during formulation; this is the goal but is yet rarely achieved, as we have observed in Projects Q of Company ABC and Company T.

The minimum role makes a limited contribution to the formulation team. The medium extent calls for equality within the product formulation team, that is, all members must be treated the same on all issues. A democratic process may be necessary to encourage the collective creativity of the team and to minimize functional barriers among team members.

The manufacturing representative needs to be a full member of the product formulation team for the role of manufacturing to function effectively (Gerwin, 1993). This calls for participation from project inception where the holistic design discussions begin. This manufacturing role addresses both future problem avoidance and opportunity identification and evaluation. In this way, the manufacturing representative is more than an information provider, and becomes a proactive contributor to the team (Gerwin, 1993).

Based on the limited number of case studies, EMP appears to be empirically related to the following factors:

- Reducing the number of design cycles, thereby reducing the amount of time spent in NPI;
- Becoming more effective as a product design recipient especially during the manufacturing ramp-up phase;
- Enabling design for manufacturing and concurrent engineering;
- Improving accuracy of the estimated manufacturing cost;
- Identifying key suppliers;

- Re-using existing manufacturing process;
- Enabling the manufacturing process development to complement company's core competency;
- Anticipating future manufacturing capability inherent in the next-generation product; and
- Softening barriers between manufacturing with marketing/product management, and R&D/design engineering.

Tentative Hypotheses

As previously stated, manufacturing is defined conventionally as a set of activities for fabricating and procuring materials, and assembly. This definition is reactive and dispersible. While it is true that some companies, such as Nike, have decided that their entire in-house manufacturing operation is non-essential and have therefore outsourced manufacturing, many other companies acknowledge manufacturing know-how and competency as essential and strategic.

A new paradigm of an effective manufacturing role is essential to leverage manufacturing competency. An effective manufacturing role should achieve the following characteristics:

- The role of manufacturing should be able to guide its operations to conform to the manufacturing specification;
- The role of manufacturing should facilitate the company to gain competitive advantage through its manufacturing capabilities; and

- The role of manufacturing will have the required manufacturing capabilities at the right time.

Consider a telecommunications manufacturer with a strategic vision of introducing a new terminal in five years that will support personal communication services (PCS). The vision is that the customer can use the terminal to place and receive calls anywhere in the world. In addition, when the user needs assistance, the terminal will provide the user with access to the right database of information. The physical design should fit in a human palm and be lightweight.

The starting point of the new business paradigm is a strategic intent statement (Hamel and Prahalad, 1993, 1994). The statement defines the end-point for the entire organization to aim at. Similarly, manufacturing has to define a future end-point towards which all manufacturing operations can aim. I define this as manufacturing anticipation. In the PCS example, the future end-points of the telephone are the physical dimension of the telephone, as well as the LCD display and the key pad. Given these end-points, the manufacturing function is able to anticipate the necessary manufacturing capabilities in order to support the introduction of the PCS telephone. Assuming the company has no previous manufacturing expertise in LCD displays, the manufacturing function can recommend to the senior management one of four alternatives: [1] outsource LCD displays to another manufacturer, then the responsibility for the manufacturing function is to integrate the LCD displays with the other components of the telephone; [2] develop the LCD manufacturing expertise; [3] buy a LCD manufacturer; or [4] develop a joint venture with a LCD manufacturer.

After the future end-point is defined, the manufacturing function needs to define a backward path from the future end-point to the current state with the necessary intermediate milestones. These intermediate steps specify the innovation necessary in order to meet the end-point and are defined as manufacturing innovation. One of the innovations for the PCS telephone is that: the processing power must double every year for the next five years in order that the telephone has the processing power to handle incoming voice and data.

After the path is defined, manufacturing has to define a way to excel within the specification. I refer to this as manufacturing excellence and it can be achieved, in part, by maximizing manufacturing productivity. To summarize, I define the paradigm of effective manufacturing role (EMR) in the context of NPI, that consists of three conceptual components - manufacturing anticipation, innovation, and excellence[20].

Consider a company that has adapted the paradigm of EMR and also deems that their manufacturing competency is strategic. Using these three concepts, the manufacturing function will define future milestones and use these milestones as guidelines to interpolate a path of necessary change to the future. Once this path is

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[20] These terms are adapted from Barker (1992). However, the process of interpolation from a future end-point is adapted from Wang and Guild (1995, 1996).

defined, manufacturing has a set of specifications to work with or, more precisely, a set of boundaries within which to excel.

The EMR paradigm explains the manufacturing strategy of the Project P. The product vision was to bring it to the market by 1999. Through Project P, the formulation team defined the necessary technology and marketing stepping stones to walk backward from the vision to the present -- just as in backcasting (Wang and Guild, 1995, 1996). These milestones defined the product line extensions that were necessary in order to fulfill the vision.

I defined the three concepts of EMR as follows:

- Manufacturing anticipation: the ability to probe novel paradigms of manufacturing, and analyze the trend of manufacturing parameters and factors.
- Manufacturing innovation: the ability to prescribe changes according to the novel paradigm of manufacturing.
- Manufacturing excellence: the ability to excel within the prescribed specifications, for example, total quality management, continuous improvement and manufacturing.

> **Hypothesis (H-1)** Effective manufacturing function participating in product formulation is positively related to the extent of manufacturing anticipation.

This is the domain that is the most unfamiliar to manufacturing's traditional role. Conventionally, manufacturing plays a reactive role in NPI of "doing the thing right".

The objective shifts to "doing the right thing" in manufacturing anticipation. I believe that manufacturing has to play this new role in the formulation team.

> **Hypothesis (H-2)** Effective manufacturing function participating in product formulation is positively related to the extent of manufacturing innovation.

Manufacturing anticipation allows manufacturing to better define the path from the current state to the end state. Because the end point is defined, i.e., the right thing has been chosen, manufacturing is then able to "do the thing right". Manufacturing innovation is manifested in the development of the product prototype; that is a specification. Manufacturing applies innovation within the pre-defined boundary of the product prototype. This is a role that manufacturing can comfortably achieve through concurrent engineering, design for manufacturing and cross-functional integration.

> **Hypothesis (H-3)** Effective manufacturing function participating in product formulation is positively related to the extent of manufacturing excellence.

This hypothesis is also a comfortable domain for manufacturing where the objective of manufacturing excellence is to achieve efficiency. The task here is to excel within the specifications defined by manufacturing innovation. Manufacturing can achieve this through total quality management and continuous improvement.

Rival Explanations

We observed two major sets of rival explanations of EMP. The first set of explanation, which we have observed from the beginning of the study, is design for manufacturing (DFM) and concurrent engineering (CE). As stated in chapter two, the key difference between DFM/CE and EMP is the timing of manufacturing participation. EMP advocates manufacturing participation at the formulation stage, which is earlier than the timing for DFM/CE, generally during the development or deployment stages.

The second explanation is Hewlett-Packard's approach called "design for supply chain management (DSCM)"[21] (Lee, 1993; Lee, Billington, and Carter, 1993). This model takes advantage of an extensive, internationally distributed manufacturing facility network. Therefore, HP's manufacturing competency is embedded as an extensive integration between product design and supply management.[22] [23] Although this approach increases the level of interdependence between HP and its vendors (Edmondson and Wheelwright, 1989), as noted by Lee, Billington and Carter (1993), "such a design strategy has significant benefits in terms of increased flexibility to meet customer demands, as well as savings in both inventory and transportation costs. . . [the] concept is now part of our manufacturing distribution strategy" (p. 11).

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[21] Lee defined "design for supply chain management to describe the concept of design of products and processes that would support the management of a supply chain in addressing the factors like logistics and transportation costs, customization strategies, inventory investment, tax and customs duties and flexibility costs to changes" (Lee, 1993, p. 46).

[22] Lee defined a supply chain as "a network including the procurement of raw materials, processing of intermediate and finished products, customization of the product for local market needs, and distribution of the product to customers" (Lee, 1993, p. 45).

[23] For other examples of involving suppliers in product development, see Levy (1997) and Liker et al. (1996).

The key difference between DSCM and EMP is their foci. The focus of DSCM method is on manufacturing role as a procurement agent. That is, manufacturing is the key enabler of ensuring the necessary material from the suppliers to be delivered at the right time and the right place. Therefore, it is necessary to leverage the existing supply chain when the company is designing a new product. This will substantially reduce the product development lead time, thereby, improve the time-to-market measure. In contrast, the focus of EMP is product realization, through the process of idea generation and evaluation. The key manufacturing role is "what to do", rather than "how to do" as the focus of DSCM. The focus is effectiveness, rather than efficiency. However, I predict that a successful manufacturing role in formulation will contribute substantially to the company's ability to design a supply chain management. Therefore, the two concepts are complementary.

Product Formulation as a Competency Building Process

Once the value of the role of manufacturing is recognized and accepted by the formulation team, a change of manufacturing skill sets is due. As noted, the new role is a substantial departure from the familiar knowledge of a manufacturing representative who does not "ordinarily have the background knowledge to influence front end decision" (Gerwin and Guild, 1994, p. 7). In this section, the skill set of the manufacturing representative is discussed.

