Product Development - Managing a Dispersed Process

by

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The Challenge of a Dispersed Product Development Process

New product development has a long history in marketing including research on customer preferences (Green and Wind 1975, Green and Srinivasan 1990, Srinivasan and Shocker 1973), product positioning and segmentation (Currim 1981, Green and Krieger 1989a, 1989b, Green and Rao 1972, Hauser and Koppelman 1979), product forecasting (Bass 1969, Jamieson and Bass 1989, Kalwani and Silk 1982, Mahajan and Wind 1986, 1988, McFadden 1970, Morrison 1979), and test marketing (Urban 1970, Urban, Hauser and Roberts 1990). The applications have been many and varied and have led to a deeper understanding of how to gather and use information about the customer in the design, testing, launch, and management of new products. Many integrative texts on product development from a marketing perspective have been published to review the issues, the methods, and the applications (Dolan 1993, Lehmann and Winer 1994, Moore and Pessemier 1993, Urban and Hauser 1993, Wind 1982).

Marketing, with its focus on the customer, has had great success. Tools such as conjoint analysis, voice-of-the-customer analysis, perceptual mapping, intention scaling, portfolio optimization, and lifecycle forecasting are now in common use. Firms that continuously and efficiently generate new products that are in tune with their end customers' needs and wants are more likely to thrive (Griffin and Page 1996). Direct communication with customers allows firms to learn from customers and tailor products to their requirements.

In parallel with the development of prescriptive tools, researchers have studied the correlates of new product success identifying communication between marketing and engineering as one of the most important factors in success (Cooper 1984a, 1984b, Cooper and Kleinschmidt 1987, Dougherty 1989, Griffin and Hauser 1996, Souder 1987, 1988). As a result, organizational process tools such as cross-functional teams (Kuczmarski 1992, Souder 1980), quality function deployment (Hauser and Clausing 1988), and co-location (Allen 1986) were developed to promote the sharing of ideas and the close integration of engineering decisions with customer needs. Process oriented textbooks now routinely consider marketing issues and the need to integrate engineering with the marketing function (McGrath 1996, Ulrich and Eppinger 2000). Clearly, the ultimate effectiveness of the tools discussed in this chapter is moderated by the incentives, behavior and effectiveness of the people implementing those tools in the organization.

As we move into the 21st century, new challenges and opportunities are arising driven by global markets, global competition, the global dispersion of engineering talent, and the advent of new information and communication technologies such as electronic mail, the world-wide web, and increased electronic bandwidth. The new vision of product development is that of a highly disaggregated process with people and organizations spread throughout the world (Holmes 1999). At the same time products are becoming increasing complex with typical electro-mechanical products requiring close to a million engineering decisions to bring them to market (Eppinger, Whitney, Smith and Gebala 1994, Eppinger 1998). Even software products such as Microsoft Word or Netscape require disaggregated, but coordinated processes involving hundreds of developers (Cusumano and Selby 1995, Cusumano and Yoffie 1998). Competitive pressures mean that time to market has been proposed as key to new product success as has marketing's orientation towards customer needs and customer satisfaction (Smith and Reinertsen 1998). Because products are marketed throughout the world, firms face the tradeoff between standardization for cost reduction and variety for satisfying a broad set of customers. This has expanded the need for marketing to look beyond the single product to focus on the product platform (Moore, Louviere and Verma 1999).

In this chapter we look at the state of the art in research that addresses these new challenges for the marketing community. We begin with an overview of the integrated end-to-end product development process indicating marketing's role in addressing the challenges of developing profitable products (and platforms). The remainder of the chapter addresses specific research challenges relating to the end-to-end process. We organize the remaining sections around the various stages of development recognizing that, in practice, these stages are often iterative and/or integrated. Specifically we address, in order, the strategic end-to-end product development process, the fuzzy front end of customer opportunity identification and idea generation, the process of concept selection and detailed design and engineering of products and processes, the testing phase where concepts and products are prototyped and tested, and the enterprise and organizational strategy necessary for success. We close with a vision of the future of research of product development.

Product Development – End to End

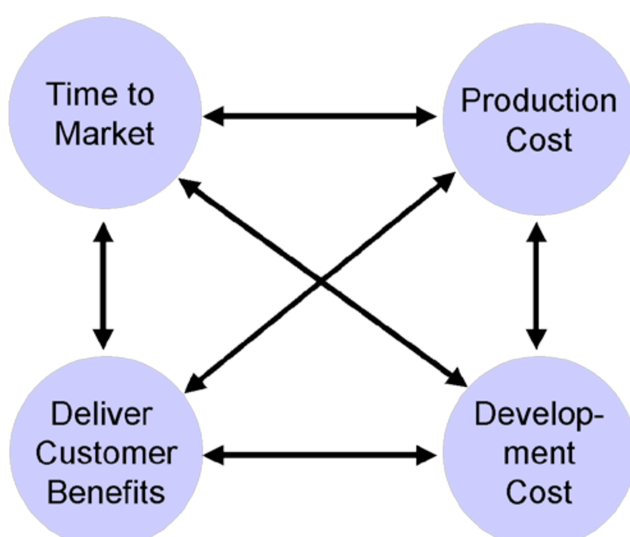
In the late 1980s and early 1990s a marketing focus on product development stressed customer satisfaction. Researchers in marketing believed that the key to success was a better understanding of the voice of the customer and a better ability to link that voice to the engineering decisions that are made in launching a product. For example, Menezes (1994) documents a case where Xerox moved from a focus on ROA and market share to a focus on customer satisfaction. Important research during that period included new ways to understand the voice of the customer (Griffin and Hauser 1993), new ways to develop optimal product profiles in the context of competition (Green and Krieger 1989a, 1991), more efficient preference measurements (Srinivasan 1988), and the ability to handle larger, more complex customer information (Wind, Green, Shifflet, and Scarbrough 1989). At the same time the quality movement focused product development engineering on improved reliability through continuous improvement such as Kaizen methods (Imai 1986), statistical quality control (Deming 1986), modified experimental design (Taguchi 1987), and design for manufacturing (Boothroyd and Dewhurst 1994). There were many successes including a turnaround of the major US automobile manufacturers. Many engineers came to believe that the key to success was a better quality product.

Also during that time both marketing and engineering realized that time-to-market was critical. Marketing saw the phenomenon as that of rewards to early entrants (Golder and Tellis 1993, Urban, Carter, Gaskin, and Mucha 1986) while engineering saw, among other things, the lost profits due to rework and delays (Smith and Reinertsen 1998). Both customer satisfaction and time-to-market became panaceas that, if only the firm could achieve them, would guarantee success and profitability.

An Integrated Process

Today, both industry and academia view successful product development as an integrated process that must overcome many tradeoffs, as depicted in Figure 1. Customer satisfaction, time-to-market, and cost reduction through total quality management are all important, but none is viewed as a guarantee of success.

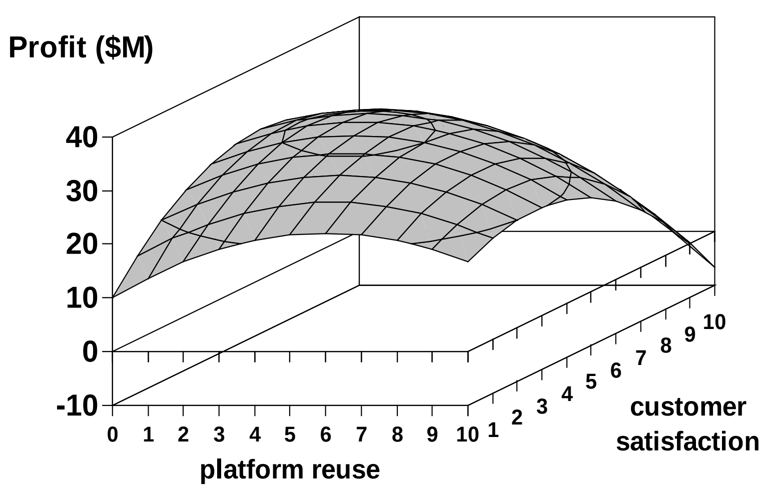
Figure 1: Tradeoffs in New Product Development (based on Smith and Reinertsen 1998)



All else equal, a product will be more profitable if it delivers customer benefits better, is faster to market, costs less to produce, and costs less to develop. Figure 1 puts research on product-development tools and methods into perspective. Research should be directed to assure that: (1) the firm is operating on the efficient frontier with respect to each of these strategic goals, and (2) the firm is making the best tradeoffs among these goals.

Research must recognize that there are tradeoffs along the efficient frontier. For example, if we focus on just two of the many goals of product development, then the efficient frontier in Figure 2 suggests that there are tradeoffs between customer satisfaction and platform reuse. A firm can become too committed to either. For example, the significant reuse of components in platforms, software, and designs may get the product to the market faster and reduce development costs (e.g., Witter, Clausing, Laufenberg, and de Andrade. 1994), but the firm may sacrifice the ability to satisfy customer needs and may miss out on ways to reduce product costs. Similarly, quality function deployment (QFD) may be an effective means to deliver customer benefits by improving communication and coordinating the efforts of multiple players in the NPD process, but some applications are too cumbersome reducing time-to-market and increasing development cost.

Figure 2: Quantifying the Tradeoffs in Product Development

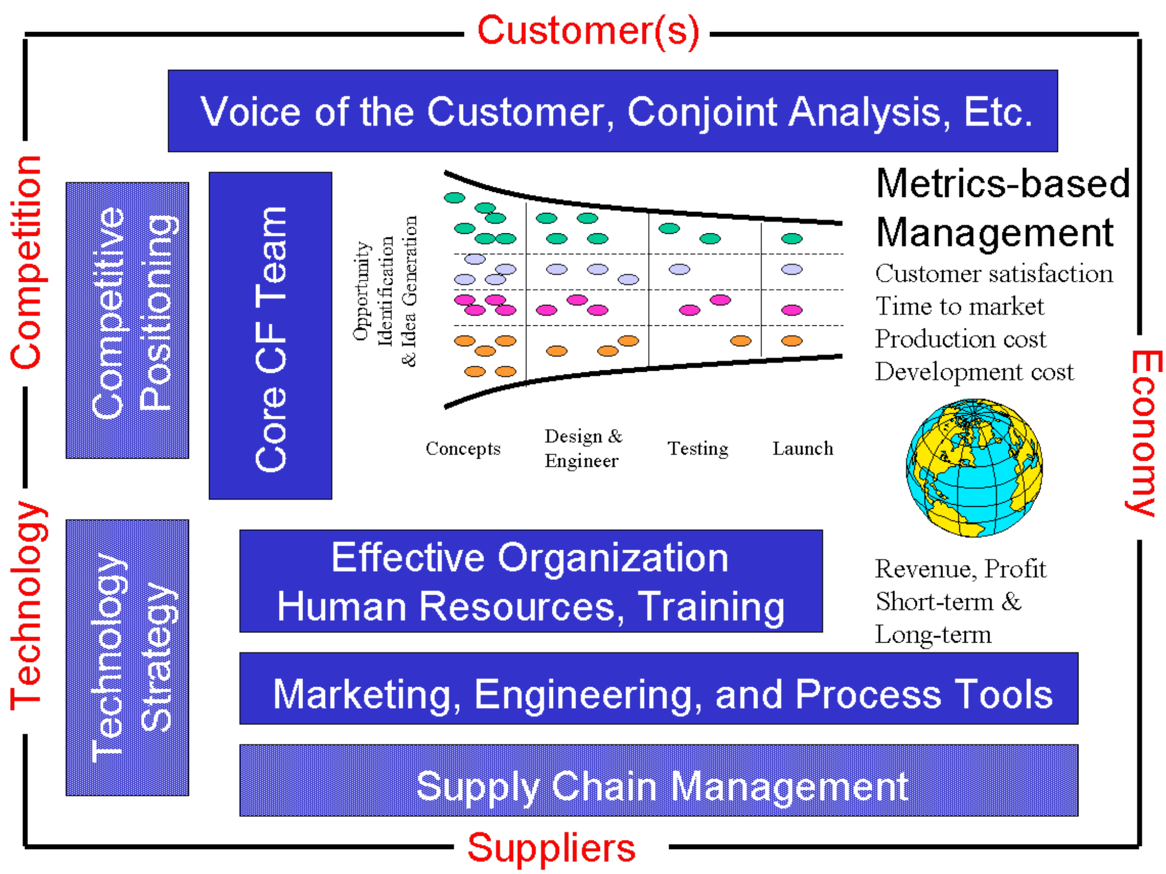


In response, product development teams have modified QFD to deliver the right benefits at the right costs. Such modifications include just-in-time QFD (Tessler and Klein 1993), turbo QFD (Smith and Reinertsen 1998), and simplified QFD (McGrath 1996). Platform reuse and QFD are just examples. As we review various product develop tools and methods, the reader should keep in mind that the tools work together to enable the firm to make the appropriate tradeoffs among the four strategic goals in Figure 1.

Product Development as an End-to-End Process

In order to make these tradeoffs effectively, most firms now view product development (PD) as an end-to-end process that draws on marketing, engineering, manufacturing, and organizational development. Figure 3, a representation of such an end-to-end process, is modified from a process used at Xerox and advocated by the Center for Innovation in Product Development (Seering 1998). It summarizes many of the forces affecting product development and highlights opportunities for research.

Figure 3: Product Development – End to End

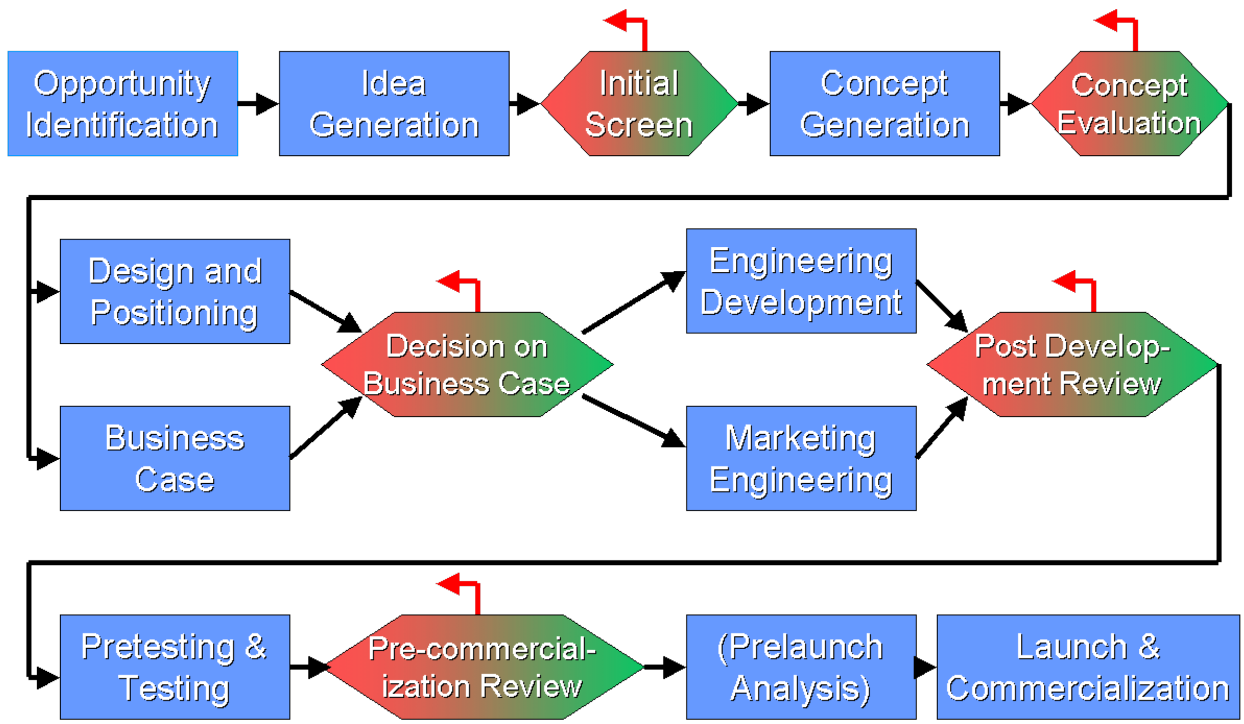


From our perspective, the five forces on the outer square of Figure 3 present the external challenges to the PD team. All actions are contingent on these forces. For example, speed to market might be more critical in the highly competitive world of Internet software. Rather than 3-year planning cycles, such firms might adopt 3-year horizons with adaptive implementation strategies that are reviewed monthly or even weekly (Cusumano and Yoffie 1998). The descriptions in the seven rectangles indicate actions that must be taken. For example, the firm must have a strategy for dealing with technology ("Technology Strategy") and employ methods to understand the benefits provided to customers by competitive product offerings, identify gaps where benefits are demanded but not supplied, and understand how competition will respond ("Competitive Positioning"), while "Supply Chain Management" helps the firm (and extended enterprise) include suppliers in developing products to meet customer needs. In this chapter we review those actions that are of greatest interest to a marketing audience, namely those in the four darker rectangles. In-bound marketing ("Voice of the Customer, Conjoint Analysis, etc.") provides the window on the customer. The myriad perspectives from marketing, engineering, design and manufacturing that must be integrated for successful PD manifest themselves in the form of a 'Core Cross-Functional Team," supporting an "Effective Organization." "Human Resources" are important, including the need to understand the context and culture of the organization and the need to develop human capabilities through training, information technology, and communities of practice (Wenger 1998). "Marketing, Engineering, and Process Tools" enable the end-to-end PD process to be both more efficient and more effective.

