A Framework for New Product Development

A White Paper

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I. Summary

This paper highlights the strategic importance of accelerated product development and introduces Intellimet's Product Development Framework. It also provides a synopsis of many development methods and tools.

Strategically, accelerated product development enables a company to meet demands of sophisticated customers that increasingly want products tailored to their preferences. It provides faster payback on investment, higher market share, increased profitability compared to competition, and enables the company to achieve market leadership.

The Product Development Framework consists of five elements: strategy, process, methods & tools, organization, and management. The development strategy is founded on an understanding of customer needs and market opportunities. It enables strategic choices on percent of effort devoted to incremental, platform, and breakthrough developments and selection of development projects. Once projects are selected, a concurrent and phased development process is followed. Methods and tools such as "managing the front end", target costing, Quality Function Deployment, variety reduction, and product data management improve the efficiency and effectiveness of the development framework. The organization structure can have a dramatic effect on development cycle time and must be selected to support the development strategy and goals. Finally, management of the development framework requires setting goals, measuring performance, appointing a development process owner, and continuously improving.

A clear understanding of the strategic importance of product development provides the motivation and the development framework provides the means to achieve rapid and cost-effective product development, successfully leveraging a company into a leading position.

II. The Strategic Importance of Accelerated NPD

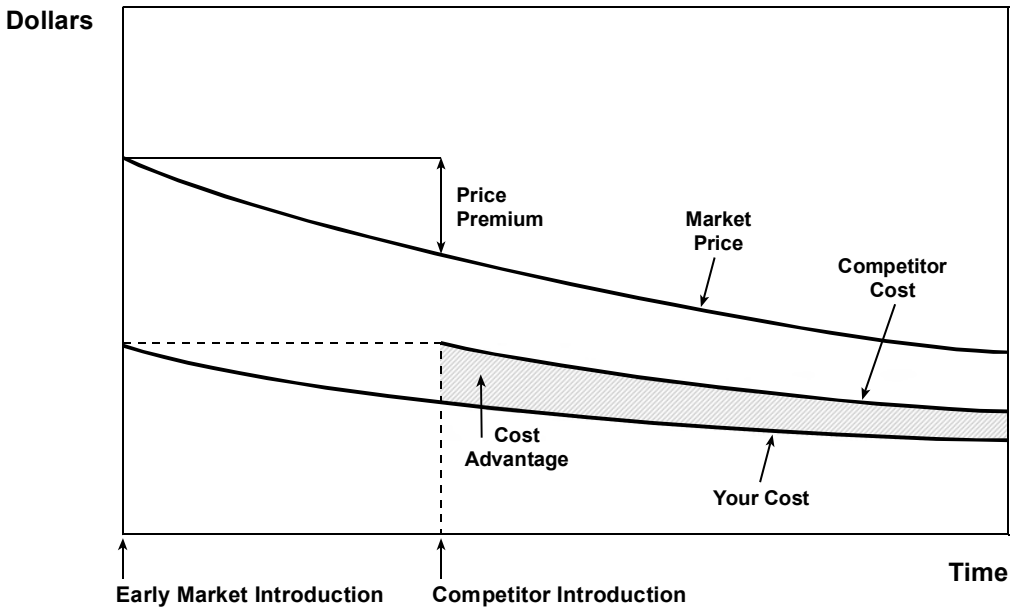
Since the 1970s it has become apparent that the traditional pace of new product development must be greatly accelerated if a company is to remain in the forefront of its competition. Companies that depend on their existing product portfolio without consideration of their effective life cycle, even if those products have been wildly successful, tend to get left behind their competition. Customers have become more sophisticated and demanding, with continually changing needs that are tailored to their individual preferences. Manufacturing capabilities are widespread, with some leverage possible for those manufacturers who utilize lean business principles. Those companies that target their resources and respond rapidly, are the nimble few who will continue to succeed and are profitable in the long term. This must occur without creating a needlessly complex and costly operating environment.