An underlying issue for product formulation is how best to acquire, retain and re-use competencies and how best to improve the inventory of competencies (Hughes and

Chafin, 1996)[24]. Often, product formulation calls for breaking away from traditional thinking, sometimes as far as a paradigm shift (Bower and Christensen, 1995). Therefore, product formulation is not a stage to which a learning curve can be easily applied. Rather, "learning from new experience" or "learning from a few experiences" stresses the value of anecdotal learning situations in product formulation.

Product formulation, as a major stage of competency building in NPI, has two implications for two related aspects of organizational learning. Learning capability emphasizes retaining and re-using knowledge. Absorptive capacity has been defined as "the ability to recognize the value of new, external information, assimilate it and apply it to commercial ends" (Cohen and Levinthal, 1990, p. 128).

Cohen and Levinthal (1989) argue that R&D not only provides new information for new products, but also enhances the "ability to assimilate and exploit existing information" (p. 569). Dual roles of product formulation are identified as concept development and competency building.

To acquire absorptive capacity, a company needs to realize who the best learning agents are. As observed during this study, the formulation team members are learning in the formulation stage. Prior studies have suggested that members must span their individual boundaries. At the company level, organizational boundary spanning activities are required to improve the organization's absorptive capability. An example is the lead

[24] For treatment of knowledge creation in company, see Nonaka and Takeuchi (1995),

user technique that has been used to extend the marketing boundary when developing new product concepts (von Hippel, 1986). Other studies have suggested that a large scale boundary spanning activity for product formulation, called the champions of innovation method, can be beneficial to a company's strategic direction in defining new product concepts (Bailetti and Guild, 1991a, b, 1992).

By participating in group learning, the team members are empowered to acquire knowledge, to share perceptions, and to make decisions. In the formulation stage, the team, as a unit, develops momentum within the organization. The literature suggests that the team should be self-organized (Katzenbach and Smith, 1992).

Team knowledge acquisition is modeled by Purser and Pasmore (1992) as an input-processing-utilization cycle. They suggest various models can be used for knowledge input selection and knowledge processing. In contrast to conventional thinking, they conclude that NPI project delay is due more often to organizational factors than technical factors (Purser, 1991; Purser and Pasmore, 1992). They also note that:

> The consumer really does know something; so does the engineer; and the plant manager; and the technician; and yes, even the boss. When knowledge is discounted because of its source, it is not available for use ... Knowledge is available for the asking but we must develop discipline in asking -- and in listening (Purser and Pasmore, 1992, p. 103).

Important lessons for competency building came from two studies which conclude that the product formulation team is the best place to retain the knowledge

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Spender and Grant (1996) and Tsoukas (1996).

gained during product generation. Members of the product formulation team should continue to be responsible and available for downstream activities, such as the transition to full production and sales, or next-generation projects (House and Price, 1991; Iansiti, 1993).

There is substantial literature that identifies core competency as the basic unit of analysis to understanding NPI (Leonard-Barton, 1992; Prahalad and Hamel, 1990; Quinn, 1992a, b; Quinn, Doorley and Paquette, 1990; Quinn and Paquette, 1990). The best run companies compete using distinctive skills -- Honda's knowledge of engines; 3M's competency in adhesives; Philip's know-how in optical-media and laser discs; Sony's expertise in miniaturization. Defining, organizing and applying core competency produces success under continuously changing conditions (Kanter, 1990). Successful companies remain focused on their core strengths, allocating resources to build them, and de-emphasizing activities that are non-value adding and less strategically important.

How can a company build advantages around core competency? Some competencies are strategically more significant than others. These are the core competencies. They provide a roadmap for a company to develop a corporate strategy that will affect business strategies (including manufacturing strategy and marketing strategy) -- where synergy can occur. A company should manage its core competency with greater care than its portfolio of products. Enhancing its core competency is one of the goals of the formulation team. Possible product designs must be developed and evaluated to fit with the company's core competency.

In the following section, the manufacturing function will be examined under the definition of competency.

COMPETENCY-BASED DEFINITION OF MANUFACTURING

Manufacturing, sometimes referred to as production, is conventionally defined as a set of activities for procuring and fabricating materials, and assembly. As discussed in previous chapters, the shortcoming of this definition is that it is reactive and dispersible. Quinn (1992a) argued that "materials without human inputs have little intrinsic value, and most of the processes which add value to materials derive from knowledge-based service activities [emphasis added]" (p. 48). Manufacturing can be better defined as a set of competencies that pertain to fabricating and procuring materials to deliver value and solutions to customers. Ideally, a company should leverage its core competencies and manufacturing should focus on developing capabilities to complement and, indeed, to participate in these core competencies.

This competency-based definition of manufacturing enriches the role of manufacturing in NPI. One exploratory study with several international companies suggested a "more aggressive and progressive response" regarding the role of manufacturing:

> . . . [a company develops] a set of distinctive competencies in manufacturing that provide a competitive advantage in the marketplace: that is, developing capabilities that allow the organization to do things significantly better than their competitors, in areas that customers value highly (Edmondson and Wheelwright, 1989, p. 75).

What are these "things" and what criteria should be used to identify them? Quinn (1992a) asserts that, "unless the facilities and manufacturing technologies are themselves part of the core competencies of the company, strategy dictates that they should be limited -- and be selectively outsourced -- whenever feasible" (p. 48). According to Prahalad and Hamel (1990), these "things" are components and subsystems that are strategic, and are often called core products. Companies should seek to repeatedly apply these core products in various end products to leverage the learning curve effect. The core products are to be identified and kept in-house, whereas the non-strategic components should be outsourced if feasible. Strategic outsourcing is more than a manufacturing issue; it is an issue to be dealt with by the NPI team during product formulation (Feitziner and Lee, 1997). To this end, a manufacturing representative should logically be on the NPI team. After all, this manufacturing role recognizes that, "its critical contribution will come through integration and complementary with all parts of the organization and the external environment, not just turning out a product from a distant factory" (Edmondson and Wheelwright, 1989, p. 78).

We observed this new role of manufacturing in Companies ABC, S and T. They intended to use off-the-shelf products as much as possible to reduce time-to-market.

NEW PRODUCT FORMULATION TEAM COMPOSITION

A product formulation team is responsible for the definition of product concepts and business cases. Throughout this discussion, the term "team member" refers to the core member of the team. This section is an attempt to explore the membership issue, especially from the formulation stage perspective.

Page (1993) reported the functional areas involved in new product formulation as: marketing (82% of the responding companies involved marketing); R&D (70%), engineering (57%); manufacturing (43%); new products (37%); sales (24%); and finance (21%). Page notes clearly that marketing, design engineering, and manufacturing are often involved. These results tend to agree with such earlier works as Galbraith (1982) and van de Ven (1986).

The actual membership for a formulation team is not as clear cut. A formulation team for "the next generation of a telecommunication system included representatives from design, product planning[25], customer service, purchasing, and various manufacturing disciplines" (Gerwin and Guild, 1994, p. 7).

When different functions work together on an NPI project, inevitable barriers exist that may slow down communication. These inherent barriers might be due to different frames of reference, or power and political process (Hitt, Hoskisson, and Nixon, 1993). Approaches, such as loose coupling[26] using integrators[27] (Dean and Susman,

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[25] In the context of Gerwin and Guild's study (1994), product planning was a function related to marketing and product management.

[26] Hitt, Hoskisson & Nixon (1993) defined loose coupling as shared values, subtle leadership, and focused attention.

[27] Dean and Susman (1989) suggested that an integrator, who is essentially a liaison, should be cross-trained so that one can understand the complexity of the issues. This

1989), and cross-functional training (Curry, 1992), are two possible alternatives for fostering communication. While these approaches might be effective, companies seem overwhelmingly in favor of multi-disciplinary teams. In a survey conducted by the Product Development Management Association, 76.2% of the surveyed companies have adopted multi-disciplinary teams (Page, 1993).

The overall objective of an NPI project is to achieve a global optimum from the product point of view (Bowen et al. (1994). Ideally this objective should supersede the objectives of all functional areas. Although companies are in favor of achieving the global optimum, in reality typically companies use the sequential decision making approach which encourages functional segregation. The essence of functional integration is to minimize functional segregation that is derived from sequential decision making (Sullivan, Woo, and Berger, 1992). In the spirit of functional integration, overlapping decision making and problem solving with more than one functional area is encouraged (Clark and Fujimoto, 1989; Nobeoka and Cusumano, 1992). Gerwin (1993) observed that some companies achieve positive results in managing risk and reducing barriers to change due to functional integration in the formulation stage.

Other studies have suggested different forms of team structure. In NPI, multi-disciplinary self-organizing teams with diversity, knowledge and tenure were found to be the most desirable (Ancona and Caldwell, 1992a, b; Curry, 1992; Sanderson, 1992;

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role of integrator is similar to the role of a "heavy weight" project manager in Japanese industry (Nobeoka & Cusumano, 1992; Nonaka, 1990; Nonaka, 1991).

Takeuchi and Nonaka, 1986). Another approach which empowers the product formulation team to interact with other innovators, proved to be effective in the further generation of new product concepts (Bailetti and Guild, 1992).

A rugby approach has called for functional participation across the entire NPI project (Takeuchi and Nonaka, 1986). This approach of coupling together critical stakeholders has also suggested electing all members at project inception. Like the game of rugby, all players are required to be present during the entire period but with different levels of intensity varying over time. Purser and Pasmore (1992) suggested that adding members to the team late would disturb the social fabric of a team since it had developed group perceptions and common knowledge bases. Therefore, the timing of participation must be managed.