The Product Development Funnel, Stage-Gate, and Platforms

The PD funnel is at the center of Figure 3. The funnel represents the traditional view that PD proceeds in stages as many ideas are winnowed and developed into a few high-potential products that are ultimately launched. We have adopted here the stages of opportunity identification (and idea generation), concept development and selection, detailed design and engineering, testing, and launch used by Urban and Hauser (1993). Each text and each firm has slightly different names for the stages, but the description of PD as a staged process is fairly universal. The key management ideas are (1) that it is much less expensive to screen products in the early stages than in the later stages and (2) that each stage can improve the product and its positioning so that the likelihood of success increases. Simple calculations in Urban and Hauser demonstrate that such a staged process is likely to reduce development costs significantly. This staged process is best summarized by Cooper (1990) who labels the process stage-gate. Figure 4 summarizes a typical stage-gate process adapted to the structure of this chapter. Stage-gate processes provide discipline through a series of gates in which members of the PD team are asked to justify the decision to move to the next stage – later stages dramatically increase the funds and efforts invested in getting a product to market successfully.

Figure 4: Cooper's Stage-Gate Process (adapted to the structure of this paper)



The funnel in Figure 3 also attempts to illustrate the concept of pipeline management by having multiple, parallel sets of projects moving through the funnel. Often the best strategy for a firm is to have sufficiently many parallel projects so that it can launch products to the market at the most profitable pace. Research challenges include the questions of how many parallel projects are necessary, the tradeoffs between more parallel projects and faster time for each project, and the number of concepts that are needed in each stage of a parallel project to produce the right pace of product introduction. Figure 3 does not explicitly capture the important characteristic of real PD processes that stages often overlap. For example, with new methods of user design and rapid prototyping, it is possible to test concepts earlier in the design and engineering stage or to screen ideas more effectively in the concept stage. Figure 3 also does not explicitly capture the iterative nature of the entire process (although we have tried to illustrate that with the feedback arrows in Figure 4). For example, if a product does not test well, it might be cycled back for further development and retested. In fact, many firms now talk about a "spiral process" in which products or concepts move through a series of tighter and tighter stages (e.g., Cusumano and Selby 1995). The key difference between a funnel process and a spiral process is that, in the latter, there is a greater expectation of iterative feedback loops as successive journeys through the funnel lead to improvements. One interesting research challenge is to formalize the organizational implications of spiral vs. funnel processes and to determine the circumstances were one is favored over the other.

The small ovals in the end-to-end PD process (Figure 3) are either individual products or product platforms. In many industries, including complex electro-mechanical products, software, and pharmaceuticals, firms have found that it is more profitable to develop product platforms. A platform is a set of common elements shared across products in the platform family. For example, Hewlett Packard's entire line of ink-jet printers is based on relatively few printer-cartridge platforms. By sharing elements, products can be developed more quickly, and at lower cost. Platforms might also lower production costs and inventory carrying costs, and provide a basis for flexible manufacturing. On the customer side, platforms enable a firm to customize features in a process that has become know as mass customization (Baldwin and Clark 2000, Cattani, Dahan and Schmidt 2002, Gilmore and Pine 1997, Gonzalez-Zugasti, Otto, and Baker 1998, Meyer and Alvin Lehnerd 1997, Sanderson and Uzumeri 1996, Ulrich and Steve Eppinger 2000).

Finally, the right side of the end-to-end process in Figure 3 illustrates the growing trends toward metrics-based management of PD. As the process becomes more dispersed among various functions, various teams, various suppliers, and throughout the world and as products become more complex, there is a greater need to balance top-management control with the empowerment of self-managed, cross-functional teams. To achieve this balance, firms are turning to a metrics-based approach in which teams are measured on strategic indicators such as customer satisfaction, time-to-market, production cost, and development cost. If the weights on these metrics are set properly, then the teams, acting in their own best interests, will take the actions and make the decisions that lead to the greatest short- and long-term profit (Baker, Gibbons, and Murphy 1999a, 1999b, Gibbons 1997).

This completes our marketing overview of the end-to-end product development process. The important lesson, that we hope to illustrate throughout the remainder of this chapter, is that the process depends upon all of its elements. Although the detailed implementation of each element varies depending upon technology, competition, customers, and suppliers, a firm is more effective if it understands all of these elements and can manage them effectively.

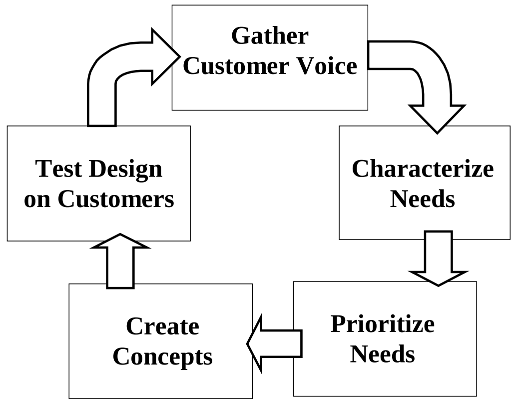
We now examine research opportunities within each stage of the PD process by beginning with the fuzzy front end of opportunity identification and idea generation.

The Fuzzy Front End: Opportunity Identification and Idea Generation

Perhaps the highest leverage point in product development is the front end which defines what the product will be, represented by the (leftmost) opening of the funnel in Figure 3. This decision balances the firm's core strengths versus competition with the demands of potential customers. Relevant topics include technology strategy and readiness, customer input, and newer, virtual-customer methods. Because this is a marketing handbook, we focus this section on obtaining information to satisfy customer needs and on idea generation. We recommend that readers interested in technology readiness review Roussel, Saad, and Erickson (1991) or McGrath (1996).

The fuzzy front end may be viewed through the lens of *uncertain search*. That is, the design team must consider a multitude of designs in order to find an ideal solution at the intersection of customer preferences and firm capabilities. Once the firm has determined the strategic value of developing a new product within a particular category, but before it can specify the detailed requirements and features of the design, it must select the more promising designs to develop and test so as to meet development-cost, production-cost, customer-satisfaction, and time-to-market targets. Promising designs are those that are technically desirable, i.e. feasible designs that exploit the firm's competitive advantages, and are attractive to potential customers. Marketing's role at the fuzzy front end of PD is to reduce uncertainty during the design team's search for winning product concepts by accurately capturing customers' points-of-view and communicating customer preferences to the design team. In some cases, the process is more direct, with engineer/designers observing and communicating directly with potential customers, possibly facilitated by marketing personnel. The ease of communication and interaction over the Internet has the potential to increase the frequency and effectiveness of such unfiltered observations. The process of listening to customers in order to optimize a new product is iterative, as depicted in Figure 5, consistent with the feedback loops in the funnel processes and with the basic intent of the spiral processes.

Figure 5: Listening to Customers



Recognizing the iterative nature of Figure 5, we begin this section by reviewing techniques for gathering raw data on customer needs. These methods include direct survey methods with which marketing researchers are familiar, but include as well Kano's model of delighting customers, the concept of disruptive technologies, methods to get at underlying meanings and values, methods for the "mind of the market," and benefit chains. We then review methods for characterizing and refining customer needs based on apparent patterns and themes and we review methods for organizing needs and identifying market segments. Needs must be prioritized and many marketing methods are quite effective. In the fuzzy front end we use the simpler and less costly methods recognizing that any information will be refined in the design and prototype phases. Thus, we save a review of these "high-fidelity" methods until the next section of this chapter. However, in this section we do review some of the more common methods of ideation. We close this section by examining how the Internet is changing the way we view the process of identifying and measuring customer needs.

Surveys and Interviews

There are many challenges when attempting to capture the voice of the customer, measure preference, and predict new product purchase behavior. During the fuzzy front end the methods must recognize that: (1) customers may still be forming their preferences and may change their opinions by the time actual products ship, (2) it may be difficult for customers to express their true preferences (e.g. degree of price sensitivity) due to social norms, (3) the questioning process itself can be intrusive, so it is best to use multiple, convergent methods, and (4) information gatherers may "filter" the voice of the customer through their own biases (e.g., Bickart 1993; Feldman and Lynch 1988; Nowlis and Simonson 1997; Simmons, Bickart, and Lynch 1993); Tourangeau, Rips and Rasinski 2000). Researchers have developed and validated multiple methods in attempts to address these issues.

Mahajan and Wind (1992) surveyed firms about techniques they used to identify customer needs. They found that 68% of firms used focus groups, and 42% used limited product roll-outs. In addition, many firms used formal concept tests, conjoint analysis, and Quality Function Deployment (QFD). The study also suggested the following improvements for customer research:

- More quantitative approaches
- More efficient in-depth probing
- Greater accuracy and validity
- Simpler and better customer feedback
- Greater customer involvement
- More effective use of lead users and field salespeople
- Methods that address a long-term, functionally-integrated strategy

The new methods we review attempt to address many of these concerns. However, research is still underway. Each method has its limitations and the value of the information depends on the quality of execution of the research.

Experiential Interviews

For evolutionary designs targeted at an existing or familiar customer base, focus groups (Calder 1977, Fern 1982), provide valuable information. However, focus groups are subject to social norms within the group and often focus on inter-subject interactions and thus miss many of the customer needs that are hard to articulate or which the customer cannot express effectively in a group setting. Thus, many firms are turning to experiential interviews in which the needs and desires of customers are explored in one-on-one interviews in which the customer describes his or her experience with the product class. The interviewer probes deeply into the underlying, more stable, and long-term problems that the customer is trying to solve. Research by Griffin and Hauser (1993) indicates that ten to twenty experiential interviews per market segment elicit the vast majority of customer needs. Qualitatively rich interviews at the customer's location are most effective, but expensive to conduct. One challenge is to limit the session length, usually to an hour or less, that engages, but does not inconvenience, the participant. In selecting interview candidates, a selection matrix that segments the market according to type-of-use and customer source, like the one in Table 1, ensures that a diversity of customers is contacted (Burchill and Hepner-Brodie 1997, Hepner-Brodie 2000). The key concept is a representative rather than a random sample in which the PD team gathers information from all the relevant segments and from customers with varying perspectives on current and future needs. In addition, if there are multiple decision makers, say doctors, lab technicians, and patients for a medical instrument, then each type of decision maker needs to be consulted. See examples in Hauser (1993).

Table 1: Customer Selection Matrix for Coffee Makers

Market Segment	**Current Customers**	**Competitors' Customers**	**Lead Users**	**Untapped Customers**	**Lost Customers**
Countertop 12-cup Drip Users					
Specialty (e.g., Espresso) Users					
High-Volume (24-cup) Users					

Multiple members of the PD team should review the transcripts. For example, Griffin and Hauser (1993) suggest that each team member recognizes approximately half of the needs in a transcript and that multiple team members are very effective at identifying more than 95% of the needs. Because non-verbal communication is critical, many firms now videotape interviews in addition to transcribing them. Such interviews, often distributed on CDs to team members, have become known as the "Face of the Customer (FOC)." For example, hearing a customer say "I use Windows on my notebook and need an accurate, built-in pointing device that doesn't require me to move my hands from the keyboard" carries more information than a filtered summary of "Good pointing device is important." Seeing the user struggle with existing pointing devices is even more persuasive. In the past, FOC methods have been expensive to implement and are used only by those firms with larger budgets. Fortunately, new developments in the use of digital video photography are making this process less expensive and easier to implement.

Many firms now include the actual design-engineers in the interviewing process when the process is cost-effective (c.f., Leonard-Barton, Wilson, and Doyle. 1993). However, in complex products where the PD team often consists of over 400 engineers and other professionals, key members observe the interviews and use methods, such as the videotapes or the CD-based FOC, to carry this information to the PD team in a form that can be used effectively.

The Kano Model: Delighting Customers

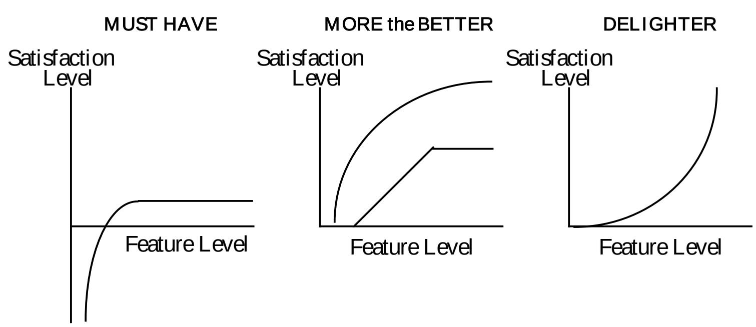
"Customer needs" are often verbal statements of benefits that customers gain from the product or service. For example, a customer might want a safer car, a computer monitor that takes up less space on the desk, or a portable computer that makes six hours in an airplane cabin more pleasant. However, in order to design a product, the PD team must map these needs into product features. One widely-used conceptual method is the Kano model.

The conceptual Kano model characterizes product features according to their relationship to customer expectations (Clausing 1994) as in Figure 6. In particular, features are characterized, roughly, according to the shape of the feature-to-satisfaction function. Although this taxonomy is an approximation to a more continuous categorization, it is nonetheless useful as a conceptual aid to understand how features affect satisfaction.

Some features address "must have" needs. Such needs are usually met by current technology and any new product must satisfy these needs. However, it is difficult to differentiate a product by increasing the satisfaction of these needs because they are already satisfied well by the competitive set of existing products. In other words, the competitive equilibrium has dictated that all viable products address these needs. If the PD team does not meet the needs then the product will elicit customer dissatisfaction and lose sales. For example, an automobile must have four properly inflated tires that perform robustly under all driving conditions. Recent problems with tire tread separation reveal the powerful negative impact of not meeting "must have" needs. However, there are opportunities to save cost if new creative technology can address these needs as well or better with lower cost. For example, Hauser (1993) gives an example where a basic need for medical instruments – printing patient records – was met with a new technology (parallel port to connect to the physician's office printer) that was significantly less expensive that existing technology (built-in thermal printers), yet met the need better.

Other needs are "more the better." When new technology or improved ideas increase the amount by which these needs are satisfied, customer satisfaction increases, but usually with diminishing returns. Such needs are usually relevant when technology is advancing rapidly, such as with computer processor clock speed. In order to stay on top of the market, a computer manufacturer must always be developing more powerful and easier to use computers.

Figure 6: Kano Taxonomy of Customer Needs



Finally, a special class of needs are those which customers have difficulty articulating or rarely expect to have fulfilled. When features are included in a product to satisfy such customer needs, often unexpectedly, customers experience "delight!" Sources of customer delight can become strong motivators for initial purchase and for customer satisfaction after the sale. Examples include complementary fruit baskets in hotel rooms, software that anticipates your next move, automobiles that rarely need service, and others such as those in Table 2. Conceptually, once a product has such a "delighter" feature that passes a threshold of functionality, customers become extremely satisfied and seek out the product for that feature.

Table 2: Examples of Kano Feature Types (circa 2000)

	Must Have	**More the Better**	**Delighter**
Car	(4) Reliable Tires	Gas Mileage	GPS-based map
Notebook	AC Adapter	Hard Drive Capacity	Built-in wireless
Software	Compatibility	Processing Speed	Auto-Fill-In

It is important to remember that the Kano model is dynamic. Today's "delighter" features become tomorrows "must have" features. For example, a graphical user interface (GUI) and multi-processing were once "delighter" features, but today they are "must have" features for any desktop computer operating system. However, the basic underlying customer needs of an effective and easy to use operating system remain. Antilock braking systems and premium sound systems were once delighter features for high-end cars, but today are "must have" features for any brand competing in the high-end segment. New "delighter" features include automatic mapping and location systems, satellite-based emergency road service, side-view mirrors than dim automatically, night-vision warning systems, and Internet access. However, the basic underlying needs of safety and comfortable transportation remain. Really successful products are frequently due to newly identified "delighter" features that address those basic customer needs in innovative ways. The dynamic nature of Kano's model suggests a need for ongoing measurement of customer expectations over a product's lifecycle.

The Innovator's Dilemma and Disruptive Technologies

The Kano model cautions us that as new technology develops, today's excitement needs can become tomorrow's must-have needs. However, the size and nature of the customer base also evolve as technology evolves. For example, as more computer users purchase laptop computers rather than desktop computers, their needs for improved levels of previously unimportant features, such as reduced disk drive size and weight, increase dramatically. If a disk-drive manufacturer is focused only on its current desktop computers, it may miss opportunities when customers move to laptop computers or new customers enter the market.

Bower and Christensen (1995) and Christensen (1998) formalize this concept and point out that listening to one's current customers, while consistent with the firm's financial goals, may enable entrants with new technologies to eventually displace incumbents. This may happen even though the new technologies are not initially as effective as the incumbent technologies on "more-the-better" features. For example, the initial small hard drives for portables were not as fast nor could they store as much information as the larger disk drives used in desktop computers. But an emerging class of portable users demanded them because they were smaller and lighter in weight. Eventually, the technology of smaller drives caught up to the technology of the larger drives on the "more-the-better" features (storage, speed). However, they dominated on the "delighter" features (size and weight). Because these delighter features were relatively more important to this new market (portable computers) than the old market (desktop computers), the new drives became the dominant technology for the new market.

Firms fall into disruptive-technology traps because current customers may not appreciate the new benefits of a new technology because it does not perform as well on the traditional features they value. However, new users, not well known to the firm, may value the new features more highly and forgive the below-average performance on traditional features. In addition, new entrants may be willing to settle for lower sales and profits than incumbents in order to gain a foothold in the market. Eventually, as the new technology achieves higher performance on traditional features, the incumbent's old customers begin switching and the firm loses its leadership position. To avoid the disruptive-technology trap and to stay on top of the needs of all customers, Christensen proposes that incumbent firms partner with (or develop) independent, "entrepreneurial" entities to explore disruptive technologies. Christensen proposes that the entrepreneurial entities be held to less stringent short-term financial and performance objectives so that they might focus on long-term performance by satisfying the "delighter" needs of the new and growing markets.

While we agree with Christensen's description of the dynamics of the disruptive phenomenon, we are less pessimistic about the ability of incumbent firms to innovative. His prescriptions do not take into account the evolving nature of customer needs nor the ability of marketing research to identify excitement needs, changes in customer preferences, and new customers. When there is an organizational will to use these proven methods, incumbent firms can innovate on such disruptive technologies.