There are many essential conditions that must exist to enable a business to complete a transformation to a new product development process that excels. Consider the following:

- The process of decision making to determine what to develop and when
- The process of setting the proper goals or targets
- The process of developing a comprehensive and realistic plan
- The organizational structure for effective execution
- The coordinated involvement and participation of a very diverse group of organizations, functions and individuals in the value chain of events that must occur
- The methods and techniques that improve product development efficiency
- An effective review and management process

Timing to market is critical and the process of getting there is tough. Being the first to market with the right product can allow a company not only to gain market share rapidly but also to conceivably charge an initial price premium while simultaneously reducing internal recurring costs. This company is positioned favorably for the moment a competitor introduces a competing product. Then the price can be reduced while keeping acceptable margins because of learning curve advantages. The competition is forced to price competitively right after introduction without learning curve advantages, resulting in a profit squeeze (see Figure 1).

Figure 1. The Profit/Cost Advantage

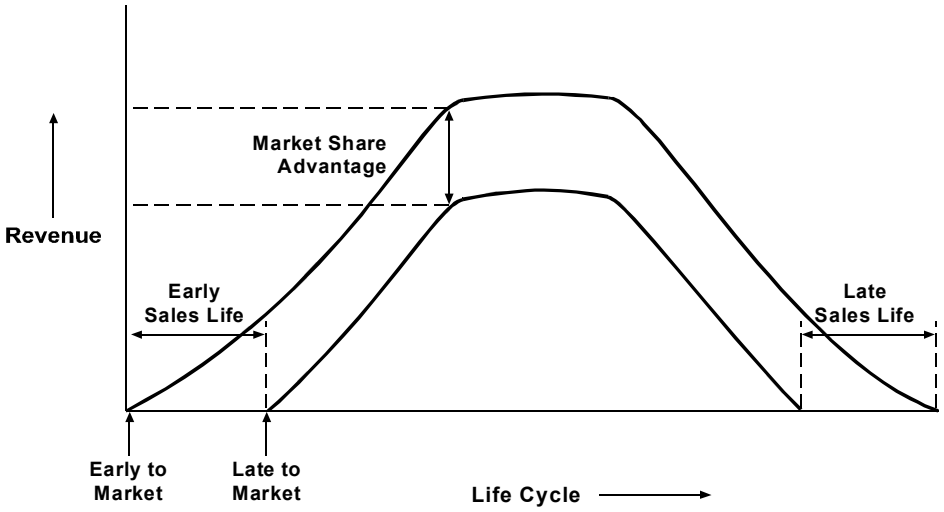


The advantages of a rapid development cycle are numerous:

- The shorter the development cycle the lower the cost, resulting in a faster payback of development expenses.
- A price premium is possible without any significant competition during early introduction. Profit margins remain higher than the competition's due to the improvements possible from the learning curve and cost reductions
- The product life cycle is extended if early to market. A good rule of thumb is that a product introduction six months earlier than the competitor can translate into a three- to four-fold increase in profits over the product's lifetime, depending on the length of the typical product life cycle in that industry. The longer the life cycle of the product, the greater the profit advantage. Early introduction allows the customer base to build some product loyalty, which also tends to create sales further out in time, enhancing the advantage of the initial sales life due to early introduction (see Figure 2)
- Market share increases if the competition has a lagging market introduction. Market share retention is better because it is unlikely that the customer will turn to the competition later due to switching costs, unless the customer is dissatisfied with the product features, quality, or service
- A short development cycle can also permit a company to delay the start of product development to take advantage of the latest in rapidly changing technologies, thus producing a superior product and still getting the product to market first
- In an industry where shifts in market needs can occur rapidly (for example, the consumer industry), the company with the shorter development cycle time will find itself in a better position to include those needs, placing it at a competitive advantage. The company will be viewed as being at the leading edge of product offerings and develop brand name recognition which translates to goodwill

These payoffs make a strong case for a company to find a way to make accelerated product development a core competency and create a culture to support this business practice. When this practice results in a continuous stream of rapid product innovation and introduction, not just an isolated one here and there, the company emerges as a market leader and forces competitors to follow in its footsteps with "me too" products with lower profit margins and shorter life cycles.