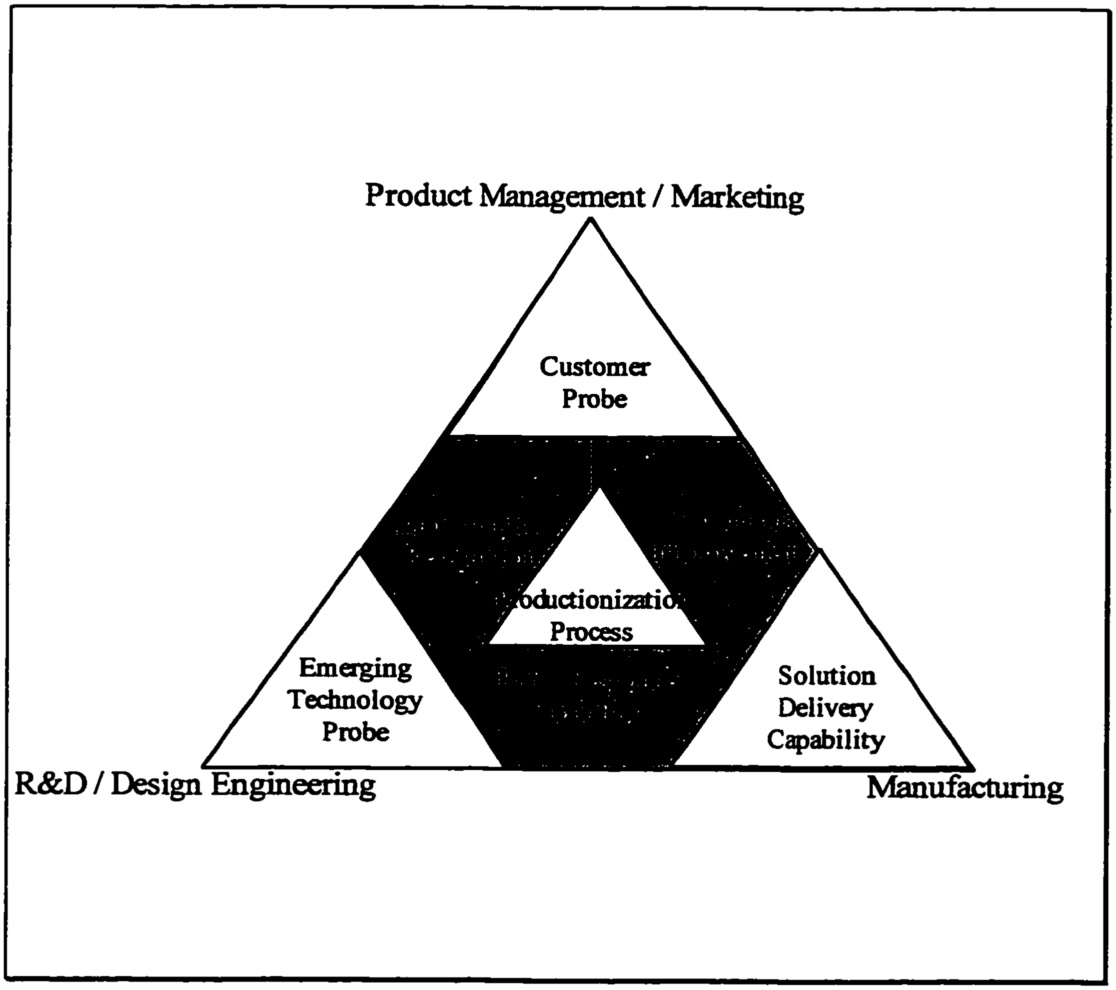
TEAM MEMBER AS COMPETENCY CARRIER

Members of the formulation team are very often drafted from their functional areas and assigned to the formulation team on an ad hoc basis over a period of time. Thus, the members of the formulation teams are accountable to two different parts of the organization: their own functional units with their line obligations, and the formulation team with their matrix obligations. This requires two roles: as competency carrier and paradigm shifter. The member is a competency carrier who has specific expertise to contribute to the team. In addition, as a competency carrier, the member is responsible for taking the new learning from the team and then ensuring a smooth future transition from product concept to development to deployment.

Developing a product concept to sustain a new product generation often involves a different paradigm (Bower and Christensen, 1995). To facilitate a paradigm shift, the team members are often responsible for convincing the senior management and other stakeholders. Some team members may experience role conflict in the process: mixed loyalty between functional department and product formulation project. For example, if the new product generation is calling for a change to the existing manufacturing process, the manufacturing representative may feel responsible for influencing the design decision to conform to the existing process, or for educating and informing the manufacturing function to prepare for such a change. The member must sometimes make difficult trade-off decisions.

In the study I observed three types of competency carriers: R&D/design engineering, marketing/product management, and manufacturing. Gerwin proposed a stronger relationship of three competency carriers with bold-lined triangulation (Gerwin, 1993). This triangular relationship, further elaborates the product formulation tasks in Figure 2.

Figure 2 Three Competency Carriers and their Roles in NPI



Product management / marketing is responsible for the customer probe, that is, collecting existing and potential marketplace information from customers, and developing a product plan. R&D / design engineering is responsible for the emerging technology probe, that is, collecting existing and potential technological and design information, and developing technological enablers to sustain the product plan set out by the product management / marketing. Manufacturing is responsible for the delivery capability, that is, generating the procurement, production, and logistic activities to sustain the product portfolio. This form of functional breakdown was observed in the Companies ABC, S, and T.

Each of the competency carriers has his/her own major responsibility in the NPI process as shown in Figure 3. The shared space shows where responsibility is shared by two adjacent carriers[28]. Product management and R&D take charge of opportunity recognition; R&D and manufacturing take charge of rapid response capability; and product management and manufacturing take charge of continuous improvement. Together, all three carriers co-own the productization process.

In product formulation, the team explores business opportunities and holistic design issues. Since the issues are not functionally specific, the functional boundaries are blurred and it is not necessary to force a clear cut functional boundary (Song, Montoya-Weiss and Schmidt, 1997). Inevitably, later in the project, as the team becomes larger and the activities become more extended, and functional specialization becomes apparent, then one can expect functional allegiance to become more obvious.

As observed in Company S and T and increasingly in Company ABC, by retaining the integrity of the team over multiple product generations, the team members become part of the company's repository of technically-integrated system knowledge

[28] The concept of "shared space" is inspired by Leonard-Barton (1995), in which the bias of a formulation team member can be due to his/her "signature skills". A signature skill is an ability by which a person prefers to identify himself or herself professionally. It is necessary to recognize the potential inherent of conflicting signature skills in a team.

(Iansiti, 1993, 1995). The team member's role is to carry competency from one function to the team, from one project to another project, and from one product generation to another generation. They are competency carriers who successfully manage the part-whole relation and integrate the system relation making them invaluable to the company (Bower et al., 1994; Hughes and Chafin, 1996; Leonard-Barton et al., 1994; Song, Souder and Dyer, 1997).

Each of the competency carriers must understand their own role in the formulation team, as well as the partnership with other carriers. This can be easily compromised and undermined. A holistic role is critical because the competency carriers are not only accountable to their own functional domain, but also are accountable to the success of the formulation project. Simply stated, they are in it together. This shared understanding by all team members is imperative for the team to become a truly high performing team[29] (Katsenbach and Smith, 1992).

Product Life Cycle Management

Product life cycle management refers to the planning, control and implementation of a product generation. A product generation refers to a "new-to-the-world" product and

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[29] One way to measure the performance of the team is to compare the sum of the individual contributions against the collective team contributions. If each of the team members does their own calculation, by summing the individual contributions up, it is called the sum of individual contributions. If it is better than the team result, the team is not a high performing team. If the team contributions exceed the sum of individual contributions, the team is a high performing team (Katsenbach and Smith, 1992). Although it is difficult to measure in real life, this qualitative measure may help a team to measure their collective success or failure.

its subsequent line extensions. Generally speaking, a product generation is the responsibility of the marketing or the product line management functions.

In the product formulation stage, there are three key questions: what is the new product? how should the product be deployed? when should the product be deployed? The success of the product formulation stage depends on how well these questions are answered. Very often the first question, the product concept, is the center of attention. However, the "how" and the "when" should not be ignored. The "how" question defines a market deployment strategy and provides answers to the following questions:

- What is the market entry strategy?
- What market segment is the new product going to serve?
- Who are the potential customers?
- What is the price range that the customer will pay for the new product?

The "when" question defines the appropriate timing to introduce the product to the market. For example, companies in the consumer electronics industry often choose the pre-Christmas period to introduce new products.

A product life cycle plan combines the "how" and "why" questions. It deals with such issues as when to introduce the initial product to market A, and when to introduce the first line extension to market B, and when another extension is ready for market C. A life cycle plan should also specify the incremental differences, such as functions or features, from the initial product to subsequent extensions.