The dynamic nature of technology and the possibility of disruptive innovation suggest that marketers carefully monitor the preferences of both customers and non-customers over time, and develop a deep understanding of the needs of both customers and non-customers. Marketers should pay careful attention to evolving, difficult-to-articulate customer needs, and to potentially new tradeoffs among customers who contemplate a different use of the technology. Tools to facilitate such ongoing monitoring, such as web-based conjoint analysis, are discussed later in this chapter.

Empathic Design and User Observation

Many firms realize that no matter how refined the research methodology and no matter how much data is collected, some insights can only be gained by observing customers in their natural habitat (Leonard Barton, Wilson, and Doyle 1993). This is particularly true when customer needs are difficult to verbalize or are not obvious. The technique of empathic design requires that members of the design team immerse themselves in the customer environment for a period long enough to absorb the problems and feelings experienced by users. If a product is inconvenient, inefficient, or inadequate, the designer gains first-hand experience with the problem. Empathic methods are particularly effective at determining the ergonomic aspects of a product. The empathic methods can be carried out by members of the PD team (after receiving the appropriate training) or by marketing professionals, but in either case, rich media should be used to capture the users experience so that it can be shared with the entire PD team.

Intuit, makers of Quicken®, the leading personal financial software package on the market, pioneered the "Follow-Me-Home" program in which Intuit employees observe purchasers in their homes from the moment they open the box to the time they have Quicken functioning properly (Case 1991). Using empathic design and user observation, Intuit has steadily improved Quicken's ease-of-use with features such as auto fill-in of accounts and payees, on-screen checks and registers that look like their paper counterparts, and push buttons to automate common tasks. More importantly, Intuit took responsibility for the entire process of producing checks including working to improve printers and printer drivers even though these were made by third parties. Empathic design highlighted problems that explained why customers were not buying Intuit's products. Even though the problem was not Intuit's technical responsibility in the value chain, Intuit took responsibility and solved the customers' perceived problems. Specifically, Intuit recognized that it could lose it's share of the software market if it did not solve the printer manufacturers' software and hardware problems. Intuit's focus on customer needs has kept the company on top of a highly competitive, ever-changing marketplace.

Holtzblatt and Beyer (1993) developed a technique known as contextual inquiry in which a member of the design team conducts an extensive interview with a customer at his or her site while the customer performs real tasks. The interviewer can interrupt at any time to ask questions about the why's and how's of the customer's actions. The results of these contextual inquiries are shared with other design team members and synthesized using affinity diagrams (described below) and work flow charts.

Underlying Meanings and Values

In addition to exploring customers' stated needs, PD teams often seek to understand customers' underlying meanings and values. One method to get at underlying meanings and values is through in-depth experiential interviews that seek to get customers to express such needs. (In other words, underlying meanings and values are really just difficult-to-articulate needs.) In addition, some firms have explored anthropological methods.

Cultural anthropology (cf. Levin 1992) is the study of hidden meanings underlying products, or meanings which are sought, but left unmet. The approach is broader than psychology-based motivational research in that it accounts for customers' social values, not just emotional needs. Issues such a company's environmental impact and minority hiring record gain significance.

How does cultural anthropology affect product design? The key is consistency with the social significance of the product. For example, if customers buy zero emission electric vehicles because of their concern about the environment, they may object to a design with batteries which produce toxic waste.

Zaltman's (1997) Metaphor Elicitation Technique (ZMET) suggests that the underlying values and meanings, which drive customers towards specific product choice decisions, may be uncovered through a process of visual self-expression. ZMET requires participants to provide pictures and images that capture what they seek in the product category. Because ZMET allows the research stimuli to be controlled by the respondents, they can express their feelings, product meanings, and attitudes.

Kansei Analysis and the Mind of the Market

A select group of products, especially "high-touch" consumer durables such as automobiles and personal information appliances, are purchased as much for the emotional responses they evoke as for the function they provide. For such products, measuring customers' true feelings toward potential designs, especially their look and feel, may prove invaluable.

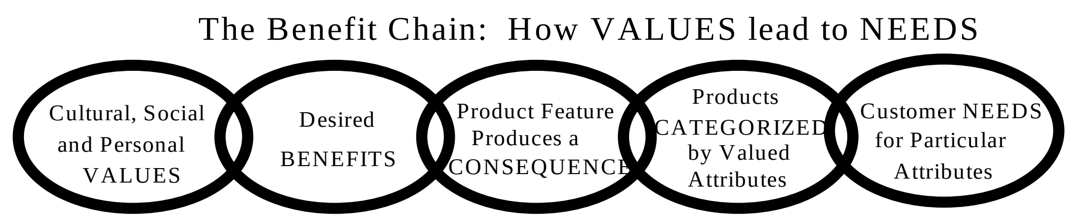
Kansei analysis may be described as the "Lie Detector" of customer research methodologies. Most techniques of listening to the customer assume that respondents provide answers that accurately reflect their preferences and perceptions. But for various reasons such as social pressure, vanity, or even inaccurate self-perception, further probing is necessary. Kansei analysis seeks these true preferences by measuring non-verbal responses to product stimuli, much in the same way that galvanic skin response, voice stress, and breathing rate are recorded in lie detector testing. Examples of other non-verbal responses that can be measured are facial muscle contractions and eye movement and dilation. By measuring these subtle physiological responses while a customer views or interacts with a new product, the PD team gauges the customer's feelings and attitudes. A grimace during sharp steering might indicate poor response in a car, while visual focus on a particular coffee maker prototype might reveal a preference for the outward appearance of that design. By correlating the non-verbal reactions of customers with the specific stimuli that produced those reactions, customer preferences for a product's "look and feel" can be determined. Similarly, by observing detailed click stream data, software and web site designers can optimize the user interface for maximum customer satisfaction.

Kosslyn, Zaltman, Thompson, Hurvitz, and Braun (1999) describe a method that delves even deeper into the physiological aspects of customer response mechanisms, a method they term, "The Mind of the Market." This work utilizes brain imaging of respondents viewing marketing stimuli, in this case automobile dealership scenarios, to assess negative and positive reactions. By comparing their results to those of another research team utilizing more conventional market research methods, they suggest that their method has promise.

Benefit Chains

Benefit chains focus on ***why*** customers have a particular need that is not yet addressed by existing products. For example, while a focus group or Kano analysis might determine that customers want smaller, lighter-weight notebook computers that perform faster, the underlying values driving those needs may not be so obvious. Are customers so ambitious that they want to accomplish twice the amount of work (notebook performance) and work everywhere they go (lightweight)? Or could it be that customers seek more leisure time (i.e., less time working), and prefer to do their work outside of the office? The underlying values driving those needs might differ dramatically and the difference in underlying values might imply different product development solutions. The workaholic notebook computer user might need more features and battery life while the leisure-seeker might need ease-of-learning and low-price. Figure 7 illustrates a benefit chain for coffee makers. Here, the user's work ethic leads to a desire for either a digital timer with auto-shutoff (or another solution such as Internet control) that helps the user satisfy his or her cultural work-ethic values.

Figure 7: Benefit Chain Structure for a Coffee Maker



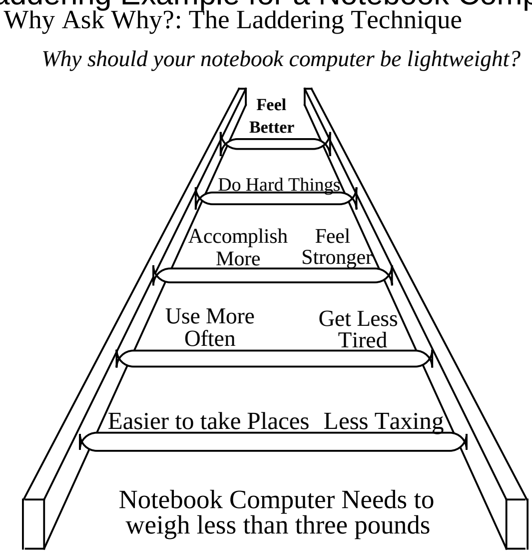
Example

"I believe in hard work."	*"I want to get to the office early every morning"*	*"I would like my coffee ready when I awake"*	*Five coffee makers feature digital timers*	*"I want the model with digital timer and auto-shutoff."*

Related methods include a *Means-End Chain* model of customer choice behavior (Gutman 1982) and a *Value-Systems* model (Rokeach 1973). These authors view customer needs as a chain reaction beginning with the cultural, social, and personal values held by the individual. The underlying values held by customers then guide their choices toward products that produce desired benefits. Since there are numerous choices for a given product, people categorize them into sets or classes, thereby simplifying the decision. The categories created by each customer are influenced by his or her values. While the leisure seeker may categorize notebook computers based on price, the workaholic may consider machines grouped according to performance.

Gutman and Reynolds' (1979) technique for measuring such benefit chain begins with Kelly's (1955) repertory grid technique. After respondents have drawn distinctions within a set of three products (by determining similarities between two products and differences with a third), they are asked which attribute they prefer. They are then asked why they prefer that attribute at higher and higher levels of abstraction until some core values are reached. This technique is sometimes referred to as laddering. It is illustrated in Figure 8.

Figure 8: Laddering Example for a Notebook Computer



Focusing the Design Team by Identifying Strategic Customer Needs

Traditional surveys and interviews, experiential interviews, Kano analysis, disruptive-technology analysis, empathic design, the study of meanings, Kansei analysis, benefit chains, and laddering all identify customer needs and desires which, if fulfilled, lead to successful new products. However, these methods are sometimes too effective producing not just a few needs, but rather hundreds of customer needs. Even for a simple product such as a coffee maker, it is not uncommon to generate a list of 100-200 customer needs. For complex products such as copiers and automobiles, such lengthy lists might be generated for subsystems (interior, exterior, drive train, electronics, climate control). But the needs are not all independent.

To proceed further in idea generation, the PD team needs focus. This focus is provided by recognizing that the needs can be grouped into strategic, tactical, and detailed needs. If we call the raw output of the various needs-generation methods “detailed needs,” then we often find that the 100-200 detailed needs can be arranged into groups of 20-30 tactical needs. For example, detailed statements by customers of a software package about the on-line help systems, “wizards,” on-line manuals, documentation, telephone support, and Internet support might all be grouped together as a need by the customer “to get help easily and effectively when I need it.” The detailed needs help the PD team create technology and other solutions to address the tactical need. However, the tactical need is sufficiently general so that the PD team might develop totally new ways of meeting that need such as communities of practice within large customers. The tactical needs might also be grouped into 5-10 strategic needs such as “easy to use,” “does the job well,” “easy to learn,” etc. The strategic needs help the team develop concepts that stretch the product space and open up new positioning strategies.

Later in the PD process (Figure 3) the PD team needs to decide on which strategic need to focus or which features best fulfill a strategic need. In later sections we review methods to prioritize these needs (and features). However, in the fuzzy front end it is more important that we get the grouping right, that is, it is more important that the right strategic and tactical groups be identified. This is because, at this stage of the process, the PD team wants to generate a larger number of potential product concepts, each of which might stretch one or a few strategic needs. The PD team also wants to explore new ideas to address these strategic needs by solving the relevant tactical needs in new and creative ways. In this chapter we review the two most common methods of grouping needs.

Team-based Needs-Grouping Methods: Affinity Diagrams and K-J analysis

The Japanese anthropologist Jiro Kawakita (denoted K-J by the Japanese custom of last name first) developed a method of synthesizing large amounts of data, including voice of the customer data, into manageable chunks based on themes that emerged from the data themselves (Mizuno 1988). The K-J method uses a team approach to develop a*ffinity diagrams* in which each voice-of-the-customer statement is grouped with other similar statements. The K-J technique requires an open mind from each participant, encourages creativity, and avoids criticism of “strange” ideas. The K-J method claims to be based on stimulating the right-brain creative and emotional centers of thought rather than relying on pure cause-and-effect logic.

Typically, each data element, preferably in the original language of the customer, is recorded onto a card or Post-it® note. The cards are well shuffled to eliminate any pre-existing order bias and are then grouped based on feelings rather than logic. The impression or image given by each customer statement suggests the group to which that card has the greatest affinity rather than any pre-conceived category. When a few cards are grouped, they are labeled with a description that captures the essence of their meaning. Card groups are then assembled into a larger diagram with relationships between the groups of cards indicated. The end result is a diagram showing the top five to ten customer needs, relationships between needs, and detailed customer voice data expressing those needs.

Customer-based Needs-Grouping Methods: the Voice of the Customer

While affinity diagrams and K-J analysis methods have proven to be powerful in many applications, they can also suffer when the team is too embedded in its corporate culture. For example, Griffin and Hauser (1993) compare affinity diagrams developed by PD teams with those developed by actual customers. While PD team members group customer needs based on how the firm *builds* the product, customers instead group needs by the way they *use* the product. Griffin and Hauser also apply hierarchical clustering (Green, Carmone, and Fox 1969, Rao and Katz 1971) to needs gathered from a larger sample of customers. Here each customer performs a relatively simple sort of needs into a small number of piles. The hierarchy of strategic, tactical, and detailed needs comes from the statistical analysis. This method, called both the Voice of the Customer and Vocalyst®, has proven effective in literally hundreds of applications. Although we know of no head-to-head comparison between customer affinity diagrams and voice-of-the-customer methods, customer-based methods seem to provide more useful structures than do PD team-based methods, and lead to more creative solutions as a result.

New Web-based Methods for the Fuzzy Front End

Information pump. The methods reviewed above provide a breadth of means to identify customer needs, whether they are articulated or unarticulated, individual-specific or bound in the culture, verbal or non-verbal, etc. Recently, the Internet has made it possible for groups of customers to communicate directly and iteratively with one another and, together, produce a set of needs that might not have been identified any other way. The “Information Pump” is a novel method of objectively evaluating the quality and consistency of respondents’ comments, in which “virtual focus group” participants opine on a common stimulus such as a new product concept (Prelec 2001). The method transforms the market research task into a “parlor” game in which respondents create true/false questions about the product concept. Other respondents in the game guess the answers and state their confidence in their answers. Those who answer the questions are rewarded on the accuracy of their answers while those who create the questions are trying to create questions that informed customers (those who see the concept) can answer better than uninformed customers (those that do not see the concept). The incentives in the game are based on “honest reward theory” and are fine-tuned to encourage both truth-telling and creativity. Early tests suggest that the Information Pump uncovers statements that independent judges view as more creative than traditional approaches with the same look and feel.

“Listening in” to customers on the Internet. The Internet also provides the means to identify customer needs by passively observing interactive customer behavior on a web site. By organizing the web site by agendas based on features or customer needs, a virtual engineer can listen in and observe how customers process attributes and, in particular, when they search for attributes, features, or needs that cannot be satisfied by any extant product. Urban (2000) demonstrates this indirect method of capturing unmet customer needs by observing customer interactions with an Internet-based sales recommendation system for trucks. While the virtual salesperson attempts to identify the ideal, current-model truck for each respondent, a virtual design engineer notes which product attributes leave the customer the most unsatisfied. The virtual engineer then "interviews" the customer to better understand the unmet needs and how to best resolve the inherent tradeoffs that prevent those needs from being met.

Ideation Based on Customer Needs (and Other Inputs)

Once the PD team has identified and grouped customer needs it must generate ideas on how to address those needs (Goldenberg, Lehmann, and Mazursky 1999). In the next section (on designing and engineering concepts) we discuss formal methods such as QFD by which the PD team can systematically generate effective concepts. But not all concepts can be generated systematically. Sometimes the PD team needs crazy and bizarre solutions which, when refined, solve the customers' needs in new and creative ways. A wide variety of ideation methods have been proposed including brainstorming (Arnold 1962), morphological analysis (Ayres 1969), group sessions (Prince 1970), forced relationships (Osborn 1963), systems approaches (Campbell 1985), varied perspectives (De Bono 1995), archival analysis (Altschuler 1985, 1996), and inventive templates (Goldenberg, Mazursky, and Solomon 1999a, 1999b). In this chapter we review the three most recent proposals and refer the reader to the references for the more traditional ideation methods.

Overcoming Mental Blocks

Adams (1986) and De Bono (1995) propose methods for overcoming the mental blocks most of us have that derive from our particular approaches to problem solving. Figure 9 depicts De Bono's six hats, representing the diverse perspectives of potential members of a product design team. Typically, each participant in a new product debate feels most comfortable wearing one or two of the hats, frequently leading to conflict. The "six hats" exercises require team members to "wear the other guy's hats" so as to improve communications and foster creative exchange. For example, one might ask members of the design team to react to a novel situation such as, "A pill is invented that makes people dislike the taste of fatty foods," from the perspective of each of the six hats. By identifying the types of thinking in which each team member engages, participants gain insight into their own problem solving approaches as well as those of others.

Figure 9: De Bono's Six Hats Method

TRIZ (Theory of Inventive Problem Solving)

Altschuler (1985, 1996) developed a technique for generating creative solutions to technical problems by harnessing archival knowledge, an early version of knowledge management. Specifically, Altschuler reviewed tens of thousands of patents and noticed that their genius was in applying inventive principles to resolve tradeoffs between a limited set of "competing" physical properties (approximately 40 in number). These solutions typically resulted in no tradeoff being made at all, for example the way aluminum cans are both lightweight and strong by virtue of their cylindrical design. Altschuler organized the patents according to the fundamental tradeoffs they resolved, and created tables so that future designers could apply the inventive principles to similar problems. More recently, others have advanced Altschuler's work into other domains of science and technology. Marketing's role in applying a method such as TRIZ is to represent the customer's voice in comparing the multiple technical alternatives generated.

Inventive Templates

Goldenberg, Mazursky, and Solomon (1999a, 1999b, 1999c) extend Altschuler's methods to propose that ideation is more effective when the PD team focuses on five templates – well-defined schemes that are derived from an historical analysis of new products. The authors define a template as a systematic change between an existing solution and a new solution and provide a method by which the PD team can make these changes in a series of smaller steps called "operators:" exclusion, inclusion, unlinking, linking, splitting, and joining. For example, the "attribute dependency" template operates on existing solutions by first applying the inclusion and then the linking operators. The authors give an example of how a new car concept was developed by creating a dependency between color and the location of a car's parts. Specifically, Volkswagen's "Polo Harlequin" features differently colored parts and has become quite popular in Europe even though it was initially intended as an April Fools' joke, Other templates include component control (inclusion and linking), replacement (splitting, excluding, including, and joining), displacement (splitting, excluding, and unlinking), and division (splitting and linking).