Figure 2. Early Launch Gains



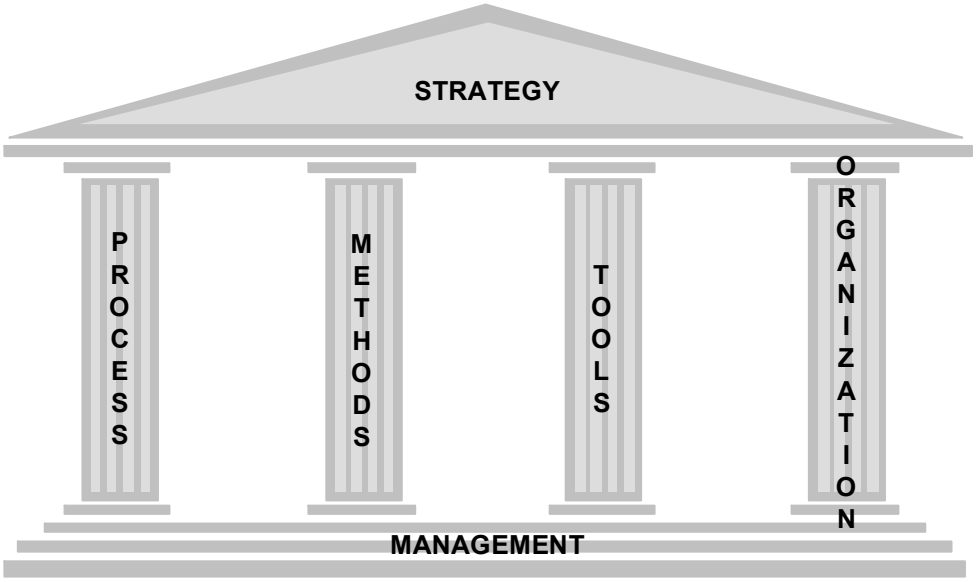
III. Intellimet's Product Development Framework

Intellimet's Product Development Framework is based on our research and experience and consists of the following elements:

- Product development strategy
- Product development process
- Product development methods
- Product development tools
- Organization structure to support product development
- Management of the development framework

Figure 3 is a representation of the interlocking elements of this Framework.

Figure 3. New Product Development Framework



The product development strategy is an essential piece of a company's overall business strategy, while the rest of the Framework's elements represent the pillars that the product is built on. Essential to the product development strategy is a "Customer-In" approach, crafting the development strategy, identifying the company's product development portfolio, and the selection and timing of development projects. Once the decision has been made to launch a project, the company should use a predefined approach for product development. The creation of the process to facilitate the implementation of the product development and business strategy requires agreement on the process elements, processing sequence, and how they must be executed. Determination of metrics and targets to be met, desired process phases and reviews, and the elimination of all non-value-added work are also part of the process definition.

Methods and tools that facilitate the process are identified for use in the appropriate process development stages. Each method or tool is tuned to a particular need and must be selected with care.

Organization of a cross-functional team structure to support the project requires careful management attention and decision-making. Team member selection should be based on each individual's ability to contribute to the development process and also to work together effectively to achieve the development targets and goals.

Management of the framework implies that a process sponsor and a process owner are identified, project management techniques are applied to individual projects, goals are set, and performance monitored.

A. Product Development Strategy

The first framework element—the product development strategy—includes several components. The first component is “Customer-In,” including the recognition of the customer as the reason for being and the use of approaches to gather customer requirements and ensure customer satisfaction. Establishing the strategy itself includes the development of "Customer-In" data and information about the competition, technological change, and sales potential. Next, the product development portfolio establishes the desired mix of development efforts from incremental to research. The final component is the process of screening and selecting product development projects.