A life cycle plan set out the product release schedule from the initial market launch to future releases. The NPI team is supposed to conform to the plan. In reality, executing a life cycle plan increases the burden on the team and possibly increases the time-to-market. For example, in order to consider re-using components for the initial and subsequent products, additional time is required to evaluate future product requirements. As a result, a life cycle plan is often treated as "nice-to-have" but not essential. After all, the current NPI team has no mandate to ensure the continuity of one release to the next. This will be the responsibility of the next NPI team. The mentality is "what can be salvaged" from the last releases and be used again. This often precludes a proactive design strategy.

A product life cycle plan calls for advanced and long-term product decisions while the product concept is still on the drawing broad (Lundqvist, Sundgren, and Trygg, 1996). More long-term decisions may pay off in the following areas:

- Long-term determination of the product life cycle boundary within the target market;
- Differentiation of non-strategic components and subsystems for outsourcing;
- Simultaneous consideration of creation, enhancement, and elimination of products within a generation;
- Possible future product requirements accounted for and incorporated in platform product planning;

- Voluntarily obsolescence of family members, not driven out by competitors -- an opportunity based innovation rather than a threat based plan alternation (de Bono, 1993; Meyer and Utterback, 1993; Prokesch, 1993); and
- Integration of all key aspects of solution delivery for the entire product generation, based on the inputs from the major NPI stakeholders such as product management, design engineering, and manufacturing.

Knowing what to avoid is a major advantage of a life cycle plan, that is, doing the right thing, requires discipline. Many companies often fall into the mega-project trap (Smith and Reinertsen, 1991). "Product development people like to be involved in big, important development projects. The mega-project gets more attention and money and presumably has a greater economic benefit" (p. 62).

Two factors contribute to the mega-project phenomenon. First, an NPI team tends to develop a "do-everything" product. This "we-only-do-it-once" mentality leads the team to spend the majority of project time on planning and leaves little time for developing. A life cycle plan encourages the team to develop a workable, possibly non-integrated and sub-optimal, solution for the initial product offering. The plan discourages the team from redefining the product concept when the team should focus on development or deployment. This can be achieved by asking the team to envision future product changes in later product iterations and delay the changes until the next offerings.

Second, the NPI team tends to have a "do-everything-in-house" attitude. Rather the NPI team should understand and focus on the company's core competencies and seek to apply them. The corollary is to outsource non-strategic components and subsystems. Otherwise, the quality of the product and the time-to-market can suffer.

Product life cycle strategy advocates a rapid stream of line extensions to continuously renew the product generations. The driving force for product changes is opportunity, rather than threats from the competition (Prokesch, 1993). It starts by recognizing the difficulty in satisfying all the needs in the first release. It is desirable to address customer needs in ongoing later releases to keep delivering additional value. This strategy is grounded on competition and 'valufacture'[30], i.e., value creation and formulation (de Bono, 1993). The goal of product generation is to continuously create and deliver value for customers. For example, Japanese consumer electronics manufacturers, such as Sony, Sharp, Panasonic, and JVC, develop subsequent product extensions[31] even when the existing products are still profitable.

This strategy has both positive and negative impacts. On the positive side, it contributes to long range planning and focuses on being customer driven. This creates an initiative to reduce time-to-market. As a result, the products are closely coupled with the

[30] The term "valufacture" was coined by de Bono (1993) to combine the meanings of two words "value" and "manufacture".

[31] Sony's Walkman has more than 160 varieties (Sanderson, 1992). Matsushita has more than one thousand varieties of video cassette recorders worldwide.

changing customer requirements. It requires careful long-term planning as early as the formulation stage of the initial product.

Keeping a step ahead of the competition depends on the organization's ability to respond to change. Response time is first embedded in the organization's technology transfer and then reflected in the NPI projects. How often is a product concept shared with downstream stakeholders? Ideally, all NPI stakeholders are encouraged to benchmark their operations with a vision of rapid and continuous product generation. For instance, design engineering integrates future product requirements in the design decision for the platform product. When all elements of a product generation share the same architecture, components can be used in more than one line extension to save development cost, reduce lead time and achieve volume discount. Supply management identifies and works closely with strategic vendors since changing vendors between extensions can be costly. Sales and services update their knowledge for different extensions. Market research collects the latest customer preference. Competitive analysis constantly monitors product and market information for present and potential competition.

Three potential negative factors must be addressed. First, if the team is working on a one-size-fits-all product concept, it complicates the task and prolongs the completion time. Another negative is the pressure to catch up with all the ever changing product requirements. This pressure is felt not only on the development team but production, supply management, distribution, packaging, documentation, sales and order taking.

Third, unrestrained line extensions could weaken the product line and lower brand loyalty, in addition to increased channel and production costs (Quelch and Kenny, 1994).

There are four types of product changes between product generations (Meyer and Roberts, 1988; Sanderson, 1992):

- Continuous improvement: a small improvement which has the smallest level of product or process changes such as production cost reduction, product reliability and performance improvement. The magnitude of the change is usually marginal and non-substantial;
- Major enhancement: an improvement that changes the components of the product, while the features and functions of the product might change little;
- New, related: a major improvement that substantially changes the components or the architectural design, i.e., the way that the components of a product are arranged, linked, and integrated;
- New, unrelated: the highest level of improvement that changes the core design of the product. This drives a product evolution to the next product generation.

The first new-to-the-world product, called platform, initiates the entire product generation. Therefore, the platform is quite possibly the most important member of the entire product generation. The platform shapes some of the key requirements in hardware, firmware, industrial design, procurement, and even business process for the entire product generation. Decisions made for the platform product may be carried into subsequent line extensions.

Quinn (1992) asserted that by focusing on a limited number of core competencies and core products, a company can have the luxury of creatively locating possible applications of these core competencies and core products in order to broaden its product portfolio.[32]

EXAMPLES OF PRODUCT GENERATION

A product generation is a set of related products that are offered by a company. Members of a product generation share common characteristics, such as performance, features, functions, and technologies. The product generation maintains an integrated set of product values to the customers. Since one generation is usually not sufficient to achieve a substantial presence in a major market, a product portfolio may be necessary (House and Price, 1991).

A product generation plan should articulate its focus, that is, a concise statement of the distinctive value that it has proposed to deliver to customers of a major target market (Browning, 1993; Kaplan and Murdock, 1991). To ensure distinctive value, the product generation plan will generally entail a new set of core design concepts embodied in new components arranged in a new architecture.

A product generation should solve a class of substantial problems. Several examples can be offered:

[32] Product portfolio refers to a set of product generations, related and unrelated, offered by a company.

- a newer version of Intel's processors, such as the 486 processor, substantially improved the price-performance ratio of its previous processor, i.e., the 386 processor;
- Apple's personal digital assistant, Newton, may have solved the portability and communication problems by providing a fully hand held, palmtop communication device, in addition to hand writing recognition;
- Rather than using the CISC technology used on a Pentium chip, Power PC used RISC architecture to boost performance. Power PC was able to run both IBM and Macintosh software (a major problem in software compatibility) and much faster than the Motorola 68000 series processors (another problem which had bothered many Macintosh users).

A product generation matures when improvements to the existing product add marginal value because of increasing level of competition. This is a signal that a different approach towards the engineering effort is required to advance the product generation to a new generation. In addition, it is also possible that a new generation is motivated by external forces, such as competition or technological advancement.

The advancement from one product generation to the next is called a paradigm shift (Barker, 1992). The critical question is: what are the set of product values that will sustain the paradigm shift (Bower and Christensen, 1995).

An NPI project for a platform product of a product generation is substantially different from a project on a stand-alone product. The product architecture must be carefully designed to anticipate future product requirements. Flexibility and modular design has became a major advantage for future upgradability (Sanchez and Mahoney, 1996; Suarez, Cusumano, and Fine, 1995; Ulrich and Tung, 1991). In the software industry, object orientation and re-usable software building blocks are other viable examples (Taylor, 1995). The business opportunities to sustain a generation of products must be well thought out.

The performance measures for a product generation are substantially different from those of a stand-alone product. For a stand-alone product, the key measures are revenue and costs. For a product generation, since the product turnover rate is higher, it is problematic to measure the success of any individual products. This is especially true for a platform product. A platform product often takes longer to design and may not yield a satisfactory financial return before it is eliminated. However, the profitability should be realized in the coming line extensions.

Hewlett-Packard has applied a longer-term return map to measure the major investment returns and time factors (House and Price, 1991). They claim that this method yields an integrated framework to the project by tracking changes made by stakeholders. The performance measures were R&D investment, investigation lead time, time-to-market, break-even-after-product release, break-even-time, and return factor. Although this method was elegant and useful, as acknowledged by the authors, it is easier to apply the method in hindsight. Using it to predict a successful product generation is "more luck than foresight" (p. 100). Another point the authors noted,

> ...to have a winning and sustained market presence usually requires at least three generations of products. Frequently, one of these generations will develop a new and significant technology, while the next generation will exploit the technology by means of rapid product development cycles -- products tailored to specific markets (p. 100).

This suggests that a longer-term product strategy, one that overlaps several generations, is required to yield a successful result, defined as "a winning and sustained market presence."

One study on system focus argues that the product generation life cycle should be viewed as a competency building process contributed to by all major NPI stakeholders, rather than by a series of isolated efforts (Iansiti, 1993). It seems that coordination of inter- and intra- product generations to form a product portfolio can yield long term results through the stretching of core competencies.