Summary of Methods for the Fuzzy Front-end

The fuzzy front-end of the PD process is the least well defined, but, perhaps, the most important phase of the process. Without good customer input and creative ideas, the process is doomed from the start. Customers do not buy products that do not satisfy their needs. Success is elusive unless the PD team generates ideas that satisfy those needs in novel ways. Thus, it is not surprising that there has been significant research to propose and test many different ways to identify customer needs and generate creative ideas in response to those needs. In this section we have reviewed the most common methods that we believe are relevant to a marketing audience. They are rich and varied; each has its own strengths and none should be used alone. For example, if PD team uses only the Kano model it could become overly focused on the product's technological features and miss underlying psychological or social needs. On the other hand, a pure focus on the mind of the customer could cause the team to miss the obvious solutions that will ultimately dominate the market. Good practice suggests that the PD team consider a variety of approaches to customer-need identification and use them in parallel. If the final output is subjected to a rigorous needs-grouping method such as customer-based-affinity diagrams or customer sorts, then the PD team will be able to assure that the ideas it creates solve one or more strategic customer needs.

Once the PD team knows the strategic needs, it needs ideas. Once again there are a variety of methods. Our own experience suggests that different teams will be comfortable with different approaches. Some teams prefer the formal systems approaches, others need the wilder approaches that "take a vacation from the problem," and still others prefer to just work alone. The organization's culture (see "Enterprise Strategy" later in this chapter) must be conducive to these myriad approaches. While creativity is lauded by most PD teams, the organizational challenges and frustrations of dealing with truly creative people frequently preempt the benefits (Staw 1995). However, if idea generation is successful, the teams will suggest large numbers of initial ideas that can later be systematically engineered into effective concepts, prototypes, and products. We now turn to systematic methods by which these winning concepts are selected and developed and ultimately shaped into products.

Selecting Concepts and Designing & Engineering Products

Returning to the PD funnel at the center of the PD process in Figure 3, we see that the many ideas created in opportunity identification are funneled to a smaller set of concepts that are winnowed still further to a viable set of products or platforms. In this section we address concept selection and the design and engineering processes that develop concepts into viable products. We begin with methods such as lead user analysis, Kaizen and Teian analysis, set-based design, and Pugh concept selection. Each of these methods builds on the customer-needs identification and ideation that took place during the fuzzy front end of product development.

Lead Users

Sometimes the best ideas come from outside the firm and, in particular, from end-users themselves. In some categories the average customer can recognize and appreciate new solutions to their basic needs and in other categories it is more difficult. More importantly, PD teams are often embedded in their corporate culture and view PD through the lens of their current products.

Von Hippel (1986) suggests that some of the best sources of insight into user needs and potential product prototypes are "lead users," customers whose strong product needs in the present foreshadow the needs of the general marketplace in the future. These users often have such a compelling need to solve their problems that they develop their own solutions. In some cases these users represent a very specialized market, but in many cases they anticipate the needs of the larger market. For example, automobile manufacturers follow NASCAR racing carefully because the racing teams face new challenges and often invent new solutions that can later be applied to a more general market. Computer projection systems manufacturers monitor early adopters, such as NASA investing in display equipment for its flight simulators, because as technology advances and costs drop the problems faced by simulator users will suggest solutions for broader markets such as video gamers.

Von Hippel describes how to identify lead users, and then how to incorporate their insights into the product design process in a five-step process:

1. Identify a new market trend or product opportunity (e.g. greater computer portability, zero emission vehicles, etc.).
2. Define measures of potential benefit as they relate to customer needs.
3. Select "lead users" who are "ahead of their time" and who will benefit the most from a good solution (e.g. power users).
4. Extract information from the "lead users" about their needs and potential solutions and generate product concepts that embed these solutions.
5. Test the concepts with the broader market to forecast the implications of lead user needs as they apply to the market in general.

Urban and von Hippel (1988) applied this technique to computer-aided design (CAD) systems. Although the conventional wisdom of the CAD developers was that the systems were much too complex for users to modify, Urban and von Hippel found that lead users who faced difficult problems had not only modified their systems, but had generated significant improvements. For example, designers of complex, integrated circuits developed 3-dimensional CAD systems that could deal with curved surfaces, multiple layers, and non-surface-mounted components. When 3-D CAD software packages were developed based on these lead-users' solutions, they were highly rated by the more general market.

Employee Feedback: Kaizen and Teian

Another source of insight into ways in which to address customer needs better is the company's own work force. In his writings on *Kaizen*, the Japanese concept of continuous improvement, Masaaki (1986) explains that each employee is responsible for both maintaining the status quo and destroying it. This refers to the notion that employees must follow certain standards, but also eliminate waste and contribute to innovation. One way in which employees can contribute is by making frequent suggestions on product and process improvements through a system the Japanese call *Teian*. See *Kaizen Teian 1* by the Japan Human Relations Association (1992). Of course, the scope of such an employee suggestion system covers more than just customer needs, but the essence of continuous improvement is meeting customer needs more effectively.

Set-based Design and Modularity

In addition to getting ideas from lead users and from the production employees, the PD team can pursue systematic methods such as set-based design. This method generates multiple design options by breaking a product into smaller subsystems, standardizing the interfaces between those subsystems, and generating one or more design options for each key subsystem. Given interchangeability between the subsystems, multiple design solutions become available to the firm, limited only by the number of combinations of subsystems that are feasible.

Ward, Liker and Sobek (1996), Sobek, Ward, and Liker (1999), and Liker, Ward, and Cristiano (1996) describe a set-based design process in which the freezing of the final choice of subsystems is delayed until the product is closer to launch. The firm can then check the pulse of a dynamic market in order to optimize the final choice of modular designs, thereby exploiting the flexibility inherent in the set-based approach. Baldwin and Clark (2000) further characterize flexibility due to product and process modularity as forms of real options and demonstrate the potentially high value of holding such options.

Pugh Concept Selection

When mass customization is not prevalent in an industry, the firm must narrow from a broad array of possible design solutions to a few critical solutions (sometimes just one). Pugh (1996) develops a method of winnowing multiple new product concepts which he terms "controlled convergence." In essence, Pugh suggests that each member of the design team independently generate conceptual solutions to the design problem. The competing ideas are then compared to a standard datum, selected for its typicality in the product category, and are evaluated as being better than, equal to, or inferior to the datum on the key dimensions that will contribute to product success. The group proceeds to eliminate weaker ideas, but also attempts to cull the advantages of each concept and incorporate it into the remaining ones before discarding it. In this way, the "winning" concept incorporates many of the best ideas of all of the other concepts. Of course, some ideas are highly integral to a specific concept, making such "cherry-picking" particularly difficult, which is why consensus-building and tradeoffs amongst the members of the cross-functional team are crucial elements of the Pugh process. Marketing's role in this process is to identify the key customer criteria on which concepts will be based and to ensure that each concept is evaluated with customer needs and preferences in mind.

Using inputs from the ideation processes, lead-user analysis, set-based design, and Pugh concept selection the PD team outputs a smaller set of high-potential product concepts. Following the PD funnel, the PD team then focuses on these concepts and develops each to their greatest potential. This means linking engineering solutions to customer needs and vice versa.

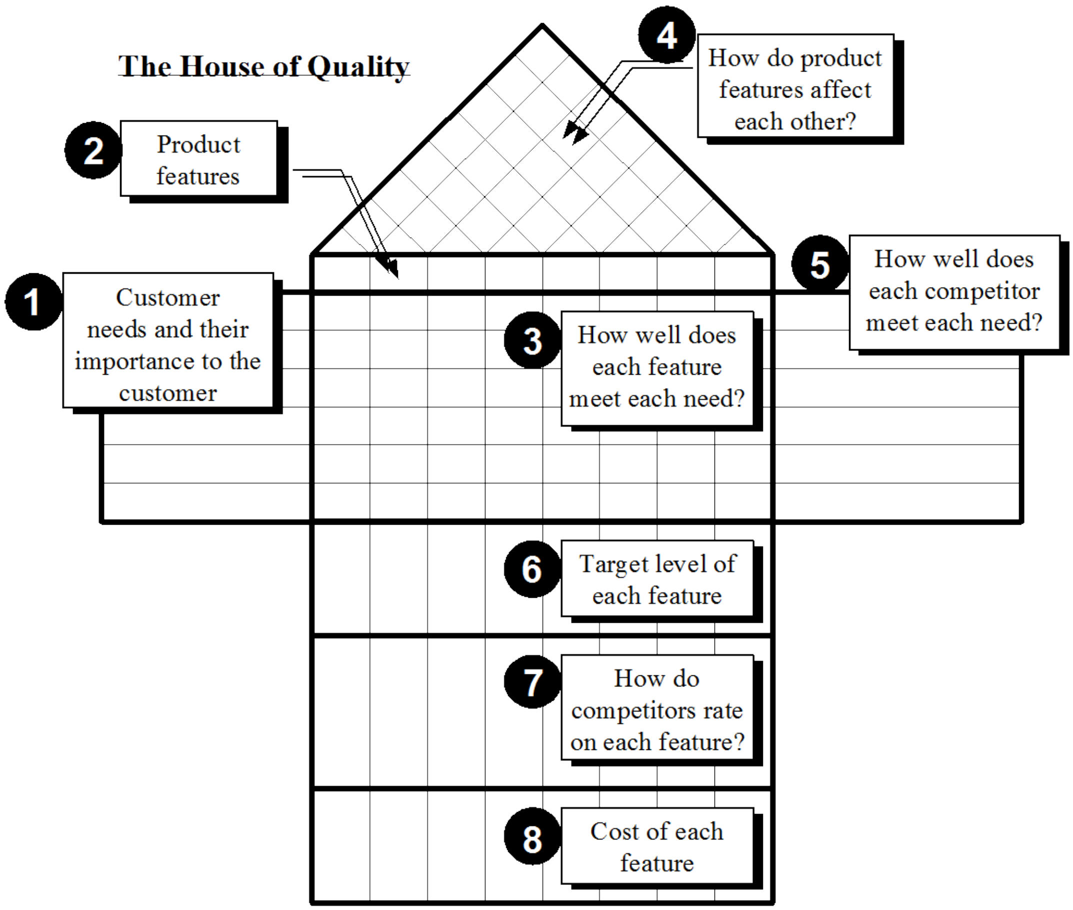
Value Engineering

From a customer's point-of-view, a product consists of a bundle of features and benefits resulting from its use, while from the firm's perspective, the product consists of a bundle of parts and the processes that result in its manufacture. When making cost and feasibility tradeoffs, it is important for the design team to connect the customer and firm perspectives. Ulrich and Eppinger (2000) describe one method of doing so known as value engineering, which relates the importance customers place on each function performed by a product to the cost of the parts contributing to that function. A key principle underlying value engineering is that the marginal cost of each part of a product should be less than its marginal contribution to customer value. To implement value engineering the team must know (1) the value placed by customers on each function and (2) the cost of the parts and manufacturing to provide that function. We address (1) below as it is most relevant to the marketing audience. For greater detail on (2) see Ulrich and Eppinger (2000). As with Pugh Concept Selection, PD teams must be extremely careful for highly integrated features and for synergies in both value creation and cost reduction.

Quality Function Deployment and the House of Quality

Value engineering requires that we link customer needs to product solutions so that the PD team can make intelligent tradeoffs and, perhaps, find creative solutions that do not require tradeoffs. Quality Function Deployment (QFD) and its more-recent progeny (Tessler, Wada and Klein 1993, McGrath 1996, Smith and Reinertsen 1998) provide the means to make this linkage. QFD itself is a set of processes that link customer needs all the way through to production requirements. Although the full QFD process is sometimes used, most notably in Japan, it is the first matrix of QFD, called the House of Quality (HOQ), that is used most often. The driving force behind the HOQ is the short, accurate, relevant list of key customer needs identified in the fuzzy front-end and structured into strategic, tactical, and detailed needs. In the HOQ, these needs are related to product features, which are then evaluated as to how well they meet customer needs. Product features are "benchmarked" against competitors' features in their ability to meet customer needs and the HOQ is used to compare the benchmarking on features to benchmarking on customer needs. Finally the total product is evaluated by the ability of its features to meet customer needs more effectively and at lower costs than competitive products.

Figure 10: The House of Quality



The HOQ provides and organizes the information that the PD team needs to refine each concept. It has proven effective in a variety of applications including consumer frequently purchased goods, consumer durables, consumer services, business-to-business products, and business-to-business services (cf. Hauser 1993). See Griffin's (1992) review of HOQ applications for an in-depth discussion of when it works well and when it does not. A further advantage of the HOQ and related techniques is that it enhances communication among PD team members (see quasi-experiment in Griffin and Hauser 1992). This is becoming even more important as PD teams become more dispersed and global. The downside of QFD is that strict adherence to the method can lead to overly complex charts and become extremely time-consuming, especially for products with many customer needs and engineering "key characteristics." Clearly, firms must adapt the House of Quality to produce benefits commensurate with these implementation costs. Ironically, complex projects that make QFD difficult to implement may be the very ones that benefit most from improved communication and coordination within the firm.

Marketing's primary input to the HOQ includes identifying customer needs (fuzzy front end), measuring how products fulfill those needs (e.g., Green, Tull, and Albaum 1988, Churchill 1998, Moore and Pessemier 1993, Urban and Hauser 1993), and understanding the tradeoffs among customer needs and among potential product features. Ultimately, the HOQ method translates customer priorities, as captured by a prioritized list of needs, into engineering/design priorities by identifying those product features that contribute the most to satisfying customers better than competitive offerings.

Tradeoffs Among Needs and Features: Conjoint Analysis

After customer needs are identified and grouped, after critical features are identified and linked to customer needs, and after high potential concepts are developed, the PD team's next step is to focus on those features and concepts that are most likely to improve customer satisfaction and lead to profitable products. Developing methods to measure such tradeoffs among customer needs and/or features is, arguably, one of the most studied problems in marketing research. We have been able to identify over 150 articles published in the top marketing journals on conjoint analysis in the last twenty years. In this section we review some of the basic ideas. See also reviews by Green (1984), Green and Srinivasan (1978, 1990). Also, because they continue to be used by PD teams, we include self-explicated methods such as those reviewed in Wilkie and Pessemier (1973).

Suppose that the PD team is developing a new laundry product and has identified the strategic needs of "cleans effectively," "safe for delicate clothes," "easy to use in all situations," "good for the environment," and "inexpensive." The team now wants to evaluate a series of product concepts, each of which stretches one of the five strategic customer needs. Conjoint analysis, applied to customer needs, is the general method to measure the customers' tradeoffs among those needs. By identifying and quantifying the tradeoffs, perhaps by customer segment, conjoint analysis helps to focus the PD team on those concepts that have the highest potential. Conjoint analysis can also be applied to product features; for example, the maker of an camera might want to know how highly customers value such features as 1-step vs. 2-step picture taking, styling covers, automatic vs. manual focusing, and automatic vs. controllable lighting. Conjoint analysis can tell the PD team which of the features is most highly valued (by which segment) and can associate a willingness to pay for those features.

Camera Example. We begin by illustrating conjoint analysis with the most common type of application – providing preferences with respect to products (or product concepts) in which the experimenter has varied the features (or other aspects) of the products systematically. We then review other types of conjoint analysis and suggest new forms that are now feasible with state-of-the-art information and communication technology.

Suppose that we have identified a set of features for a new camera from a combination of sources including experiential interviews, empathic design, Kansei analysis, and the Information Pump. In general, this feature list will be quite extensive, but for the purpose of this chapter we will illustrate the feature list with a reduced set of five features.[1] We might conclude that customers have needs that can be addressed through various levels of the five product features in Figure 11.

Figure 11: Simplified Conjoint Features and Levels

Product Feature	Alternative Levels			
Price (P)	$15	$20	$25	$30
Weight (W)	16oz.	20oz.	32oz.	64oz.
Light control (L)	Auto	1-step		
Size of picture (S)	postage stamp	3 inch square	standard	
Focusing (F)	Auto	manual		

For example, one product permutation would cost $25, weigh 16oz., have automatic light control, produce 3-inch square pictures, and require the user to focus manually. In all there are 4 x 4 x 2 x 3 x 2 = 192 permutations, each of which might be a viable product. In principle, we could ask a sample of customers to evaluate each of the 192 potential products, but this would be an extremely unwieldy task. As the number of potential products increases the task becomes quite burdensome (Green, Carroll, and Goldberg 1981, Green, Goldberg, and Montemayor 1981, Malhotra 1986) and the quality of the data degrades (Bateson, Reibstein, and Boulding 1987, Huber, Wittink, Fiedler, and Miller 1993, Moore and Semenik 1988). We must also be concerned with biases that can result when the number of levels varies across features (Wittink 1989), potentially drawing more attention and importance to those features with more levels.