1. "Customer-In"—Understanding the Customer and the Marketplace

Customers want higher quality goods, at low prices, targeted just for their needs. Customer-In enables companies to direct all efforts, including product development efforts—to achieve high levels of customer satisfaction. Customer-In is a philosophical underpinning—a strategic choice to be customer oriented. It starts with the company’s leaders and permeates the entire company culture. It includes guiding principles such as:

- Treating the customer as king or queen
- Thoroughly understanding the customers’ use of the products and services
- Meeting customer desires and needs, not just demands and specifications
- Anticipating the customers’ desires
- Proactively contributing to customers’ success

Customer-In is also a comprehensive set of elements, systems, and processes designed to achieve customer-focused goals. It uses a multitude of “listening posts” to understand and anticipate customers’ desires and needs, the potential market, and competitors’ current and future capabilities. These listening posts can include structured visits to customers, seminars, trade publications, complaint reports, comparisons with competitive products, joint calls on end users, market trend analysis, demographics, and many other sources of input. This type of detailed market analysis and competitive evaluation provides the direction essential for continued product development success.

2. Establishing the Development Strategy

In order to combat potential pitfalls encountered in product development projects, a company must establish and utilize a comprehensive development strategy. Establishing strategy requires a proactive approach, which combines the study and understanding of two critical elements of the strategy, viz.

- Customer-In and the marketplace
- A company's core technologies and research into future technologies (both design and manufacturing)

A thorough understanding of these elements requires gathering data about customers, markets, technologies, and competitors. To make sense of this information, functional maps are useful. Some typical maps include:

- *Product Profile* – comparing product features and attributes relative to competitors
- *Product Generation* – timing and life cycle of products and the relationship of one product to another
- *Engineering Skills* – skills composition of the engineering workforce
- *Performance Tradeoffs* – range of performance combinations possible among dimensions that may conflict (e.g., weight and efficiency)

Integrating the two elements of the strategy—technology and market—enable leaders to formulate good decisions about a desirable future product portfolio with clear goals and objectives. These front-end activities provide the opportunity to address policy issues, market timing and frequency of introduction, technology availability and development, product differentiators, cross-functional and multiple-project related concerns, skills development, training, hiring and resource balancing.

Technology does not have to be developed solely from within the company, but can be the result of acquisitions, joint ventures, and industry consortium efforts. Competitive evaluations provide the ability to make the above decisions armed with the knowledge of what the main competitors' plans are, allowing the company to thwart these plans with strategies for market timing, pricing, competitive features, and technology investment and introduction. Market intelligence provides the ammunition to assess what the market is demanding by regional areas or target customers, anticipate developing customer trends, identify product differentiators, determine what pricing the market can bear, predict product life cycles, and assess sales volume potential.

Once the information is gathered and evaluated, leaders can establish the strategy. The strategy includes priorities for which products must be developed and in what sequence, over a three to five year time frame. The product development strategy must result in a company plan for development and implementation of the knowledge and capabilities available. It should be structured so as to have the technology or process available and proven out prior to project implementation. Leading edge companies develop and integrate product technology, marketing, process development, supplier, quality and other roadmaps, throughout the business, that support the strategy and evolve into a multi-functional product development roadmap.

Once the strategy is crafted, portfolio and project selection can occur.

3. Developing a Product Portfolio

One of the greatest challenges faced by any company, which must survive competitive pressures, is the determination of what products to develop to meet market needs, at what price and at what entry point in time. A sub-set of this decision process involves deciding how to best use available resources to develop products that fall into the following three categories:

- *Platform or next generation products:* Platform products constitute the core of the company's business. They typically have a longer design life because they comprise the basic architecture which incremental products can be based on. Platform products provide core customers with a complete systems solution, break new ground and involve a significant shift from existing platforms in product design and process design. The core offerings must provide the desired modularity and standardization, which can be built upon without adding undue complexity.
- *Incremental products:* This category includes the improvement or expansion of current product platform offerings with the addition of new performance or aesthetic features; improvements in design to use more standard parts or modules; and improvements required for manufacturability, reliability, or cost considerations. Incremental products could be needed to address niche markets or to enhance the product portfolio before the next platform products are released.
- *Breakthrough products:* This category of development is even more radical than the platform products, usually requiring the use or development of new product and material technologies and related new processes to manufacture the product. Such a product could be the beginning of a new product category and could serve to elevate the company's position relative to its competitors by being first to market with a product in a new business area.