In summary, defining an effective manufacturing role is about allocating manufacturing resources to the most critical areas and outsourcing the others. This requires the product formulation team to establish priorities to identify what is core and strategic and what is not. Product generation specifically defines the product and market requirement. The specification given in the product generation facilitates the formulation team to establish clear priorities. Therefore, I suggest that the scope of the product formulation should include a product life cycle plan.

Based on the observations from Company ABC and Company T, a productization process may be an appropriate step to ensure the long term competitiveness of the product generation. Designing such a process requires a large amount of effort and therefore it is not recommended for all NPI projects. After all, the long term viability of the product generation is still unknown, therefore, resources should not be pre-committed. For Project Q, the vision of the company dictated such a process to be designed because the company was looking for a new product line to substitute an existing product list, which was the major revenue generator for the company.

Product Formulation Process

A process refers to a systematic view of work flow activities that pertain to performing tasks associated with it. The lack of systematic work flow viewed during formulation occurs because the formulation stage is fuzzy (Smith and Reinertsen, 1991). A product formulation process may be necessary to ensure the product formulation is completed on-time.

The notion of "re-engineering" calls for rethinking of the approach to business, including the innovation process (see for example Davenport, 1993; Elzinga et al., 1995; Hammer, 1990). The principle of re-engineering has two facets. First, a company should organize around outcomes, not tasks.

Two apparent advantages of organizing an innovation process by tasks and carrying them out by individual members of the team are functional expertise and economies of scale. However, such segmentation tends to restrict team members to thinking about only their responsibilities, and not to see the larger context (Kanter, 1983, chapter 7). In addition, for a more complicated product, e.g., in the electronics industry, often the real challenge is how to preserve product integrity, such as backward compatibility of products. In a highly innovative process, economies of scale are often very difficult to accomplish. Since the formulation team commits to a project for a relatively long period, the members of the team should not work independently. Hammer (1990) suggested the appropriation of a concurrent group to manage all tasks.

The second facet is that it lets people use the output of the process to perform the process. This principle could be used as an argument for user participation or involvement in the process. From the information systems literature, contributions of user involvement to system success have been documented (e.g., Doll and Torkzadeh, 1991). Similarly, in product innovation process, as manufacturing and marketing are recipients of the product design, they should participate in the pre-development phase, according to the principle of re-engineering.

RATIONALE OF A FORMULATION PROCESS

Managing a formulation stage involves planning, controlling and implementing activities associated with formulating a product concept. In the many instances that we observed in Company ABC and other "best practice" companies, the formulation stage was ad hoc.

The major reason to have a process is to stay focused. Because the output of the formulation stage cannot be easily defined and articulated, the formulation team can lose track of the purpose and objective of their project. According to Beckman (1992), companies can lose track of their exploration activities and end up with mega-projects that attempt to do everything. This results in the second biggest challenge for a formulation team - meeting deadlines.

The most immediate and tangible cost of a formulation stage is the cost of delay. The cost of delay has been identified as more critical than the cost of exploring new ideas or the cost of making a mistake (Smith and Reinertsen, 1991). Studies have shown that companies spend about 25-35% of the NPI project duration in formulation (Page, 1993; Pittiglio, Rabin, Todd, and McGrath, 1993; Smith and Reinertsen, 1991). Because companies use substantially less manpower in formulation than in development, the impact of a delay in the formulation stage is often underestimated. "The true sources of delay [during an NPI project] are in the early stage" (Smith and Reinertsen, 1991, p. 44). Control of the lead time and focus through the formulation process of any projects is useful for assisting senior management and the formulation team to manage the formulation stage.

There are several advantages to having a process, such as the following:

- Determines the ownership of the process, the accountability and end-to-end responsibility of the team;

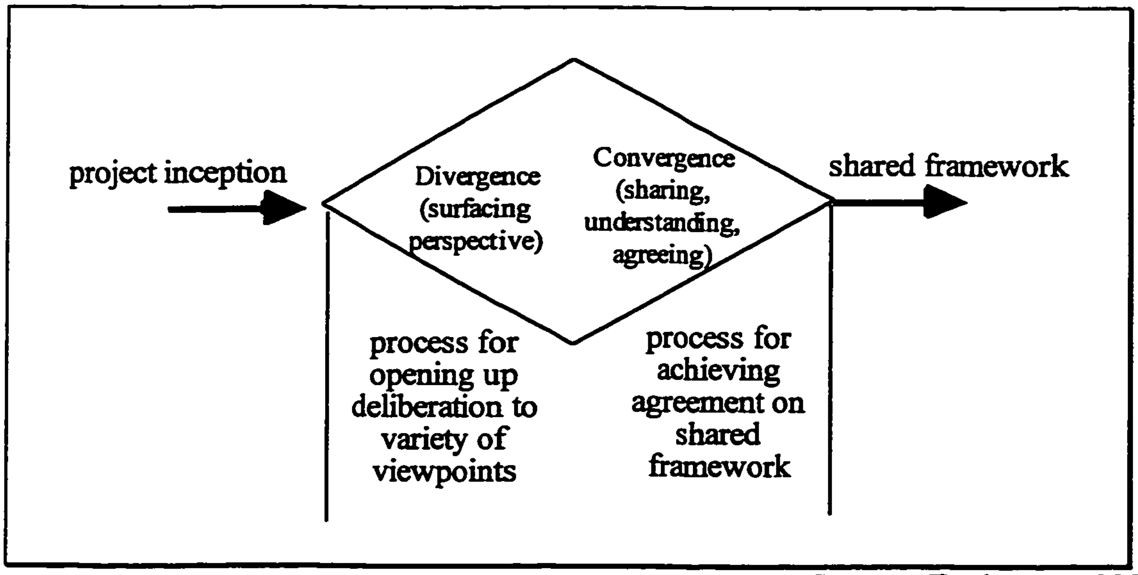
- Accelerates information flow and improves data dissemination and decision making;
- Facilitates the executive management and the multi-functional team establishing milestones and review procedures, eliminates errors and rework caused by multiple hand-offs from one functional area to another;
- Selects an appropriate time frame to manage, and identifies the necessary controllable and environmental factors to manage the fuzzy process.

CONVERGING CONCEPT EXPLORATION PROCESS

Some companies stay focused during their formulation stage by recognizing that formulation is a highly iterative process with cycles of concept exploration. (Beckman, 1992a). Through the cycle of divergence-convergence, the formulation team is able to effectively narrow down promising opportunities (Olshavsky and Spreng, 1996).

A cycle consists of stages of divergence and convergence of concepts (see Figure 3). Divergence of concepts is the result of brainstorming sessions where many new concepts are identified. Convergence of concepts is the result of filtering concepts, through sharing, arguing and agreeing among team members.

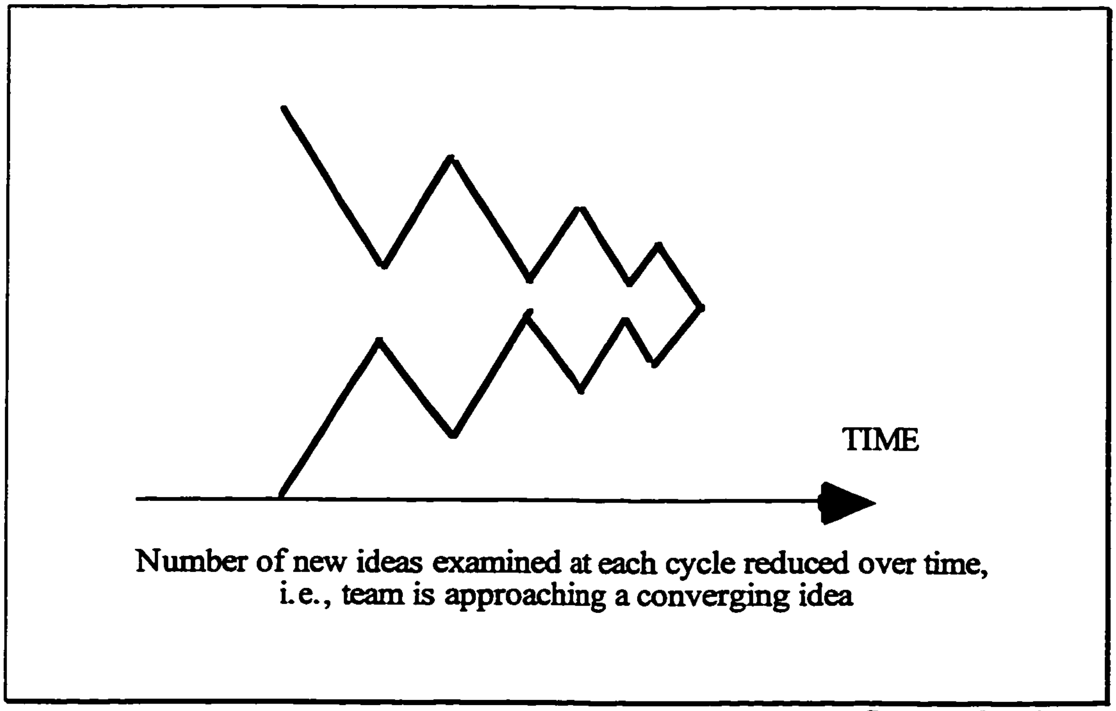
Figure 3 Divergence-Convergence Cycle



Source: (Beckman, 1992a)