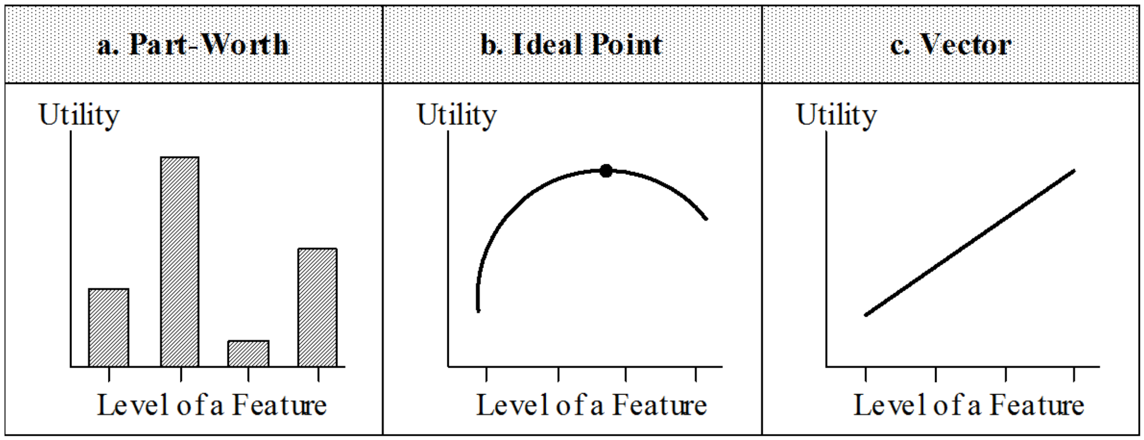
[1]Some features might include price, picture quality, picture delivery, opening of the camera, removable cover or not, picture taking process (1 vs 2 steps), light selection (3 settings vs feedback), disposable camera, camera with cartoon characters, metallic vs plastic camera, battery type: AA vs AAA, picture size, color vs. black & white, chemical vs. digital picture vs. both at the same time, zoom lens vs. regular, holster for the camera, picture has a sticky backing, the film is decorated, the film contains some advertising to reduce cost, panoramic pictures, waterproof camera, manual control over the picture, picture cutter included in the camera, etc.

Factorial designs. It would be even more cumbersome if we asked customers to evaluate products that varied on the twenty-two camera features in Footnote 1 – if these were a mix of two-level and three-level features this would yield almost 400 million potential products. Instead we would like to capture the information that customers would provide about tradeoffs among features by asking each customer to evaluate a much smaller number of products. For example, for the five features in Figure 11 we may not need to ask each customer to evaluate all 192 feature combinations. Instead, we could use a more efficient experimental design known as a fractional factorial design. If we assume that all of the features are independent we can simplify the number of combinations still further by using a special fractional factorial known as an orthogonal array. For example, we might use one orthogonal design called a "hyper-greco-latin-square" design and ask each customer to evaluate just 16 carefully chosen products. (A similar experimental approach, known as Taguchi [1987] methods, is used in describing reliability testing and statistical sampling.) The actual details of a particular fractional factorial design, that is the specific levels of price, weight, light control, picture size, and focusing for the 16 potential products, can be determined using listings compiled by Addelman (1962) and Hahn and Shapiro (1966) or by using computer programs produced by SAS, Systat, Sawtooth Software, Bretton-Clark Software, and others. The key research area here is in determining the best designs for a given number of combinations. For example, a common criterion is called D-efficiency, a measure of the determinant of the information matrix (Kuhfeld 1999; Kuhfeld, Tobias and Garratt 1994).

Respondents' tasks. The task by which customers express their evaluations of products varies. See Cattin and Wittink (1989) for a survey of industry practice. By far the most common task is to simply ask the respondents to rank order the product profiles in terms of preference. For example, each respondent might order a set of cards according to his or her preferences for (or likelihood of buying) the products depicted. Each card, known as a full-profile, describes a product consisting of differing levels of the key features. Other tasks include asking the respondent to evaluate pairs of profiles (Srinivasan and Shocker 1973, Bateson, Reibstein, and Boulding 1987) or tradeoffs among features displayed two at a time (Johnson 1974, Segal 1982). The respondent might be simply asked to rank order the profiles (Green and Wind 1975) or the customer can provide a scaled evaluation (Carmone, Green, and Jain 1978, Hauser and Shugan 1980, Currim, Weinberg, and Wittink 1981, Leigh, MacKay, and Summers 1984, Srinivasan and Park 1997). Another common data collection procedure simply presents the customer with sets of alternative products profiles chosen from an experimental design and asks the customer to select the product he or she prefers from each set of product profiles. This method, known as choice-based conjoint analysis, uses a quantal choice model such as a logit or probit model to estimate the part worths from the choice data (Arora and Huber 2001; Elrod, Louviere, and Davy 1992; Carroll and Green 1995; Haaijer, Wedel, Vriens, and Wansbeek 1998; Huber and Zwerina 1996; Louviere, Hensher, and Swait 2000; Oppewal, Louviere, and Timmermans 1994; and Orme 1999). All forms of data collection appear to be reliable (Bateson, Reibstein, and Boulding 1987, Green and Srinivasan 1990; Louviere, Hensher, and Swait 2000); none seem to dominate either practice or the academic literature.

Part worth functions. Once we have the ratings (or rankings or choices) for each profile in the experimental design, we represent this information by a utility function, that is, a real-valued function of the feature levels chosen such that differences in utility represent differences (or rank orders) in preference among the products. If the features are independent, as is assumed in an orthogonal array, then the utility of a product is simply the sum of the uni-attributed utilities of each of the features (Keeney and Raiffa 1976). If the features are specified by discrete levels as in Figure 11, then the utility of each of the levels of each of the features is called a part worth. That is, the utility of a camera that costs $25, weighs 16oz., has automatic light control, produces 3-inch square pictures, and requires the user to focus manually would be equal to the part worth of $25, plus the part worth of 16 oz., plus the part worth of automatic light control, plus the part worth of 3-inch square pictures, plus the part worth of manual focus. (We can also represent utility as the product of the part worths – it is only separability that is implied by independence.) Part worths are illustrated in Figure 12a. However, if the features are continuous we might also represent the utility by a more continuous function. An ideal point model for features where more is not always better (e.g., picture size, Figure 12b) is one such continuous function and a vector model where more is better (e.g., quality of picture, Figure 12c) is another such continuous function. Decreasing functions (e.g., price), concave functions (e.g., clarity of sound), and anti-ideal point (e.g., the temperature of tea) models are also possible. See the discussion in Pekelman and Sen (1979).

Figure 12: Conjoint Utility Functional Forms



In some cases the features might not be independent. For example, the desire of the customer for manual focusing might depend upon the quality of image that can be produced with the camera's lens and film. In this case, conjoint analyses use more complex experimental designs that allow interactions and estimate utility functions that cannot be represented simply as the sum (or product) of the part worths. See Green and Devita (1975), Akaah and Korgaonkar (1983), and Johnson, Meyer, and Ghosh (1989).

Estimation. In order to estimate the utility or part worth functions we must *decompose* the overall preference rating (or ranking) into the utilities of the features (with or without interactions). Early applications assumed that only the rank-order information was relevant and used monotonic analysis of variance (monanova) to estimate the part worths (Green and Srinivasan 1978). Alternatively, linear programming provides accurate estimates based on a criterion of mean absolute or directional errors (Srinivasan and Shocker 1973, Jain, Acito, Malhotra, and Mahajan 1979, Malhotra 1982). However, many researchers have discovered that customers can provide valid preference data which has strong metric properties (Huber 1975, Hauser and Shugan 1980, Currim, Weinberg, and Wittink 1981) while other researchers have found that treating rank data as if it were metric provides accurate estimates (Carmone, Green, and Jain 1978). Thus, many applications use OLS regression or other metric methods. If risk is important in the design decision, then von Neumann-Morgenstern utility estimation can be used by asking respondents to evaluate product profiles in which one or more of the features is uncertain (Hauser and Urban 1979, Eliashberg and Hauser 1985, Farquhar 1977, Kahn and Meyer 1991).

Compositional methods. Conjoint analysis is usually thought of as a decompositional technique in which part worths are estimated by asking respondents to evaluate potential products (or reduced sets of features of those products). However, there is also a long tradition in marketing of compositional methods in which the customer is asked to specify directly the importance or part worth of a need or feature. These methods, also known as expectancy-value or self-explicated methods, were reviewed by Wilkie and Pessemier in 1973. In these methods, the customer rates each product on each need (rates) and evaluates the importance of each need (weights). The utility of a product is then the sum of the weights times the rates, summed over customer needs. More recently, Srinivasan (1988), Srinivasan and Wyner (1988), and Bucklin and Srinivasan (1991) use a method called Casemap in which they have modified self-explicated methods for part worth estimation. After an initial conjunctive phase (described below), Casemap asks customers to specify the importance of each feature or need and the relative value of each level of each feature or need (relative to a base level of that feature or need). The part worth is then the product of these two values. Such self-explicated methods have the advantage of being relatively easy for the respondent – for example, Casemap can be completed over the telephone and does not require that a sample of customers come to a central location. Casemap and other self-explicated methods have proven to be accurate and reliable (Bateson, Reibstein, and Boulding 1987, Akaah and Korgaonkar 1983, Green and Helsen 1989, Hoepfl and Huber 1970, Huber, Wittink, Fiedler, and Miller 1993, Leigh, MacKay and Summers 1984).

Conjunctive processes. Standard conjoint analysis asks respondents to evaluate products that vary on all levels of all of the features or needs. But many researchers have hypothesized that not all levels of all features or needs are acceptable to respondents. For example, a customer who wants a camera for a wedding might not accept a postage-stamp size picture; no levels of the other features will compensate the customer enough to make him or her buy a wedding camera that produces such small pictures. When features have such minimum acceptable levels (at least a 3-inch square picture) the customer is said to follow a *conjunctive* process (Einhorn 1971, Grether and Wilde 1984). This is similar to the "must haves" identified by the Kano hierarchy of needs outlined earlier. Casemap and other methods (Sawtooth 1996) have modified conjoint analysis to account for such conjunctive processes by first asking the respondent to specify those levels of the features that are unacceptable. Prior specification of unacceptable levels improves prediction if done carefully. However, Green, Krieger, and Bansal (1988) and Klein (1986) caution that if the questions are not pre-tested and implemented carefully, the respondent will falsely reject feature levels that he or she would have later accepted.

Reducing respondent burden. While the basic concept of conjoint analysis is both powerful and simple, a key implementation barrier has been the respondents' task. Although we can reduce the number of profiles based on the five features in Figure 11 to an orthogonal array of 16 profiles, such a reduction is not always possible if the number of features and levels is large. For example, Wind, Green, Shifflet, and Scarbrough (1989) report a successful application of conjoint analysis to the design of Marriott's Courtyard Hotels in which there were 50 factors at a total of 167 levels. Clearly, we cannot ask respondents to evaluate even a reduced experimental design for such problems. As a result, researchers and practitioners have focused on means to reduce the burden on respondents. We have already reviewed tradeoff analysis (e.g., Johnson 1974) in which respondents compare two features at a time, choice-based conjoint analysis in which respondents choose among sets of profiles (e.g., Carroll and Green 1995), and the elimination of unacceptable feature levels (e.g., Srinivasan 1988). (Malhotra [1986] also proposes a method that screens unacceptable profiles.) There has also been much effort allocated to very efficient experimental designs (e.g., Kuhfeld, Tobias, and Garrett 1994). We review here three other methods for reducing respondent burden: (1) methods that mix individual and market-level data (hybrid conjoint), (2) methods that employ multi-stage data collection in which the first task is simplified (hierarchical integration and customized designs), and (3) methods that adapt the questions to the respondent's early answers (adaptive conjoint analysis).

Hybrid conjoint analysis (cf. Green 1984) combines self-explicated methods at the level of the individual respondent with decompositional methods that split the experimental design across respondents to reduce the complexity of the data collection task. For example, respondents might explicitly rate the part worths of each feature on a 1-10 scale and then rank order a subset of full-profile cards. The estimated utilities are based on both types of data. Although, at the level of the individual respondent, hybrid conjoint analysis may not provide the detailed accuracy of full-profile methods, hybrid methods have proven quite accurate at the segment or market level (Akaah and Korgaonkar 1983, Green, Goldberg, and Montemayor 1981). Recently, Lenk, DeSarbo, Green and Young (1996) propose a hybrid method in which they use hierarchical Bayes (HB) methods to estimate individual utility functions with reduced numbers of questions per respondent. The HB methods improve accuracy by the use of heavy computation and will become more common as the cost of computation decreases dramatically with the advent of inexpensive but powerful computers. With HB methods, caution should be exercised as the number of parameters to be estimated grows in relation to the number of data points obtained from the respondents' conjoint tasks.

In hierarchical integration, respondents evaluate products on higher level features, facets, or needs. They then evaluate the relative impact of features that affect those higher level constructs. Methods for the more-detailed evaluations include traditional conjoint analysis (Hauser and Simmie 1981), hybrid conjoint analysis (Wind, Green, Shifflet, and Scarbrough 1989), choice-based conjoint analysis (Oppewal, Louviere, and Timmermans 1994), and self-explicated methods (Hauser and Griffin 1993). In a related method, Srinivasan and Park (1997) used customized conjoint analysis, a modified method in which respondents use self-explicated methods to evaluate all features and then evaluate a subset of the most important features with full profile conjoint analysis. The subset chosen for the drill-down is customized to each respondent.

The third stream of research directed at reducing respondent burden employs adaptive methods. The most common is Sawtooth Software's adaptive conjoint analysis (ACA, Sawtooth 1996). In ACA respondents are first asked a series of self-explicated questions. They are then asked to evaluate pairs of profiles in which a subset of the features vary. The method is adaptive because each question after the first is chosen with an heuristic that attempts to gather the most information per question. Final questions then establish the relative scales of the self-explicated and adaptive components. ACA has proven accurate under the right circumstances and has proven to add incremental information relative to the self-explicated portion of the interview (Huber, Wittink, Fiedler, and Miller 1993, Johnson 1987, Orme 1999). However, Green, Krieger, and Agarwal 1991 caution that ACA might not be as accurate as the full profile method when the latter is feasible. Johnson (1999) proposes that one can post-analyze ACA data with hierarchical Bayes analysis to improve its accuracy.

Recently, Toubia, Simester, and Hauser (2001) propose an improved algorithm based on the new interior-point algorithms in mathematical programming. They also ask an initial question, but then choose subsequent paired-comparison questions such that the answers maximally reduce the feasible set of utility parameters. Simulations suggest that (1) the interior point algorithms can gather as much information as traditional ACA, but with fewer questions, and (2) for many situations the initial self-explicated questions can be skipped for a further reduction in the respondents' burden. The new "polyhedral" methods appear to do well relative to traditional ACA approaches when the researcher is seeking to obtain part worth estimates with relatively few questions, when respondent wear out is a concern, and when the responses to self-explicated questions are noisy. Dahan, Hauser, Simester, and Toubia (2001) further test the polyhedral methods in an empirical application to laptop computer bags. In their study, they allocate respondents to questions chosen by either (1) the polyhedral methods, (2) traditional ACA, or (3) efficient fixed designs. After completing the conjoint task, respondents are allowed to select and keep a laptop computer bag (plus any change in cash) worth approximately $100. The new methods appear to improve predictions relative to the extant methods and appear to provide valid and reliable part worths with relatively few questions. These polyhedral methods have been extended to produce an adaptive choice-based conjoint method that does well in simulation, but there have not yet been any empirical tests of the polyhedral choice-based method. In general, the polyhedral methods show interesting potential, but need further testing.

Dahan and Orlin (2002) propose a different adaptive approach to conjoint analysis, in which full-profile, web-based conjoint cards from a fractional factorial design are ranked by respondents. By limiting respondents to sort orders that are perfectly consistent, that is, sort orders for which the estimated utility function exactly reproduces the sort order when applied to the conjoint cards, the Conjoint Adaptive Ranking Database System (Cards) approach significantly reduces questioning burden and internal inconsistency. Of course, the method weighs the ranking of more desirable cards higher than low ranking cards, necessitating careful priming for respondents' early choices. In order to speed web-based response times between clicks, all feasible sort orders are calculated in advance and stored in a high-speed database. This new approach had yet to be tested empirically.

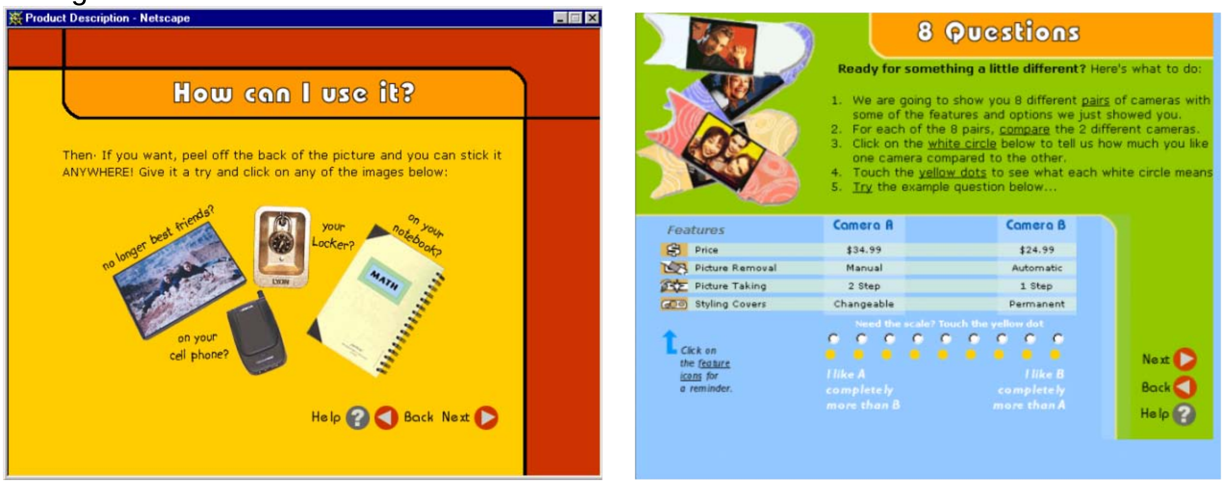
Summary of Conjoint Analysis. Conjoint analysis is a powerful tool for understanding the tradeoffs customers make between various features of a product. Conjoint analysis uses the list of key customer needs or product features determined by the techniques discussed in the fuzzy front end. It prioritizes those features based on the amount of extra benefit customers derive from a feature or from another way of satisfying a customer need. The results can be used to improve designs, optimize them for value, and predict market share and product success.

New Web-based Methods for Designing and Engineering Product Concepts

The advent of new information and rapid-communication technologies such as extremely powerful desktop computers, the Internet, and the World Wide Web (web) are leading to new and exciting methods of concept evaluation. We review some of these methods here. Demos, open source software, and working papers describing the methods in this section (and the polyhedral methods of the previous section) are available at mitsloan.mit.edu/vc.