In the product development strategy, all three of the above development products are supported by the desirable research and development projects that invest in the new product, material, or process technology know-how necessary to address technology trends. The leadership must determine what percent of resources to allocate for platform, incremental and breakthrough development projects.

4. Product Selection

The final component of the Product Development Strategy is a reliable process for selecting development projects. The selection process is founded on a clear understanding of the markets and competition, a well-articulated strategy, and targets for the development portfolio.

Many companies are slow to surface and act on new ideas. Therefore, the front end of the development process often presents the greatest opportunity for cycle time reduction. Companies should be open to product ideas from both internal and external sources. For expediency, new product ideas must be encouraged, discussed in a responsive forum, and acted upon in a timely fashion.

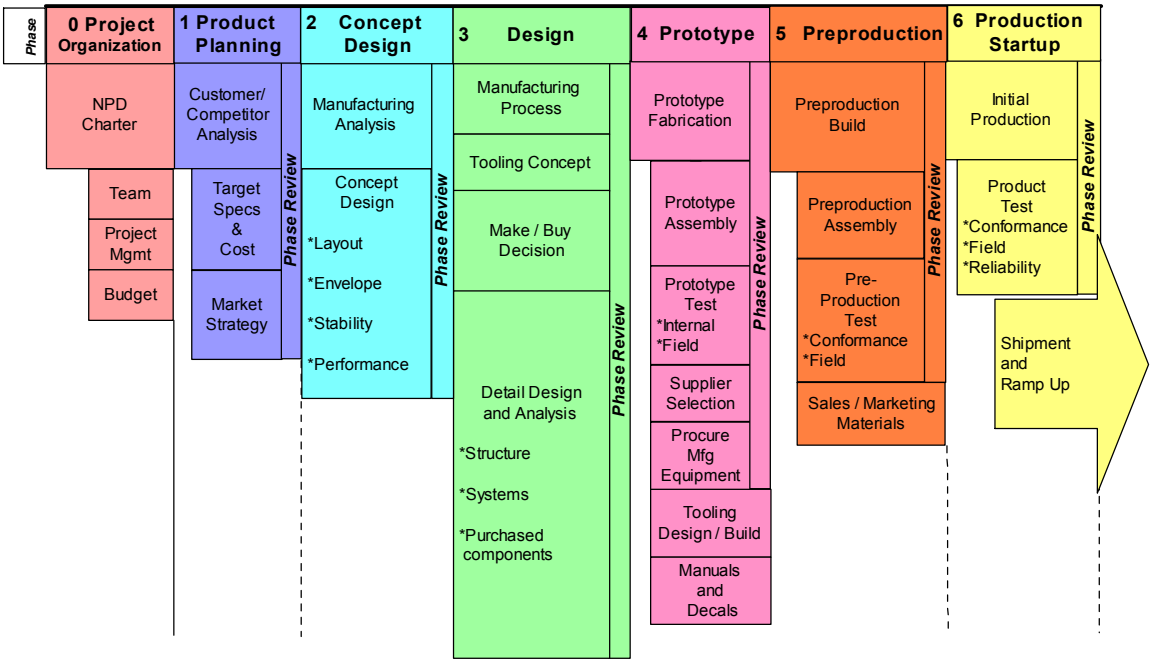
Clark and Wheelwright describe a funnel, which screens a variety of project opportunities and eventually selects a few projects for development. The selection process begins with idea generation. The company should institute procedures and incentives that encourage ideas from throughout the company and its customers and suppliers. Monthly or quarterly, or when a special need arises, new ideas go through an initial screen to determine completeness or readiness for review. The review team checks the idea's fit with the development strategy, required areas of knowledge, and potential impact. While some ideas are rejected, most move ahead with a least some further investigation to detail the proposed project and its benefits. A second screen is used as a go/no-go decision point. Projects that pass this screen are chartered and launched into the product development process.