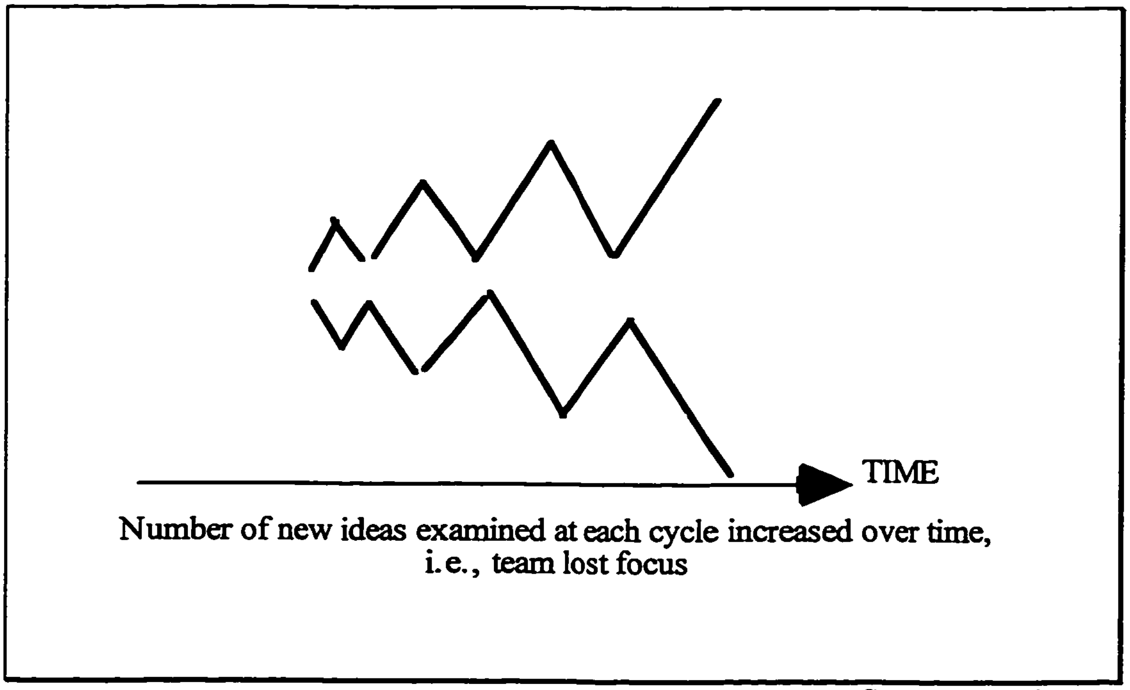
The useful formulation process includes multiple iterations of opportunity generation and evaluation. Ideally, the number of opportunities passed through each evaluation gate should be gradually reduced over time (see Figure 4). This is essential to confine the formulation process to a reasonable duration. In reality, the opposite is often experienced where the number of ideas initially examined is few and is gradually increased over time. The team risks losing focus due to the fact that the boundary of the product concept is not well articulated and agreed upon by the team (see Figure 5).

Figure 4 Multiple Iterative Cycles of Convergence-Divergence -- Ideal Situation



Source: (Beckman, 1992a)

Figure 5 Idea Diverged -- Lost Focus



Source: (Beckman, 1992a)

Based on experience from Pittiglio, Rabin, Todd, and McGrath (1993), some companies manage better and faster during the formulation process. They manage to eliminate unpromising projects early on without wasting substantial amounts of resources. In addition, they manage to have shorter time-to-market. Their investment decisions result in a higher proportion of products deployed because many of these companies are able to remain focused during the formulation stage.

To prevent unnecessary project delay and to ensure the project remains focused, a dedicated project manager may be needed to focus on managing the formulation process, while the formulation team focuses on developing the content (i.e., the product concept). Although the value of assigning a project manager to facilitate the new product introduction project is well established in the literature, the value at the product formulation is still unclear (Clark and Fujimoto, 1991; Wheelwright and Clark, 1992, 1995). Project manager as the key member of the formulation team was clearly cited by Company T, but not with Company ABC or Company S. However, assigning a high-credential project leader to lead a NPI team since project inception has been a common practice in Japanese companies (Nonaka, 1991; Nonaka and Takeuchi, 1995; Takeuchi and Nonaka, 1986).

Future Research Opportunities

The following are the research opportunities identified in this study.

Rough-cut product concept. A product concept is a rough-cut frame of reference that the formulation team can use to describe their common ideas. However, the extent of rough-cut versus precision is very difficult to balance. Using the Pareto principle, also known as first approximation rule, about twenty percent of the entire effort is used to attain eighty percent of the result. If this is applicable in the rough-cut product concept, then what should the eighty percent include?

Product Formulation Project Management. Although the significance of product formulation is identified in the literature, there are virtually no studies found on how to manage a product formulation project. The research opportunity is on how to reduce the fuzziness of a product formulation through project management.

Next-Generation Product. The first version of a next-generation product has significant impact and influence on the subsequent version. As this study revealed, formulating a next-generation product is considerably more difficult than an "one-off" product. More studies are required to explore how a NPI for a next-generation product should be managed.

Product generation as a vehicle for paradigm shift. Product generation is often driven by a paradigm shift. However, the critical question of how to manage such a shift requires more understanding. In this study, I propose that product formulation is a vehicle to achieve the paradigm shift in the context of NPI. More research is necessary to understand the relationship between formulation and paradigm shift.

Paradigm shifter. Shifting a paradigm is more than an abstraction; it takes paradigm shifters to make this happen. There appears to be two types of paradigm shifters. The first type is the product champion. To operate effectively during formulation, the formulation team must be able to work with incomplete information and imperfect conditions. The team needs a sponsor to represent them to management, and the product champion does this. The second type of paradigm shifters are the core members of the formulation team. They are a critical resource that must take the product concept and implement it in their line functions. However, the exact role of the paradigm shifter remains undefined.

Paradox of prototype and demonstration. A benefit of concept prototype or demonstration is that it fosters communication within a mutually agreed frame of reference. However, any demonstrations may constrain significant concept changes and prototypes can be expensive. These factors may create unreasonable expectations on the part of customers, senior management, partners and colleagues. This paradox must be better understood.

Allocating resources for ad hoc projects. The core members of the formulation team often report to two units: the line unit and the formulation team. The critical issue of how to assign resources for the ad hoc project needs to be understood. Other related questions concern how to cope with failure at product formulation and how to integrate product formulation team members back into functional areas.

Appendix

Validity, Reliability, Limitations and Learning Journey

The purpose of this appendix is to discuss this study in terms of validity and reliability, as well as limitations. In addition, this appendix will illustrate how the learning was cumulated over the course of this study.

Validity and Reliability

The research design and the research implementation of this study were measured against the four logical tests of construct validity, internal validity, external validity and reliability (Yin, 1982). Table 11 shows the tactics used in this study:

Table 11 Study Validity and Reliability

	Tactic Used
Construct Validity	• Use of multiple sources of evidence (more than one interviewee; verify information with documentation; and interview interviewees more than once, whenever possible). • Use methodology of participant observation at the primary site. • Establish chain of evidence.
Internal Validity	• Explanation building over the course of study. • As an exploratory study, this study has not developed any causal relationships, only certain conditions are shown to lead to other conditions.
External Validity	• Use more than one research site. • Very limited external validity because of the small sample size.
Reliability	• Use more than one observer during interviews. • Use team debriefing after the interviews to develop a agreed upon view.

Individually, an observer, because of her educational discipline, training, work experience, current job function, would contribute to her observation bias in the data collection phase. One way to reduce this bias is to add multiple observers to the team, assuming they can resolve their observational differences, the observational bias would be reduced because of multiple observers are used (Yin, 1982). Therefore, this study was designed to have five observers to reduce the individual observational bias. In addition, there was also a risk of the team bias, that is, the collective bias of the team because of, for example, Company ABC's served industry, customers, product portfolio offering, and market position. It is important to acknowledge that such a bias may have operated.

Being exploratory, this study used Company ABC to establish an initial point of reference. It is important to accept that this study has limited external validity because of the small sample size. Despite the small number (five in phase one and four in phase two), multiple NPI projects were studied and multiple research sites were used to establish the diversification of sample (five companies from five different industries). In addition, whenever possible, more than one interviewee was requested, or more than one interview was requested.

Most of the tactics mentioned in Table 11 have been discussed in Chapter Three, except the concept of chain of evidence. Yin (1982) proposed that case study research should maintain a chain of evidence thereby increasing its construct validity. As noted by Yin, "the principle is to allow an external observer -- the reader of the case study, for example -- to follow the derivation of any evidence from initial research questions to ultimate case study conclusion" (p.102). Yin proposed to allow the observer to trace the evidence from the research question to the conclusion, and vice versa.

Following are two chains to illustrate the approach used in this study. The first chain is to recount the construct development of effective manufacturing role, starting from the research question and ending with the tentative hypotheses. The second chain retraces the findings of three competency carriers, starting from the results and backtracking to the research question (the numbers with each bullet refer to the page number of this thesis for cross-reference purposes).

First chain: What is the effective manufacturing role?