Web-based conjoint analysis. McArdle (2000) reports on the application of conjoint analysis to the design of a new camera. The advantages of such web-based applications are that rich, contextual, yet virtual media can be used to illustrate products. For example, in Figure 13a the respondent is shown how he or she can use the camera – with a single click the respondent can view animations of the camera or pictures in use. Similar screens enable the respondent to better understand the features that are being varied. Then the respondent is presented with a conjoint analysis task, in this case paired comparisons (Figure 13b). The task is made easier for the respondent by animating the scale and by making detailed feature descriptions or product demonstrations available with a single click.

Figure 13. Web-based Product Demonstration and Pairwise Tradeoffs for a Camera

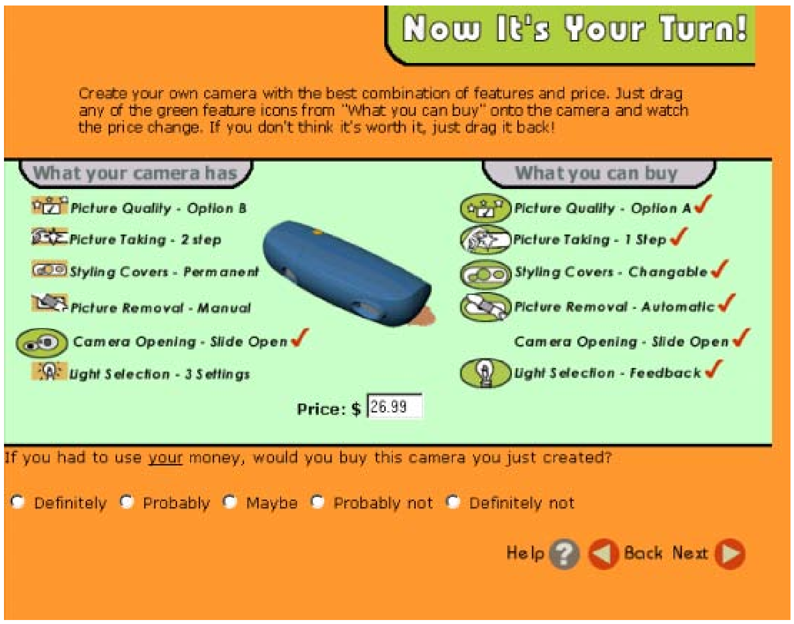


The advantage of web-based conjoint analysis is that the respondents can complete the task remotely. For example, McArdle (2000) compared samples of respondents who answered the questions in the comfort of their homes to respondents who completed the questions on a more-traditional, dedicated computer in a mall-intercept environment. The qualitative results were quite similar, although there was some slight variation due to sample selection. Certainly with further development the methods can be made to converge. Although McArdle used a fixed, orthogonal design, both Sawtooth and Toubia, Simester, and Hauser (2001) provide web-based adaptive methods.

With further testing and development web-based conjoint analysis has the potential to grow dramatically. For example, many companies are forming panels of web-enabled respondents who can complete conjoint tasks. NFO Worldwide, Inc. has a balanced panel of over 500,000 web-enabled respondents, DMS, Inc., a subsidiary of AOL, uses “Opinion Place” to recruit respondents dynamically and claims to be interviewing over 1 million respondents per year, Knowledge Networks has recruited 100,000 respondents with random digit dialing methods and provides them with web access if they do not already have it, Greenfield Online, Inc. has an online panel of 3 million respondents, and Harris Interactive, Inc. has an online panel of 6.5 million respondents (Buckman 2000). Prototypes of automated web-based systems have demonstrated that it is technically feasible to enable an inexperienced user to conduct a web-based study, complete with analysis, in under a week (Faura 2000).

User design with DnD. The interactivity of the web coupled with rapidly advancing computer power makes it possible to explore creative methods to gather information on customers' preferences. For example, Dahan and Hauser (2002) describe a method of feature-based user design on the web in which respondents drag and drop (DnD) their preferred features onto a design palette that illustrates the fully configured product, as seen in Figure 14.

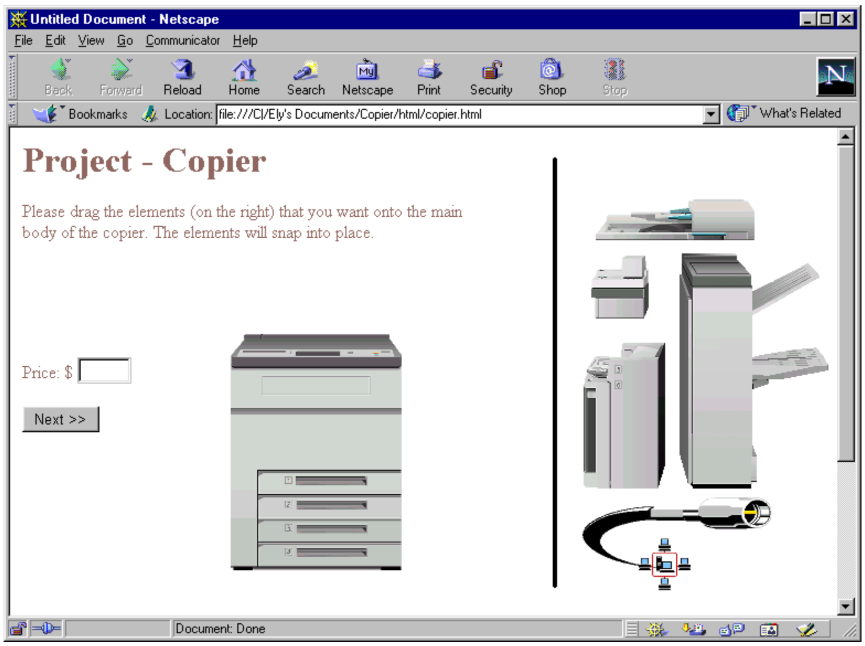
Figure 14: User Design of an Instant Camera



As these choices are made, tradeoffs such as price and performance are instantly visible and updated, so the respondent can interactively learn his or her preferences and reconfigure the design until an "ideal" configuration is identified. The method includes full configuration logic, so that only feasible designs can be generated, i.e., choices on one feature can preclude or interact with choices on other features. User design provides an engaging, interactive method of collecting data on customer tradeoffs. This data can be used to narrow the set of features. The reduced set of features can then form the basis of a more extensive conjoint analysis. McArdle (2000) reports that the conjoint analysis of the camera features in Figure 13 predicted well those features that customers selected with DnD (Figure 14). See explicit comparisons for this and other applications in Dahan and Hauser (2002). See also Leichty, Ramaswamy and Cohen (2001).

The DnD interface employed in user design market research may presage that which will be used to sell mass-customized goods over the Web. For example, as shown in Figure 15, customers may appreciate a highly visual interface in which product features are literally dragged and dropped into place. Park, Jun, and MacInnis (1999) demonstrate that customers arrive at different "ideal configurations" depending on whether they are asked to add options to a base model or subtract options from a fully loaded model, suggesting that the initial configuration of a user design web site may have high impact on the data collected (in the case of market research) or sales effectiveness (in the case of mass-customized e-commerce).

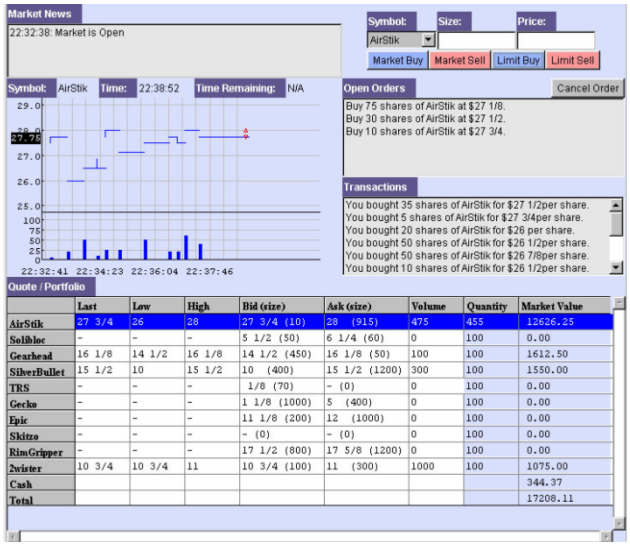
Figure 15: User Design of a Printer/Copier



Securities Trading of Concepts (STOC). One criticism of concept testing methods that rely on direct feedback from potential customers is that customers may not have the incentive to be completely truthful. Further, in most real purchase situations, customers may be influenced by others' opinions and choices, a network externality not easily accounted for with traditional concept testing methods. Chan, Dahan, Lo, and Poggio (2000) offer a potential solution to these concerns in the form of a proposed market research methodology, Securities Trading of Concepts (STOC), depicted in Figure 16.

Utilizing the communications and conceptualization technologies of the Internet, participants compete in a simulated trading game in which the securities traded are new product concepts. The prices and trading volumes of these securities provide information as to the underlying preferences of the individual traders and of the group as a whole. The idea that the price mechanism conveys information efficiently is well understood in financial contexts. Early applications of the STOC method suggests that it can identify those concepts that have the highest customer-demand potential, but further application and validation is necessary.

Figure 16: Securities Trading of Concepts (STOC)



Summary of Methods for Designing and Engineering Concepts and Products

Marketing plays a major role in the design and engineering of product concepts and in the selection of product features. Lead user analysis, Kaizen and Teian methods, set-based design, and Pugh concept selection provide means by which PD teams can selectively winnow product concepts to focus on those that are most likely to succeed. However, a key criterion in any winnowing process is customer acceptance and customer willingness to pay for product features that solve their needs. Thus, QFD and the HOQ provide the means by which product focus and customer focus converge.

Perhaps the most important marketing input to the design and engineering process is the analysis of the tradeoffs that customers make with respect to needs and product features. These methods, generally called conjoint analysis, include both decompositional methods in which customers evaluate bundles of needs or features and compositional methods in which customers directly evaluate the needs or features. Both methods work well and provide valuable input to the HOQ and other concept selection and refinement methods. Finally, new methods are being developed to take advantage of new computing and communications technologies such as the World Wide Web. Web-based conjoint analysis, new adaptive methods, user design methods, and Securities Trading of Concepts all have the potential to increase the effectiveness and reduce the cost of the marketing input to concept selection and refinement. In some cases, we expect the costs to drop dramatically and the time-to-completion of the market input to drop from six weeks to a few days. These improvements are most likely for consumer products for which web-based panels are available. For business-to-business products, where it is harder to recruit the appropriate respondents, cost reductions may be more difficult to realize, but the time reductions should be realized. Once fully developed and tested, web-based developments should enhance the ability of the PD team to design and engineer concepts.

Prototyping and Testing Concepts and Products

Returning to the PD funnel in end-to-end process in Figure 3 we see that after the product concepts have been generated, winnowed and refined, they need to be tested before they can be launched. The goal in this phase of the PD process is to evaluate the concepts (and engineer the final product) so that any launch is highly likely to succeed. The team must make tradeoffs among the cost of testing, the advantage of further development, and any delays in product launch. A testing method should be accurate and cost effective.

Recently, there has been significant new work done to understand the role of testing and the optimization in the PD process. The PD process is examined as a unified entity such that reductions in cost and uncertainty at one stage affect cost and uncertainty as subsequent stages. Thus, the tradeoffs between time-to-market, development expense, production cost, and quality can be viewed as an optimal search for the best product design. Testing thus becomes a search process under uncertainty and can be optimized. This section will review this new work as well as cover many of the testing methods in the literature.

Target Costing: Design for Manufacturing and Assembly (DFMA)

Dahan and Srinivasan (2001) highlight the potential importance of unit production cost in the marketing success of a new product. Specifically, they suggest that investments to reduce unit manufacturing costs increase profitability through six mechanisms: (1) market share improvements due to lower prices, (2) primary market growth due to lower prices, (3) reduced channel costs due to greater volume, (4) "virtuous cycles" of learning due to higher cumulative volumes, (5) quality improvements due to simplified designs, and (6) strategic benefits due to competitive disincentives. In short, they suggest that marketers work with their operations counterparts at the early phases of new product design to ensure that low costs are locked in early.

Boothroyd, Dewhurst, and Knight (1994) describe methods of dramatically reducing unit manufacturing costs for a broad array of products, primarily through part count reduction and simplification of the assembly process. Because cost reductions may require changes in the appearance or performance of the product itself if taken to extremes, marketing input, to the extent that it captures cost-benefit tradeoffs as customers would make them, is invaluable to making these decisions.

Ulrich and Pearson (1998) demonstrate empirically using a method they term “product archaeology,” that unit manufacturing costs for products competing in the same category (coffee makers) vary greatly, holding quality constant and standardizing for feature variation. They argue that while some of these cost differences may be the result of local manufacturing economics or variations in plant efficiency, a significant portion of the cost differences result directly from design decisions made early in the product development process. Once these design decisions are frozen, reducing the excess costs that may result from them is nearly impossible.

Rapid Prototyping Methods

Thomke (1997, 1998a, 1998b), and Thomke, von Hippel, and Franke (1998) discuss the increasing importance of new technologies such as rapid prototyping, simulation and combinatorial methods in exploring multiple technical solutions during the early phases of product development. In essence, these techniques automatically generate and test variations on a product concept theme using parametric design. Marketing’s role in this context is to provide methods by which customer response can be estimated for different feature combinations, combinations that make up part of the objective function used to evaluate those potential designs that pass the technical screening test. For example, while a certain percentage of potential body designs might pass a computer-simulated crash test, only a subset of those body designs might meet other customer requirements for aesthetics and performance. Methods of testing multiple designs with customers are needed, as described next.

Parallel Concept Testing of Multiple Designs

Gross (1967) suggested that multiple advertising campaigns be developed and pretested so as to improve the expected effectiveness of the “best” campaign. Srinivasan, Lovejoy, and Beach (1997) apply similar thinking to PD and suggest the need for more parallel concept testing prior to “freezing” the design of a new product. They base their analysis on experience with PD classes taught at Stanford University in which teams of students design competing products within the same product category. Over years of teaching the course, they note the difficulty of accurately predicting which student designs would fare best in simulated market competitions based on actual respondent preferences. They suggest carrying forward multiple concepts until a later stage of development, testing these with potential customers, and then selecting from among the winning concepts. Once the winning concepts are selected, they can be tested further (funnel PD process) or the team can iterate to opportunity identification and ideation (spiral PD process).

Dahan and Mendelson (2001) quantify this argument and determine the optimal number of concepts to test given the cost per test and the nature of upside profit uncertainty. Their analysis suggests that the statistical theory of extreme values is relevant to concept testing and that the optimal number of tests is related to the ratio of profit uncertainty (e.g. standard deviation of the profit distribution) to the cost per concept test. Further, they show that the nature of upside profit uncertainty, whether fat-tailed, exponential-tailed, or bounded, significantly impacts the degree of optimal parallel testing. Specifically, they show that the effect of declining unit testing costs, as might result from moving to web-based testing, on total concept test spending, depends on the tail-shape parameter of the distribution of potential profits, not just on the cost per test. They note reversals of total R&D spending depending on the interaction between this tail-shape parameter and unit testing cost.

Internet-based Rapid Concept Testing

Dahan and Srinivasan (2000) developed and tested a web-based method of parallel concept testing using visual depictions and animations, in this case of bicycle pumps. Respondents viewed eleven new product concepts, and expressed their preferences by "buying" their most preferred concepts at varying prices. These choices were converted into individual part worths for each concept using price and product as the only features in a conjoint analysis. These results were compared to a control cell in which similar part worth measurements were conducted using working physical prototypes of the bike pump concepts. The results showed that both the verbal and web-based visual methods identified the top three concepts from the control group, and that the web-based methods measured these preferences with greater accuracy. As in the fuzzy front end and in the design and engineering phase, we expect that these web-based methods will grow in power and applicability as more researchers address the challenges of implementing these methods. With further development and testing, these virtual concept testing methods have the potential to reduce the cost and time devoted to concept testing.

Automated, Distributed PD Service Exchange Systems

As new methods are developed to model and test customer response to new products more rapidly and inexpensively, it is becoming more important that PD teams can design and cost out these concepts rapidly and inexpensively. However, as product development becomes more dispersed, firms are outsourcing more and more services. Even within a firm, members of the PD team who are experts in gathering the voice of the customer might be in California (say near lead users for automobiles), while experts in the physical design of the car door might be in Detroit, experts in developing the wiring harness (for the door) might be in Mishima, Japan, and experts in wind tunnel simulation might be in Seattle. Furthermore, each sub-team might represent their expertise in a computer model that is not compatible with the other experts. One model might employ a spreadsheet (e.g., Excel), another might utilize a statistical package (e.g., SPSS), another a CAD system, and the last a mathematical modeling system (e.g., MatLab). But all must work together if they are to design a car door for the new Ford Thunderbird.