B. The Product Development Process

This section discusses the second framework element—the product development process. The process starts once the decision is made to launch a project. An effective development process requires that all functions involved agree to and follow the process requirements and procedures. Components of the process include setting features and target costs via the voice of the customer (Customer-In), establishing process phases and reviews, and eliminating non-value-added work. The objective is to design a quality product that delights customers and can be manufactured at the required demand volume and rate.

The development process can easily be viewed as sequential because there are a series of phases that occur in an order of precedence. Phased events are often driven functionally, which tend to result in functional interests being placed ahead of the development team goals and objectives and sometimes in conflict with business goals. Process steps are not begun before the prior steps are fully completed. This promotes the serial product development process even more, each step being triggered by a hand-off from the previous step (the proverbial "toss it over the wall syndrome"). Operating in functional silos accompanied by a natural aversion to risk, discourage team members from joint planning activities. The phases illustrated in Figure 4 are generic and can vary from company to company depending on the complexity of the development effort. Terminology for each phase can vary but generally include similar sub-sets of activities. For example, the Pre-Production phase is also called the Pilot Production phase. Phases can also be added based on the degree of complexity of the development effort. Each phase is traditionally concluded with a phase review to ensure that all the requirements for that phase have been satisfactorily completed. The phase review also provides an opportunity to identify and implement remedial measures for open issues or unmet requirements. Often considerable documentation requirements must be fulfilled for completion of each phase.

Figure 4. New Product Development



Costs that could be incurred if the development process is kept traditionally sequential from department to department are shown in Table 1. Dataquest, Inc. published this data for a serial process. It shows an extreme case of the relative costs associated with design changes that occur at various stages of the product development process. In this particular instance of a major electronic product, tenfold increase in costs was experienced for design changes at successively later stages in the process.