- What is the effective manufacturing role in product formulation?
- Literature review suggests the possibility of synthesis of product innovation and manufacturing process innovation (Ettlie, 1988; Soderberg, 1989; Utterback and Abernathy, 1975, 1978).
- Project M suggests that the manufacturing function is accountable for manufacturing related NPI targets at the formulation, such as reducing the number of components. Also the manufacturing function should share accountability with other functions to ensure the minimum number of design cycles are attained.
- Project O suggests that the manufacturing function should be responsible and accountable for the product manufacturing cost and the design for manufacturing issue.
- Project P suggests that if a project is a visionary project, manufacturing participation at this time may not be necessary.
- Project Q suggests that the manufacturing function is the key stakeholder in designing a productization process for the project.
- The visit to Company S suggests that product formulation activity should not depend on advanced technology development. Also the manufacturing function is not only accountable for the success of one-off products, but responsible for working with other functions to ensure that the product portfolio will succeed over time.
- The visit to Company T suggests that one of the key responsibilities for the manufacturing function at the formulation is supply chain management.
- While enfolding literature (Eisenhart, 1989; step seven of an eight step research method, see Table 3, which is located at the Chapter three of this thesis), Lee argued that supply chain management is an important role for the

manufacturing function (Feitzinger and Lee, 1997; Lee, 1993; Lee, Billington, and Carter, 1993).

- A construct of early manufacturing participation was developed. Three tentative hypotheses were proposed.

Second chain: Three competency carriers

- In Chapter Six, the three competency carriers at the formulation stage are identified. Their individual and shared responsibilities are outlined.
- While enfolding literature, I found that several studies are related to the issues of product formulation as a competency building process and on how to organize a formulation team (Curry, 1992; Dean and Susman, 1989; Edmondson and Wheelwright, 1989; Gerwin, 1993; Gerwin and Guild, 1994; Page, 1993; Quinn, 1992a; Takeuchi and Nonaka, 1986).
- The visit to Company S suggests that the company has organized its division with the same key functions since the late 1980s.
- Project Q suggests that a team of forty Company ABC employees, including marketing/product management, design engineering/R&D and manufacturing, are responsible for re-designing the productization process for the project.
- Project M suggests that a team structure with the three competency carrying functions was noted and their responsibility are noted.
- Literature review suggests that functional coupling is essential to any NPI project (Gold, 1987; van de Ven, 1986; Wilemon, 1990).
- When asked about the role of manufacturing in the formulation team, the research question assumed that a product formulation team is in place. Therefore, it is necessary to better understand the composition of the team and the role of its team members.

Other than examining the chain of evidence, the reader could examine whether the learning obtained has been logically cumulative, and whether the evidence is convergent thereby building confidence over time. As Figure 6 shows, the sequence of research activities can be depicted as a chain of events.

Figure 6 Learning Journey

progressive and cumulative learning over time

	Chapter Two Literature Review	Chapter Four Phase One Primary Site	Chapter Five Phase Two Secondary Sites	Chapter Six Learning Integration
Challenges	Integrate several bodies of knowledge	Gain access to conduct study on-site, bring team members up-to-date, and find common grounds to achieve agreements	Select sites, obtain permission, and set up meetings	Integrating field findings with literature
Efforts & Logistics	Eighteen months of reading and proposal preparation	One year to gain access, and four months for interviews	Two months to select sites, three months to gain access, and two months to organize interviews	Two years to prepare the thesis
Evidence	Solely based on literature	Contrast and compare observations from different projects, achieve agreement with team members	Contrast and compare observations from different companies, achieve agreement with team members	Contrast and compare observations from all sites and literature
Unique Value	Quick to understand the issue	Different perspectives from different functional groups within one site	Different perspectives from different companies, team members ask their counterparts how to implement change	Knowledge integration

Each stage has added unique value to better understanding of the subject matter. In addition, the sequence of the four stages is important to allow the learning to be cumulative. For example, the learning gained from Company ABC was compared and contrasted through the visits to other companies. Even though all team members were from Company ABC and shared the role of learning agent, we all had a different set of a priori knowledge and experience, also called absorptive capacity (Cohen and Levinthal, 1990). Different absorptive capacities contribute to the construct validity of this study.

The process of seeking convergence to a new paradigm was observed in the course of this study. In the context of exploratory research, cumulative learning was inductive in nature and eventually a new paradigm began to emerge, showing that the explanation of the phenomenon can be built over time (i.e., explanation building). For instance, I observed that because the team members were gaining better understanding as the study progressed, they became opinionated and subjective. This potential for bias can be expressed as 'if one looks hard enough, one can find the evidence he/she is looking for.' Because the team had five members, this study attempts to use more than one source for each piece of information to counter the subjectivity. In addition, being subjective in the process of an exploratory study is understandable, and may be acceptable, because the goal of the study is not hypothesis testing.

Working with companies to collect data has two major challenges. The first one is that it takes time to gain access and to work with busy people. As shown in Figure 6, it took almost a year to convince Company ABC to accept my research proposal, and many months to schedule meetings. The logistic challenge should not be overlooked.

Second, the science and the practice are fundamentally different in perspective. As T. S. Eliot has observed, "between the idea and the reality ... falls the shadow" (The Hollow Men 1925). This is an accurate description of the gap between the science and the practice. The challenge of this study is to balance between the dichotomy.

Because the science and the practice have different vantage points, each camp has its own set of measures. The science camp emphasizes ideas, theories, and proofs. The measure is testable hypotheses, and eventually the power of generalizing the results. The practice camp emphasizes practices, implementation, and management of change. The goal is on how to institutionalize the changes. Therefore, the result is action items for different functional groups to work together to improve the existing process, or to organize another information sharing session to disseminate the findings.

As an exploratory study, perhaps this study can be viewed as a fresh light or a flash infusion of energy (may be short-lived too) attempting to better understand the role of manufacturing at product formulation. Perhaps the contribution of this study is not only on the exact science side, but also on the practice camp side because I have worked to create a forum of discussion within Company ABC and the other secondary sites to look at how to improve their manufacturing role. However short the flash of light this study be, it has influenced these companies in a small way.

Limitations of this Study

This study has six characteristics and each of them contributes to a limiting factor of this study:

- This is an exploratory study that deals with an emerging issue. The findings of the study reflect a process of change that is still in transition. Therefore, the findings of this study have a limited shelf life.

- This study did not achieve the power of generalization as a limited number of projects and sites were studied.
- Because of the limited number of sites, this study did not achieve the power of reliability because similar studies carried out at another set of selected companies may not yield the same results obtained in this study.
- This study attempts to uncover new insights, based on field observation, to support but not to validate emerging constructs. Therefore, the validity of this study is limited.
- This study describes a process of seeking converging evidence to achieve a theoretical saturation of an exploratory study. Because the end point of this study is not prescribed, the closure of this study could be pre-mature.
- This study uses multiple sources of information to verify a given piece of information, whenever possible. This step would eliminate some of the objectivity bias embedded by the information giver. However, the result is not guaranteed.

Dual Role as a Problem Solving Intern and a Management Scientist

As an exploratory investigation, this study sought to maximize learning on several fronts. Two roles were performed by me during the field exploration -- my involvement with Company ABC as a problem-solving intern and as a management scientist responsible for the advancement of scientific knowledge. In the latter role, I had to remain neutral and objective -- in essence, I had to maintain an open-mind to different ideas. de Bono (1985) describes this role as wearing a "white thinking hat". "White hat thinking is a discipline and a direction. The thinker strives to be more neutral and more objective in the presentation of information" (p. 55). During the course of the field exploration, I tried to consciously appreciate the rationale behind different ideas. This discipline of open-minded thinking allowed me to contemplate freely without an existing frame of reference. Unlike other investigation team members, I did not have to justify what had I done in past NPI projects, or what should be done for my current NPI project. Instead, my focus was to understand the information obtained in the field encounters.

As a problem-solving intern, I was responsible for advancing the practice, i.e., making specific recommendations tailored for Company ABC. Concerns related to this role were process-oriented, such as: what kind of changes are necessary; what is the extent of the required changes; how are the changes to be implemented; what is the next action item; is there a plan to fall back on; and who is the change agent? These concerns were all related to how to improve the situation, i.e., a problem-solving role.

de Bono (1991) referred to this action thinking bias set as someone wearing "brown brogues".

> The emphasis in brown brogue action is on practicality, pragmatism, and good sense. What can be done in this situation?...Brown brogue action is determined moment to moment by the actual situation. Quite often the situation falls outside established routine or training...Flexibility is a key aspect of brown brogue action. You change your behavior as the situation changes (p. 63-64).

Many team examples illustrate this type of "brown brogue" mentality. The investigation team had to alter their research strategy due to changes beyond their control. During the course of field exploration, the team spent a lot of time looking at how to implement and communicate the main results of this study to their peers and superiors. Initially, the team did not intend to introduce a new product formulation process but later agreed this would likely be the most effective way to share learning within their organization.

One aspect worth mentioning was my assumed state of knowledge about this subject matter. Before the collaboration with Company ABC began, I spent almost two years reading and formulating ideas. I built several a priori categories of information to facilitate my understanding. Over the six months, the team members challenged my understanding by revealing contradictory evidence. For example, I advocated a full-time team devoted to product formulation. The team members agreed this was a good idea in principle but pointed out it was almost impossible in practice. Disagreements such as this caused the team and myself to re-examine some of my original thinking, i.e., how best to manage the formulation stage.