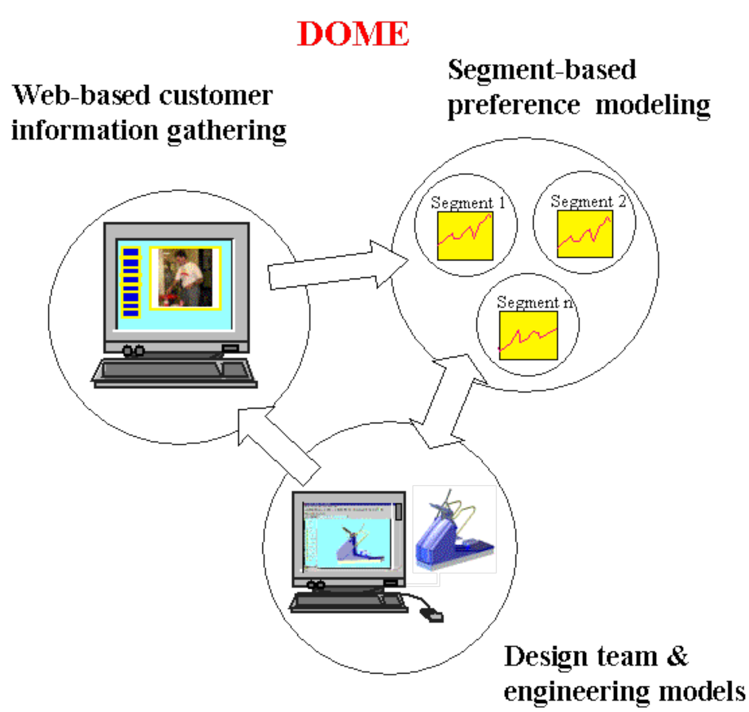
While in the past, these teams would spend considerable time communicating and developing compatible analytical systems, new automated and distributed service exchange systems such as DOME, depicted in Figure 17, make it possible to dramatically reduce the communications costs and speed the product to market (Senin, Wallace and Borland 2001; Wallace, Abrahamson, Senin and Sferro 2000). The key idea behind DOME is service (and data) exchange rather than just a data exchange. For example, the voice-of-the-customer team might invest in a conjoint analysis of the features of a car door – sound insulation, ease of opening and closing windows, styling, etc. and build a choice simulator that predicts sales as a function of these features. The physical modeler might build a CAD system in which physical dimensions (height, width, length, curvature, wiring requirements, etc.) are input and in which shape is output. The wind tunnel expert might build a simulator in which shape and insulation are input and in which noise level and drag are output. The wiring harness designer might want all of these inputs and can output information such as the power delivered to the electric windows and automatic door locks. Each of these teams, and many others, require and generate information that is connected through a virtual web – the voice-of-the-customer expert cannot run the conjoint simulator without the noise level, the wind tunnel expert cannot estimate noise level without a physical model, and the physical modeler cannot produce a CAD drawing without interfacing with the wiring harness expert.

Systems such as DOME address these communication problems by setting up a “services” exchange on a common computer platform. Each distributed expert team need only access a software envelope for its program (Excel, SPSS, MatLab, etc.) and post its input requirements and output services. Then either a central administrator, such as the core PD team, can build an integrated system or each expert can trade information in a services marketplace. In the latter case the services exchange provides the means for the market to function and information is exchanged in a free market of services. To date, DOME has been implemented with Ford Motor Company and the US Navy, however, testing continues. The challenge to marketing researchers is to develop systems that are compatible with such service-exchange platforms so that customer information is as fully integrated as engineering-design and production-cost information.

Information Acceleration

Web-based rapid concept testing provides the means to gather customer input about virtual concepts, and service exchanges provide the means to design quickly these virtual concepts. However, in order to make the demand vs. cost tradeoffs, the PD team needs to simulate product acceptance in a marketplace where sales are affected by marketing variables such as advertising, word-of-mouth, and sales force presentations.

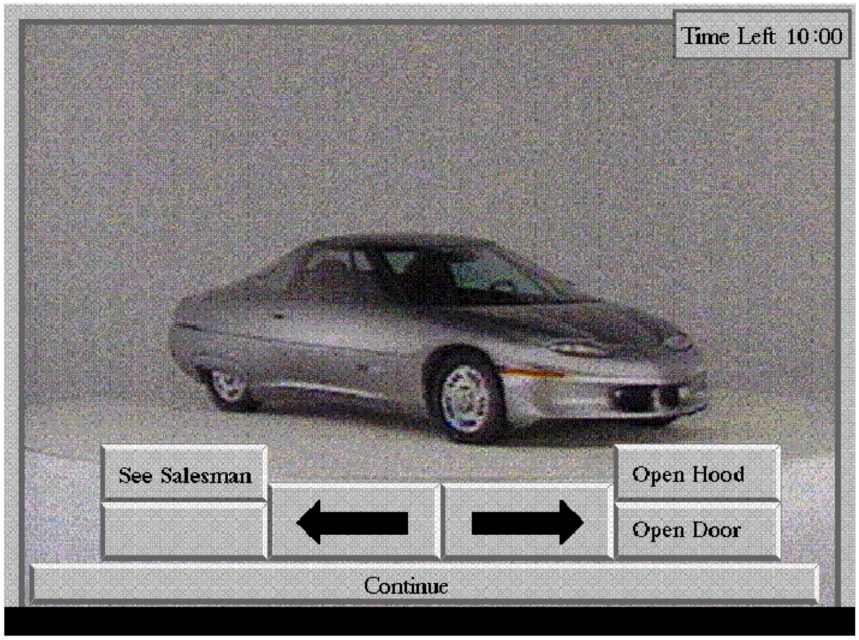
Figure 17: Distributed Object Modeling Environment (DOME)



Furthermore, really new products often stretch technology and customer comprehension of the benefits of technology. For example, prior to the development of the personal computer, word processing was done by professionals rather than by virtually everyone, spreadsheet analysis was limited to a few financial professionals, and personal finance was done with the checkbook rather than programs like Quicken. There was little demand for web browsers before the Internet became widely available and little demand for home networking before broadband capabilities were ubiquitous. Thus, in testing really new products and concepts it is often necessary to place potential customers in new information states with new perspectives on the world. Some of the early attempts at simulating future environments for the customer were called information acceleration (IA). They relied heavily on central location interviewing with multimedia computers that, at the time, were high end. Today, with the rapid advancement of the web, and with streaming video and other multimedia capabilities, we expect that IA methods will become more widespread.

We illustrate IA with Figure 18 from Urban, Weinberg, and Hauser (1996). Figure 18 is a prototype electric vehicle. Customers could view this vehicle on the computer, walk around it virtually, and even (virtually) open the hood, truck, and doors. In addition customers could "talk" to other consumers like them, interact with a virtual salesperson, view advertising, mock-ups of consumer magazines, and other stimuli they were likely to see when shopping for a new vehicle. Furthermore, they were accelerated into the future with accounts of alternative future environments that were either favorable, neutral, or unfavorable towards electric vehicles. IA has been tested and validated in a number of other environments including medical equipment and durable consumer products (Urban, Hauser, Qualls, Weinberg, Bohlmann, and Chicos 1997).

Figure 18: Example of Information Acceleration



Pretest-Market and Prelaunch Forecasting

Web-based concept testing, service exchanges, and IA deal with product concepts or virtual prototypes. However, once the virtual prototype is developed and the actual product is engineered, the PD team still seeks to reduce the risk of a full-scale launch. Thus, once a firm has refined its product concepts, developed prototypes, and can produce its products in limited quantities, it needs to test the full benefit proposition that includes the physical product, service, distribution, and marketing actions such as advertising, detailing, sales force presentations, word-of-mouth, and publicity. We call such testing either pretest-market or pre-launch forecasting.

In a typical pretest-market analysis, potential customers are shown products in a setting that is chosen to simulate the purchase experience. For consumer products they might be shown television advertising, magazine articles, tapes of other consumers talking about the product, sales force presentations, consumer magazine reports or whatever media are appropriate to the product category. For consumer packaged goods, they might be recruited at a mall, brought to a room to see advertising, then brought to another room that simulates a grocery store. They would be asked questions about perceptions, preferences, and purchase intentions and allowed to make an actual purchase in the simulated store.

The methods of analysis include trial/repeat analysis (Eskin and Malec 1976), recursive analysis (Pringle, Wilson, and Brody 1982), norms (Blackburn and Clancy 1980), econometrics

(Blattberg and Golanty 1978), logit analysis (Silk and Urban 1978), and preference distribution modeling (Hauser and Shugan 1983, Hauser and Gaskin 1984). Indeed, most of these models combine multiple methods. For example, Silk and Urban (1978) explicitly use two parallel models and examine the convergent validity between the two before making forecasts. In general, the models predict well and have proven robust across many applications (Urban and Katz 1983). In recent years the set of product categories has broadened tremendously. For example, the Assessor group at MARC, Inc. reports applications from frequently purchased products (candy, soda, deodorants) to consumer durables (personal computers). See critical reviews in Narasimhan and Sen (1983), Shocker and Hall (1986), and Ozer (1999).

In some situations, such as automobiles, the PD team wants to test the market before launch, but after the production facilities have been built. Although volume is less of an issue, the team needs to know what it will take to sell the product. That is, it needs an estimate of the required investment in advertising, dealer incentives, and promotion. To extent that production is flexible, it also wants to know how many items it will likely produce with each set of features such as global-positioning and mapping systems, premium sound systems, or even metallic paint. In this case, pre-launch methods are used (e.g., Urban, Hauser, and Roberts 1990). In a typical pre-launch application, consumers are shown advertising, magazine articles, and word-of-mouth simulations. This is similar in nature to pretest-market analyses. However, customers are also allowed to experience the product through test drives (for automobiles) or home use. “What-if” models are built to forecast the impact of market variables and diffusion models are used to forecast the timing of sales (Bass 1969, Mahajan, Muller, and Bass 1990, Mahajan and Wind 1986, 1988).

Mass Customization and Postponement

In some cases, the best strategy might be expeditionary marketing in which many products are placed on the market simultaneously allowing the market to decide which are fit to survive (Hamel and Prahalad 1991). However, expeditionary marketing only makes sense if the firm can easily ramp up production on the successful products and if the cost of failure is low (both directly and in loss of goodwill). The combination of efficient retailing (including e-commerce), product and process modularity, and flexible manufacturing systems are now making these conditions common in a variety of product categories. In particular, we are seeing an explosion in the sale of custom-configured goods that are only assembled after demand is observed. Perhaps the prototypical application of this system has been the build-to-order system used by Dell Computer to dominate the market for personal computers (Rangan and Bell 1998). The direct sales approach makes particular sense when obsolescence costs are high and "middleman" markups are significant, as in the PC business. Cattani, et. al. (2001) model these tradeoffs and show that in many cases a hybrid approach including make-to-order and make-to-stock is optimal. Gilmore and Pine (1997) characterize four approaches to "mass customization" and suggest that the optimal approach depends heavily on the nature of the product and the markets it serves. These concepts represent a radical shift not only in manufacturing strategy, but also in the marketing thinking underlying product development. Specifically, once a firm adopts a mass-customization approach, the design problem shifts from searching for optimal bundles of features and optimal product lines to defining optimal common platforms, features, and level options, component-by-component pricing and custom-configuration user interfaces. Feitzinger and Lee (1997) provide extensive examples of products that benefit from modularity and postponement of at least some aspects of production until after demand is observed. For example, by pre-sewing "white" sweaters in various sizes and delaying the dyeing of sweater yarns until after early demand has been observed, Benneton mitigates against the risks of overproducing unpopular colors or under-producing the season's "hottest" colors, while still being able to respond to demand quickly. Similarly, Hewlett Packard reduces its inventory risk by postponing differentiation of its printers based on geography (affecting power supplies and the language of the manuals) until very late in the distribution process. The manuals and power supplies are treated as separate modules to be inserted into the pre-manufactured, generic printer box.

However, it is still vitally important that the PD team use the methods described earlier to winnow the concepts and features that are made available to the customer. Customers are limited in their ability to search among features – without some focus, even the best mass customization process might fail.

Summary of Prototyping and Testing Concepts and Products

In most cases the launch of a new product is very costly in terms of commitments to production, distribution, and marketing. It is good management strategy to invest early to refine the product and its marketing and to reduce the risk of failure. This includes methods to reduce cost and risk (DFMA), methods to develop and test prototypes rapidly, and parallel development to manage the pipeline. As the product nears market, PD teams have used effectively pretest and pre-launch forecasting experiments to get early readings on how well the market will accept the product or product line. These methods have been in use for almost thirty years and have proven accurate in a wide variety of circumstances.

With the advent of new information and communications technologies, improved prototyping and testing methods are becoming available. Web-based rapid concept testing, information acceleration, and automated and distributed service exchange systems are enabling PD teams to work together and develop products faster and more profitably. The true advantage of these methods is that they can be used with virtual prototypes, thus enabling the PD team to forecast market response in parallel (or prior to) the development of the physical product. We expect these trends to continue, especially as the Internet and the worldwide web transform the final development and testing of concepts and products. For researchers in marketing, there are exciting opportunities to explore web-based methods for prototyping and testing products and concepts and there are exciting opportunities for seamless integration with engineering, operations management, and production through methods such as services exchanges.

Enterprise Strategy

Previous sections addressed the concept of an end-to-end product development process with stages of opportunity identification and idea generation (the fuzzy front end), the design and engineering of concepts and products, and the prototyping and testing of concepts and products. In each stage there are many tools and methods available to understand the customer and to make use of that information to develop profitable products. However, product development is not done in a vacuum. Rather, its success or failure depends heavily on the organization in which it is embedded. (Review Figure 3.) To be successful, the firm must align its culture, incentives, and processes to ensure that the people involved in the process can do their jobs effectively. While tools and methods might work well in theory or in demonstration programs, to make a difference they must improve the effectiveness of the entire organization. And this is not trivial.

The Challenge of Developing an Effective Product Development Organization

Despite many new tools and methods in the design of an end-to-end product development process, and despite the new web-based tools, many organizations are struggling with the execution of those processes. For example, Wheelwright and Clark (1995) document that despite the fact that their suggestions in earlier work have produced isolated successes, many organizations are facing difficulty in using these methods on an ongoing basis. Repenning (2001) and Repenning and Sterman (2000b) document this phenomena further suggesting that while new processes might be excellent, it is difficult to implement them in real organizations facing the challenge of actually getting products out the door. Of course this in not limited to product development. Many previous management practices have had trouble with implementation including customer satisfaction programs, quality circles, total quality management, business process re-engineering, and some information technology (Anderson, Fornell, and Lehmann 1994, Howe, Gaeddert, Howe 1995, Klein and Sorra 1996, Lawler and Mohrman 1987, Orlikowski 1992).

One reason for failure has been communication and suspicion – a new tool or method challenges those team members who have enjoyed the rewards of being an expert in the use of the old tool. New methods and priorities shift the importance of people and functions. Another reason for failure is that too much is expected too soon. New tools and methods take time to learn and they divert energies from the task of getting a project out the door. If the benefits of the new tool are obvious right from the beginning it will be adopted quickly. But if the benefits of the new tool are spread over future projects while the cost is incurred on the current project, then team members may not have the incentives to invest. See examples in Griffin (1992). Indeed, if the investment in the new tool is so great that it detracts from current performance, then the process can enter a death spiral of self-confirming attribution errors. That is, team members see that the current project takes longer or is more difficult and they attribute this to the new tool or method (Repenning 2000, 2001). Managers attribute the delays or costs to the team members, which leads managers to suggest the use of more tools (beyond optimal allocations), which just reinforces the delays and costs (Repenning and Sterman 2000a, 2000b).

To overcome some of the problems of implementation researchers have proposed boundary objects, communities of practice, relational contracts, and balanced incentives. We review each in turn.

Boundary Objects

Carlile (1999) suggests that tools and methods are more likely to be used in a real organizations if differences and dependencies across boundaries in the firm are represented and understood by product development team members. He suggests that certain objects, called boundary objects, effect communication by allowing team members to learn different thought worlds, propose alternatives, test tradeoffs, transform knowledge, and create new solutions. The key ideas here are that these boundary objects must be accessed by two or more team members, that the team members often have disparate skills or thought-worlds, and that in order to work together on the boundary object, the team members must evolve a means to communicate. In some cases, the technical value of the boundary objects pale in comparison to their implicit ability to enhance communication among team members.

For example, CAD/CAE tools, by generating frequent virtual prototypes during the development process, help assure that components are integrated and that development proceeds in a closely coordinated manner. Similarly, Cusumano and Selby (1995) describe a process at Microsoft where disparate programmers provide code to the common program (say Microsoft Office). Frequently and periodically, the entire program is "built" in order to synchronize and stabilize the entire package of code. Each component of code must, in this process, work with the entire package. Finally, Carlile and Lucas (1999) argue that "technical work in cross-functional settings will be more effective when it: (1) establishes a common model and language, (2) uses that logical structure and language as a shared team process to explore constraints and risks, and (3) keeps the interactive process alive by continuing to carry forward alternatives and some degree of design flexibility."

Communities of Practice

Organizational studies suggest that process knowledge is often deeply embedded in social groups within the organization (Brown and Duguid 1991, Lave and Wenger 1991, Wenger 1998). There are new challenges to tap such implicit and tacit knowledge about processes so that human capabilities in product development tools and methods diffuses within organizations. This includes encouraging such communities of practice through mechanisms by which they can share knowledge. In the coming years we expect that interest in this area will grow as the Internet and information technology makes possible internal markets (and external markets) through which such implicit process knowledge is shared.

Relational Contracts

Recent research in agency theory suggests that formal incentive mechanisms are not sufficient to "induce the agent to do the right thing at the right time (Gibbons 1997, p. 10)." Thus formal mechanisms are often supplemented or replaced with long-term implicit relationships in which decisions are delegated informally to self-managed PD teams through self-enforcing relational contracts. By viewing the relationship as a repeated game, Baker, Gibbons and Murphy (1999a, 1999b) suggest that the greater information inherent in the informal relationships enables these relational contracts to succeed.

Balanced Incentives

Cockburn, Henderson, and Stern (1999) suggest that those best practices that diffuse are practices that are complementary to one another – they must be adopted as bundles rather than individually. For example, they suggest that science-based drug discovery in the pharmaceutical industry required that organizations adopt more high-powered incentives within the research organization. Their research suggests that PD tools and methods cannot be viewed in isolation, but as part of a more comprehensive end-to-end process. The tools and methods that the organization accepts will be those that work well in the context of the overall process.

Dynamic Planning

Repenning and Sterman (2000a, 2000b) suggest that firms wishing to adopt new tools and methods adopt a dynamic – rather than a static mental model. That is, firms should view the diffusion of new tools and methods as an investment that is amortized over multiple projects rather than requiring immediate return on a single project. They suggest further that the firm study the dynamic interrelationships between the expectations of managers and the self-allocation of effort among product development teams. Repenning (2001) further develops these analysis tools by coupling ethnographic inquiry with formal dynamic modeling. The ethnographic inquiry provides the basic hints; the formal modeling generalizes these hints and highlights the key feedback loops that are driving the dynamic behavior of the systems.