Table 1

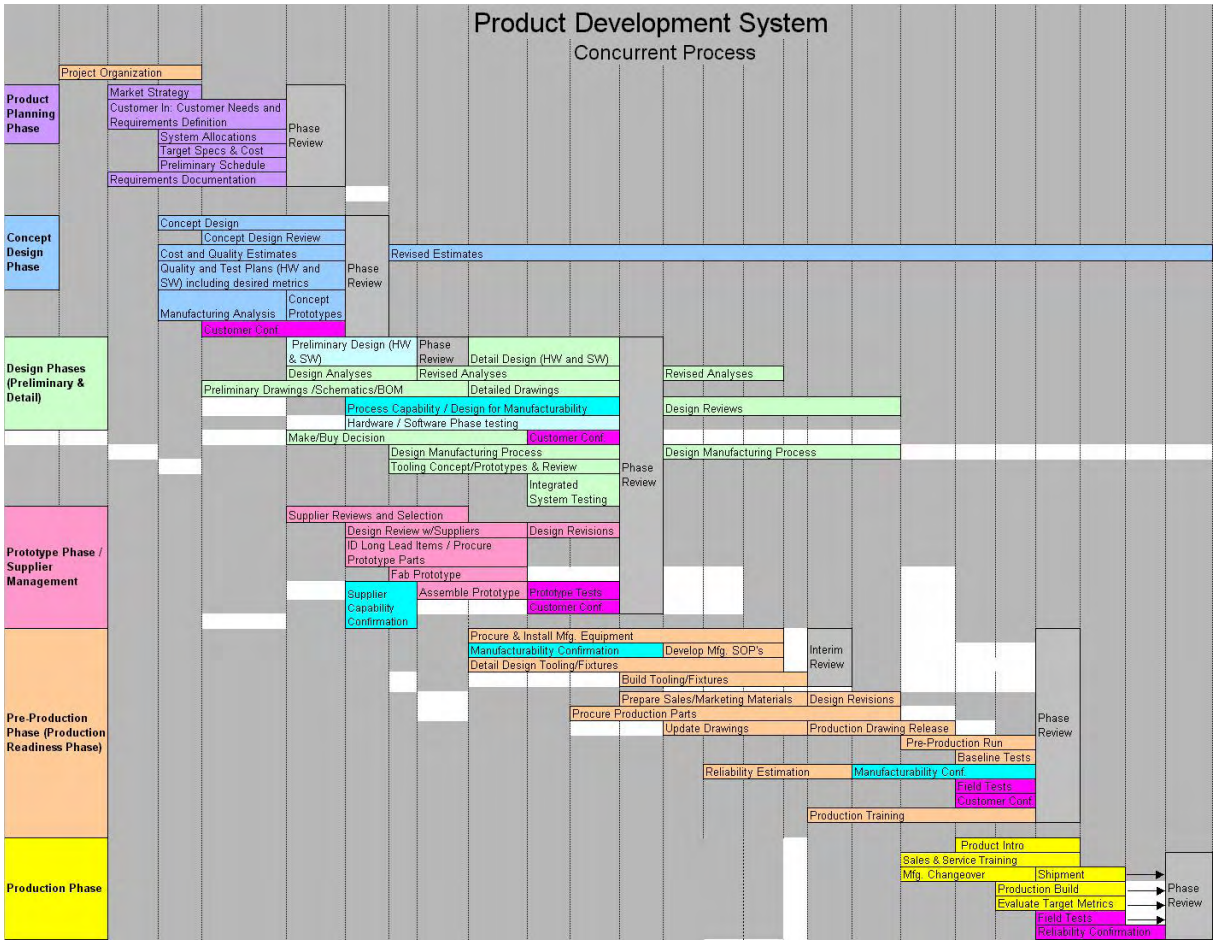
When design changes are made:	Costs
During design	$1,000
During design testing	$10,000
During process planning	$100,000
During test production	$1,000,000
During final production	$10,000,000

Data: Dataquest Inc.
As reported in *Business Week,* "A Smarter Way to Manufacture,"
McGraw-Hill, Inc., April 30, 1990, p. 110

Because a critical objective is to get the product to market as quickly as possible to gain competitive advantage, the development process must be designed to function in parallel with others wherever possible. Best-in-class practice requires the design of a process in which all the team members are working together to resolve decisions expediently and are aware of the impact of each function's decisions on other areas. This compresses the development time frame considerably. However, the organization mind-set to evolve from a sequential process to a concurrent process is often a major step. Joint planning increases the probability that team members will seek out ways to cut down on cycle time and determine how to make activities more concurrent, thereby reducing the need for changes downstream. Concurrent engineering promotes better inter-functional dialogue and encourages more frequent communication of status and issues through periodic team meetings, informal and formal reviews, and the establishment of criteria which encourage identification of the minimum information needed to begin working on succeeding steps in the process. The question team members should ask is, "What is the minimum information that I need to progress to the next task?" rather than, "When will the prior task be completed so that I can begin the next one?"

Figure 5 shows how the traditional serial process can be greatly compressed by performing several activities in parallel, creating a concurrent process. This is possible if each activity starts when the minimum information required to begin the activity is available from the prior (supplier) task. Team members are working together in a closely integrated fashion with clear lines of communication and physical accessibility to each other through co-location.

Figure 5. Product Development System



Concurrency promotes both designing a product with the features and functions that the customer wants and designing an efficient production system. Design for Manufacturability and Assembly disciplines (further discussed in the Tools Framework element) lead to more informed choices and mistake-proofed solutions. Design for Lean Manufacturing enables production capabilities and includes such principles as:

- One-piece flow of parts and assemblies through the production process
- Takt time production (build to the rate of customer demand) in work cells with time for each process balanced with the other processes
- Right-sized equipment that is easy to move and fast to changeover
- Short production lead time

As a result, the organization becomes more responsive, shortens its development cycle time, and avoids mistakes—which otherwise would aggravate cost containment objectives.