I believe that my dual roles worked well in this exploratory study. While the "white hat" provided the ability to look at the fundamental value, the "brown brogues" offered flexibility to consider what actions had to be taken.

Glossary

Absorptive Capacity : The ability of an organization to recognize the value of new external information, assimilate it, and apply it to commercial ends (Cohen and Levinthal, 1990).

Architectural Innovation : Product innovations that change the architecture of the product (i.e., the way the components of a product are arranged, linked, and integrated), while leaving the core design concepts and, thus, the basic knowledge of the underlying the components untouched. An architectural innovation can be the result of a change of component that creates new interactions and new linkages with other components in the established product. Often, architectural innovation is comprised of some changes to the components (Henderson and Clark, 1990).

Base Skills : The ability to use knowledge effectively and readily in the execution of a task (e.g., material processing, precise welding, micro-processor design) (Prahalad and Hamel, 1990).

Benchmarking Study : A study to compare a company's performance with other best-in-class companies. Some of the measures used in benchmarking studies are manufacturing yield rate, time-to-market, team composition. The purpose of the study is to identify the gap between companies.

Best Practice Company : A term which implies a company that has excelled in a certain domain. In this study, this term is defined as the four companies the investigation team visited.

Boundary Spanning Methods : A range of techniques aimed at accelerating new product introduction. Activities include obtaining information, resources, and support from others, using this information to create a viable product, and finally, transferring the technology and enthusiasm for the product to those who will bring it to market (Ancona and Caldwell, 1990).

Champions of Innovation Method : A champion of innovation is an individual, or small group of individuals, who have recently championed the adoption of innovative solutions to address leading edge needs of their firms. This method is a technique to permit new product/service formulation teams to engage in boundary-spanning activities for merging exploratory technical research breakthroughs with potential market applications (Bailetti and Guild, 1991a, b).

Commercial Specification : A written communication of a high level product design concept that is discussed, agreed upon and circulated. The communiqué is unambiguous and comprehensible to both users and technologists; specifies what is required, but not how it should be done; and is written based on market understanding and appreciation of the technology requirements for manufacturing (Holt, 1983).

Component : A component is a physically distinct portion, either a software or hardware or both, of the product that embodies a core design concept and performs well-defined function (Henderson and Clark, 1990).

Core Competency : A base skill, or a combination of base skills, that individually or when arranged in a core product, is critical to attaining sustainable competitive advantage in a broad range of end products. Core competencies are the collective learning in the organization, especially, regarding the coordination of diverse production skills and the integration of multiple streams of technologies (Prahalad and Hamel, 1990).

Core Design Concept : The trajectory of the design concept that conforms to the core product (Clark, 1985).

Core Product : A physical combination of one or more core competencies. The core product is the platform from which the end products are delivered and is the base for a long-term program of technological change for introducing a series of new end products, which can be produced profitably and quickly (Prahalad and Hamel, 1990).

Early Manufacturing Participation : A model to describe the timing of the role of manufacturing in a product formulation stage.

Effective Manufacturing Role : A model to describe the characteristics of an effective role that manufacturing should play in a new product introduction project.

There are three conceptual components defining EMR: anticipation, innovation and excellence.

Enhanced Product : An enhanced product opens new market opportunities (i.e., niches) through existing technology. Niche creation conserves the existing core design concept. An enhanced product often involves changes to components for improving the product features and performance without altering the product architecture (Wheelwright and Sasser, 1989).

Gatekeeper Network : A boundary-spanning technique that involves individuals who provide valuable ideas and guidance to the innovation process through their personal networks of outside contacts, their reading of the literature and their participation in professional forums (Allen, 1977).

Incremental Improvement : While improvement introduces somewhat minor changes to the existing product, it exploits the potential of the established product and core design concept, and often reinforces the production cost reduction, product reliability and performance, an incremental improvement enhances the core competency and enforces the product's competitive position (Henderson and Clark, 1990).

Lead User Technique : Lead user technique is a boundary-spanning activity that introduces lead users as the principle source of innovative ideas and indications of technological potentials. Lead users identify needs that will be general in a marketplace months or years before the bulk of the marketplace encounters the needs, and positions itself to take advantage of the situation by obtaining a solution to those needs (von Hippel, 1986).

Major Technology Improvement : A technological improvement that changes the components and architecture of the product. The value of the product will be significantly and positively affected, but the core design concept behind the product remains unchanged (Roberts and Meyer, 1991).

Manufacturing (or Production) Process Management : Manufacturing process management is a process which is part of the manufacturing strategy and involves a series of activities which are performed upon the material to produce the final product and create a greater product value (e.g., machining, packaging, assembly, equipment maintenance, testing, printing, and facility operations) (APICS Dictionary, 1987).

Manufacturing Strategy : A collective pattern of decisions that act upon the formulation (i.e., process innovation) and deployment of manufacturing resources (i.e., manufacturing process management) (APICS Dictionary, 1987).

Minor Technology Improvement : A technological improvement that has the smallest level of product or process technological change. The magnitude of such change is usually marginal and non-substantial (e.g., an evolutionary change to the firm's existing product technology; a new product that corrects known problems; a product component change; a production process tuning; change in the tolerance level of the product or component; adjustment of the tolerance level of the manufacturing process)(Inferred from Roberts and Meyer, 1991).

New Product Formulation Process : A systematic view of work flow activities that pertain to identification and evaluation product concept and definition of business case.

New Product Formulation Team : A new product formulation team is the term for the new form of product design team proposed by this study. A formulation team is a multi-disciplinary team of domain-specific experts headed by a project coordinator. Its mission is to identify and design a business-worthy product. The team first decides on a high level design concept, then develops a detailed market plan and product prototype. Possible team participants are product managers, market researchers, and product designers (Bailetti and Guild, 1991a,b).

Portfolio of End-User Products : The portfolio of end-user products is the platform of offerings that the Strategic Business Unit delivers to its customers. Market leadership of the portfolio is derived from how well the products have sold. How and where the product came from are not the major issues and the components that make up the product are generally not of great concern (Prahalad and Hamel, 1990).

Proactive Manufacturing Role: A characteristics of a manufacturing role in a new product formulation stage. The role offers foresight in manufacturing process planning by anticipating future product requirements.

Process Innovation : Process innovation, as part of the manufacturing strategy, manages the changes in the manufacturing process. The changes are often initiated by a product change or a growth in volume demand. These forms of change will be the force for driving the efficiency and the reliability of the manufacturing process, as well as for the quality and the cost of the product (Inferred from Abernathy and Clark, 1985).

Product Innovation : An innovation that may lead to the introduction of a new product. The magnitude of the innovation can vary from incremental to radical and has a prolonged effect on the innovation and manufacturing processes (Abernathy and Clark, 1985).

Product Generation : A set of product members including an initial "new-to-the-world' product and its line extensions.

Product Portfolio : A set of related or unrelated product generations offered by a company.

Product Life cycle Plan : A plan that outlines a product release schedule.

Quality Function Deployment : A systematic technique to relate customer requirements to engineering characteristics (Hauser and Clausing, 1988).

Radical Innovation : As the name suggests, this form of innovation is based on an entirely new and different set of engineering or scientific principles. The core technology is changed so that the established technical and product competencies (i.e., core competence) are disrupted but a long term program of technological change (i.e., core product) is initiated. Radical innovation establishes a new set of core design concepts embodied in components that are linked together in a new product architecture. Radical innovation can be applied either to existing markets and customers, or be used to open new markets and potential applications (Abernathy and Clark, 1985).

Relay (Sequential) Approach : In a sequential approach to multi-stakeholder collective decision making, all tasks for the project are divided into independent phases. The tasks in each phase are completed by a group of functional specialists who are responsible for the phase and who pass on, or relay, information to the group responsible for the next phase. In this way, information flows sequentially from phase to phase (Takeuchi and Nonaka, 1986).

Rugby (Non-sequential) Approach : In a concurrent approach to multi-stakeholder collective decision making, all functional specialists are involved from the beginning to the completion of the project, which includes implementation and project follow up. Information flows back and forth, so it is non-linear. This approach does not primarily maximize innovation efficiency in the short term, but ensures high quality innovation decisions. However, once the decision is implemented, efficiency may still be possible .

Skunk Works : An approach to develop new products by physically isolating the team until the project is completed.

Sources of Competitive Advantage : Advantages such as cost advantage (e.g., cost of innovation, production cost, and marketing cost), and product differentiation (e.g., uniqueness, and product attributes and functions) which improve the competitive position and create value for the firm (Porter, 1985).

Strategic Architecture : A road map to the future that establishes objectives for competency building in the long run (Prahalad and Hamel, 1990).

Strategic Business Units (SBU) : Strategic business units organize the firm in product-market departmentalization. An SBU is an autonomous business unit that manages a related portfolio of end products (Prahalad and Hamel, 1990).

Strategic Intent : Strategic intent envisions a desirable leadership position and establishes the criteria that the firm will use to chart its progress. It sets targets that are worthy of attention and directs individual and collective efforts and commitment.

Strategic intent defines the end but is flexible during the means and remains stable over time (Hamel and Prahalad, 1989).

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IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6″

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