Deployment of Capabilities with Web-based Tools

The adoption of new tools and methods does not just happen. New capabilities and knowledge are required on the part of the product development team. For example, Ford Motor Company has a technical staff of 25,000 professionals that are expected to undertake 40 hours of training each year – a total of 500 person-years of effort to learn new processes. This is indeed a substantial commitment. On the other hand, industry estimates that approximately 75% of the training materials in Fortune 100 companies are redundant, with some of these costing $300,000 each to create and $50,000 to translate into each additional language (Learnshare 2000). While traditional methods of apprenticeship are still important (Lave 1991), new opportunities are available with web-based training in which materials are less expensive to reproduce, can be shared across firms (subject to competitive issues), and can be updated easily. For example, Ford expects courses to take on average one-third less time for equivalent learning gain (e.g. a three-day instructor-led course takes two days on average with the web-enhanced version).

Process Studies of the Antecedents of Product Development Success

Complementing the study of the organizational culture under which product development teams operate, there is an extensive literature on the antecedents and consequences of product development success. The goal of this literature is to identify variables and constructs that are correlated with success across firms. For example, earlier in this chapter we reviewed some of this literature to suggest that communication between the marketing function and the technical development function is a strong correlate of product development success.

This literature relies primarily on questionnaires sent to product development professionals. These professionals report their perceptions of various constructs and their perceptions of the success of the product development project. Griffin and Page (1993, 1996) provide a comprehensive review of this literature (referencing 77 articles). To date, the strength of this research stream has been exploratory in nature – identifying potential constructs that affect success. Table 3 summarizes, in alphabetical order, eighty-two of the constructs that have been found to affect product development success, either directly, indirectly, or in interactions with other constructs.[2]

Although each of these constructs is correlated with success to some degree, few studies have included a broad set of constructs and few have used regression analysis or path analysis to identify the relative impact of these constructs (Montoya-Weiss and Calantone 1994, 411-412). Furthermore, researchers are only now beginning to model the full implications of endogenous decisions by firms. For example, a high-potential market is likely to attract competitors, thus the net impact of "market potential" and "market attractiveness" might be to neither heighten nor diminish observed success (Cooper 1984b).

Perhaps the best summary of this literature to date is the meta-analysis of 47 scientific studies by Montoya-Weiss and Calantone (1994). These researchers identified the eighteen constructs that were reported most. For ease of comparison they grouped these constructs into four categories: strategic factors, development process, market environment, and organization. According to the authors, all eighteen constructs had a significant impact on success (Fisher combined test) and all but three had medium to large correlations (0.2 to 0.3) with some measure of success. The remaining constructs were included in only one study (speed-to-market) or no studies (costs, market competitiveness). Because this literature is still developing, not all of the studies reported correlations,

[2] See, for example, Atuahene-Gima (1995), Ayers, Dahlstrom, and Skinner (1997), Bonner, Ruekert and Walker (1998), Calatone and di Benedetto (1988), Cooper and de Brentani (1991), Cooper and Kleinschmidt (1993, 1994, 1995), Datar, Jordan, Kekre, Rajiv and Srinivasan (1997), Goldenberg, Lehmann and Mazursky (1999), Griffin (1997), Griffin and Hauser (1994), Ittner and Larcher (1997), Kahn (1996), Lambert and Slater (1999), Lee and Na (1994), Mishra, Kim and Lee (1996), Moorman (1995), Moorman and Miner (1997), Olson, Walker and Ruekert (1995), Rosen, Schnaars and Shani (1988), Sharda, Frankwick, Deosthali, and Delahoussaye (1999), Song and Parry (1997a, b), Song, di Benedetto and Zhao (1999), and Song, Montoya-Weiss and Schmidt (1997).

thus the authors also report the number of times a construct was found to affect a measure of success. Table 4 summarizes the average correlations and number of studies.

This literature has the potential to enlighten and focus future research on the antecedents of product development success. The greatest research need is for studies that combine a comprehensive set of constructs, deal with endogeneity in a sophisticated manner, and develop measures with greater internal and external validity.[3]

[3] Montoya-Weiss and Calatone (1994) provide an excellent discussion of the threats to internal and external validity including issues that only significant correlations are reported even when a large number of constructs are included in the study, issues that respondents often are allowed to self-select successes and failures, and issues that much of the literature relies on respondents perceptions rather than objective measures.

Table 3. Antecedents of Product Development Success

address clear needs	information acquisition	product definition
adequate team	Innovativeness	product differentiation
adequate resources	instrumental market information	product-firm compatibility
clear strategy	interdepartmental collaboration	product-market fit
company resources	internal commitment	proficiency of formal PD activities
competitive intelligence	management accountability	product organization
conceptual market information	management commitment	quality of launch execution
concurrent engineering	management support	quality of service
costs	market competitiveness	R&D, marketing integration
cross-functional integration	market growth	relational norms
cultural antecedents	market intelligence	resource availability
customer satisfaction	market orientation	rigorous tools
customer needs and benefits	market potential	service expertise
customer service	market size	standards
decentralization	marketing orientation	strategy
degree of product newness	marketing skills and resources	superior product
empowerment	marketing synergy	supplier involvement
entrepreneurial climate	newness to firm	synergy
environmental uncertainty	newness to market	technical complexity
evaluation and reward procedures	Novelty	technical innovativeness
execution of marketing	organizational memory	technical skills and resources
execution of technical	organizational memory dispersion	technical synergy
experience with market	pioneering advantage	templates of change
focus	platform reuse	time-to-market
formal processes	pre-development proficiency	uniqueness
formal cross-functional integration	product advantage	value to the customer
formalization of user inventions	product champion involvement	
high quality teams	product complexity	

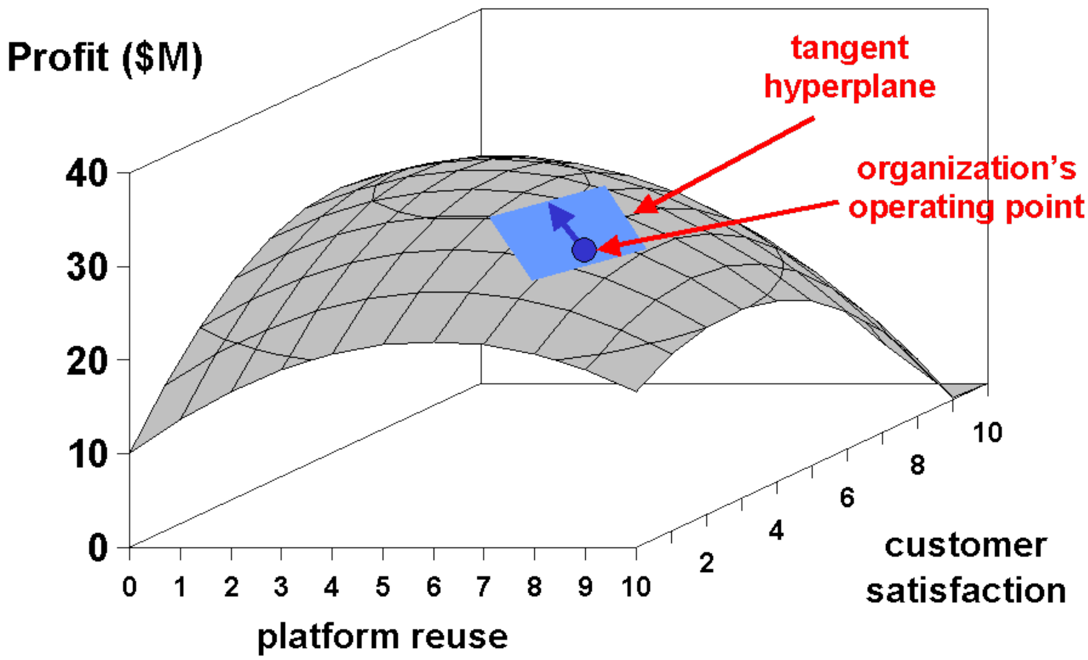
Table 4. Meta-analysis of Academic Literature
(from Montoya-Weiss and Calantone 1994, 408, 410)

	Quantitative Comparisons		Qualitative Comparisons	
Construct	Number of Studies	Average Correlation	Number of Studies	Percent of Studies
Strategic factors				
Technological synergy	6	0.27	18	67%
Product advantage	5	0.36	16	59%
Marketing synergy	5	0.30	14	52%
Company resources	3	0.30	9	33%
Strategy	1	0.32	8	30%
Development process				
Protocol	7	0.34	19	70%
Proficiency of technical activities	7	0.28	18	67%
Proficiency of marketing activities	5	0.33	18	67%
Proficiency of pre-development	5	0.29	11	41%
Top management support/skill	2	0.26	9	33%
Financial/business analysis	1	0.27	8	30%
Speed to market	1	0.18	8	30%
Costs	0	–	4	15%
Market Environment				
Market potential	4	0.24	23	85%
Environment	2	0.29	15	56%
Market competitiveness	0	–	2	7%
Organization				
Internal/external relations	3	0.31	13	48%
Organizational factors	3	0.30	12	44%

Adjusting Priorities to Maximize Profit

Although process studies provide valuable insight with respect to the constructs which correlate with success across firms, they do not provide a tool that managers can use to adjust the emphasis they place on these constructs within their firms. This is particularly challenging because the impact of these constructs is contingent upon the capabilities of the firm and the context in which it operates. Furthermore, because the impact of these constructs is likely to be non-linear, the process studies do not indicate the optimal level for a particular firm. Furthermore, there are tradeoffs among foci (say customer satisfaction vs. platform reuse – review Figure 2) and it is possible to overshoot if too much emphasis is placed on one construct, say customer satisfaction, at the expense of another construct, say cost reduction through platform reuse. For example, too large an emphasis on customer satisfaction might prove too costly and reduce profit even as it increases long-term revenue.

Figure 19: The Metrics Thermostat



To address the issue of selecting priorities within a firm, we turn to adaptive control (Hauser 2001, Little 1966, 1977). The concept is quite simple. Suppose that we are operating within a division of firm. It is likely that the implicit culture and relational contracts are relatively homogeneous within this division. The product development teams understand the culture and operate accordingly. Thus, they understand the implicit priorities that are placed on constructs such as customer satisfaction and platform reuse. The net result of the firm's culture, its competitive environment, its capabilities, and its human capital produces a response surface such as that illustrated in Figure 2. Such a response surface summarizes how achievement with respect to metrics, such as customer satisfaction, affects profits. However, response surfaces are rarely static. New challenges for the firm, both internal and external, are likely to shift the response surface in Figure 2. As the response surface shifts, the firm must adjust its priorities.

To understand and adjust its priorities though adaptive control, we must first understand, conceptually, the relationship between metrics, such as customer satisfaction, and the firm's profits. In Figure 19, we reproduce the response surface from Figure 2 and examine its "local" properties. At any given time we are likely to observe the firm operating on some portion of this curve as indicated in Figure 19 by the dark circle (λ). Moreover, because the implicit culture is relatively homogeneous, most of the observations of customer satisfaction, platform reuse, and profit for launched products will be in the neighborhood of the operating point as indicated by the tangent hyperplane in Figure 19.

Thus, a regression of profit on customer satisfaction and platform reuse within the hyperplane will suggest to the firm how to adjust their emphasis on customer satisfaction and platform reuse in order to increase the profitability of their product development projects.[4] While this example is based on two constructs, customer satisfaction and platform reuse, it is readily extended to a larger number of constructs. For example, adaptive control can be applied to top-level constructs such as customer satisfaction, platform reuse, and time-to-market and, simultaneously, to a larger number of lower-level constructs that enable the firm to achieve those strategic priorities.

These methods have been applied to a major product development firm (3 strategic constructs, ten enabling constructs, and seven covariates). Based on data from almost all of the development projects over a five-year period for a key division of the firm, the "metrics thermostat" was able to identify that the firm (or at least that division) was placing too little emphasis on customer satisfaction and too much emphasis on platform reuse. Because the results had high face validity, the firm reacted with three initiatives: (1) the firm created the role of a "marketing engineer" who was responsible for assuring that the voice of the customer is incorporated in the design and that the product is designed to be marketed, (2) the firm adjusted its channels to reach the customer better and to match customers with the appropriate products, and (3) the firm undertook a major study of platform reuse to optimize their portfolio with respect to upstream/downstream technological development, a balance of product variants and major redesigns, and enterprise coherence in software development.

The metrics thermostat has been applied at a major office equipment firm, a major automotive firm, the US Navy (acquisition reform), and the US Air Force (sustainment of the fleet). In each case, basic insights were obtained and suggestions were developed for improving profit (or capability for the military applications). Nonetheless, the metrics thermostat needs further testing, especially for marketing applications. The basic theory is remarkably robust – for example, directional improvements can still be identified even if the hyperplane approximation includes projects further from the operating point, even if the response surface is changing over time, and even if there is some heterogeneity – as long as none of these violations is "too severe." However, the weakness of the metrics thermostat is that the data upon which it is based is often difficult to obtain. Despite directives to manage by metrics, firms often do not collect metrics systematically nor maintain them in a central database. Furthermore,

[4] Figure 19 indicates the suggested change in customer satisfaction and platform reuse. To achieve this, the firm must adjust its priorities with respect to these measures, thus we need a mapping from measures to priorities on measures. This relies on agency theory and is beyond the scope of this chapter. For more details see Hauser (2001). For more details on agency theory see Gibbons (1997).

the number of data points for any of the within-firm metrics regressions are quite small requiring statistics to be supplemented with judgment.[5]

A Vision of the Future of Product Development

Throughout the 1980s and 1990s the focus of research on product development by marketing academics has been on bringing customer information into the product development process and on using that information. Significant strides were made in conjoint analysis, voice of the customer methods, product optimization, demand forecasting, and market testing. Toward the end of the 1990s the challenges of product development began to change as markets and competition became more global, as engineering and design talent became more dispersed, as internal product development efforts migrated into the extended enterprise, and as information and communication technologies changed the way people worked. The new challenges call for a product development process that is integrated, information intensive, almost instantaneous, and makes strong use of new technologies such as the Internet. We call this new vision i4PD: integrated, information, instantaneous, and Internet.

Integrated

The research challenges of the next decade are those that address product development as an integrated, end-to-end process that requires a detailed understanding and coordination of customers, competition, and internal capabilities. Research points to core teams that are either cross-functional or have the ability to make use of cross-functional knowledge embedded in the firm. Furthermore, design now means the design of the product, the assembly and manufacturing process, the service delivery process, the entire value chain, and the marketing materials – all integrated to provide high value to the customer. For example, research on voice-of-the-customer methods in the next decade must consider not just data collection, but how the PD team will use that data.

Information

Ultimately, it is people who design products, but as the process becomes more integrated the demands for information have grown. For example, cutting-edge, PD teams must integrate information from the customer, the assembly process, the manufacturing process, the channel delivery process, and the marketing process. In some cases, this means new roles – some firms now use “marketing engineers” who help design a product so that it is easy to market. However, integration demands

[5] Fortunately, the metrics thermostat is robust with respect to a small number of data points. It “does no harm” in the sense of not recommending changes when the results are not statistically significant.

information – the right information to the right people at the right time so that they can make the right decisions. Thus, many of the research challenges in the next decade will involve methods to assure this information transfer. Methods such as services exchanges are just the beginning of integrated information systems that could lead to greater product development competitiveness.

Instantaneous

Speed-to-market has been proposed as a competitive advantage – at least if it can be obtained without sacrificing cost or customer satisfaction. New methods such as virtual prototypes, web-based voice-of-the-customer methods, web-based conjoint analysis, the Information Pump, listening in, Securities Trading of Concepts, and user design all have the potential to provide information to the PD team almost instantaneously. We call this entire set of methods the virtual customer. For example, traditional conjoint analysis studies take a minimum of 6-8 weeks. New web-based methods have the potential to reduce that to two days, opening up the potential for the PD team to have its customer-preference questions answered almost instantaneously. In fact, it might soon be possible to get statistical information about customer wants and needs almost as fast as it used to take to debate them. Virtual prototypes mean that products can be "created" in days, and Internet connectivity means that these prototypes can be tested with customers in hours. Service integration methods mean that many engineering design decisions can be reduced from months to days. Interestingly, in the future we might be in a situation where the decision on how fast to introduce products might be more of a strategic decision on product positioning rather than constrained by the firm's ability to design and test products.

Internet

By Internet we really mean information and communications technologies. It is these technologies that are enabling the process to be integrated, information intensive, and instantaneous.

The i4PD paradigm is one perspective on the future of product development; a perspective that describes how the process will look. But we must not forget the human side of product development. One of most important insights of the late 1990s was the need to study the use of PD tools and methods within the organization. By understanding corporate culture and incentives, the new end-to-end processes should be robust, knowledge-based, people-based, and market-based. By robust we mean a process that can adapt to changes in the environment, market conditions, and organization. By knowledge-based we recognize that the firms that will be most competitive will be those that can train their PD teams to design and build products most effectively. We cannot study the process in isolation of the people we are asking to implement the process. The process will not succeed if we do not assure that the team members have the capabilities to exploit it. This means not only training, but also communities of practice, boundary objects, and dynamic thinking. By people-based, we mean that the process respects the teams' needs and that the metrics and incentives (explicit and implicit) are designed so that team members, acting in their own best interests, make decisions and take actions aligned with the best interests of the firm. Finally, by market-based we mean two things: first that the process will be responsive to customers and competitors, and second, that it empowers teams to make their own choices in the context of their own specific expertise and knowledge.

In the end, we believe that research on product development in the 21st century will concentrate on understanding an end-to-end process *that really works in real organizations*. We do not expect a fad of the month, but rather research to understand the science of organizations, marketing, and product development so that methods and tools are embedded in a self-learning and self-evaluation process that is right for the firm and its markets.

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