A more advanced state of the art of concurrent engineering is associated with autonomous product development teams. Autonomous teams dispense with the use of the traditional stage-gate process, thus eliminating waste associated with intense preparation to satisfy senior management's stage-gate reviews. These teams use regular (e.g. daily, first thing in the morning) stand-up meetings to stay on top of issues and to provide continuous support to the team members to rapidly accomplish their tasks. Senior management has a standing invitation to attend any meeting and are kept continuously informed. More formal reviews are held only as needed.

C. Methods

This section highlights the third Framework element—product development methods—by summarizing several methods that enhance a firm's development efforts.

1. Managing the Front End

The largest loss of time-to-market typically occurs in the front-end decision-making process—from the moment a concept is born to the time the design process can begin. Figures 6a and 6b illustrate the uncertain front end and the importance of measuring the cycle time elements. It is an attractive place to look for accelerating decision making and reducing cycle time. Clearly, understanding customers and their needs, evaluating the marketplace and assessing competitors' plans and capabilities in the front-end, accelerates the process of deciding whether the concept is worthy of pursuing. The product must fill a real need and at the same time broaden and enhance the product portfolio. It must also be timely and at a price the customer will accept. This approach is commonly known as "Customer-In", as opposed to a "Product-Out" approach. The latter is driven from within the company and is based on the

presumption that the company knows what the customer needs, defines the product requirements and performance characteristics, determines when it will release the product and can convince the customers that they need it.

If company leaders find that front-end time is excessive, they should focus on the components of the product development strategy—Customer-In, establishing the strategy, developing the product portfolio, and the product selection process.

Figure 6a. The Uncertain Front End

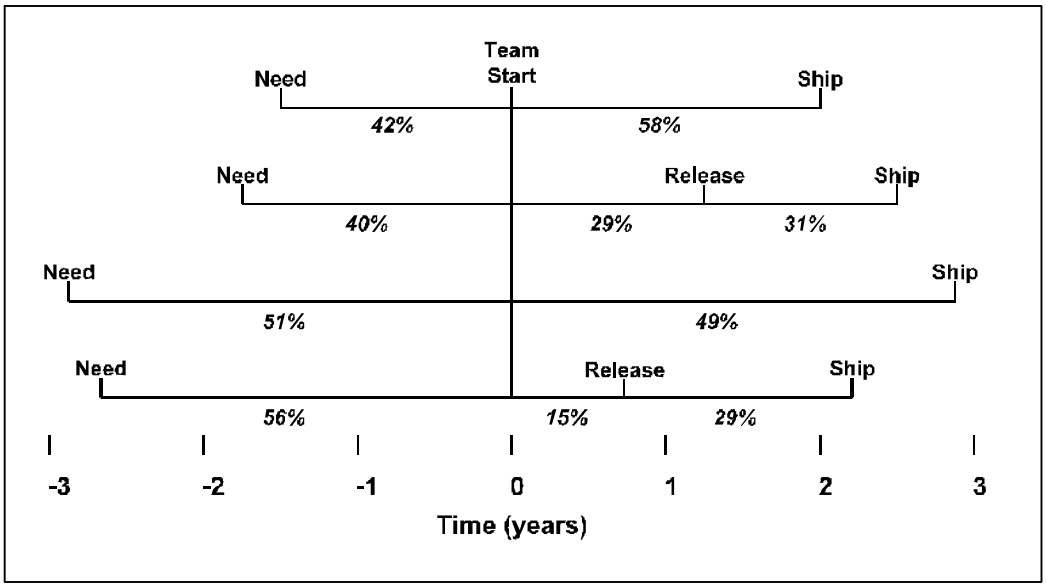
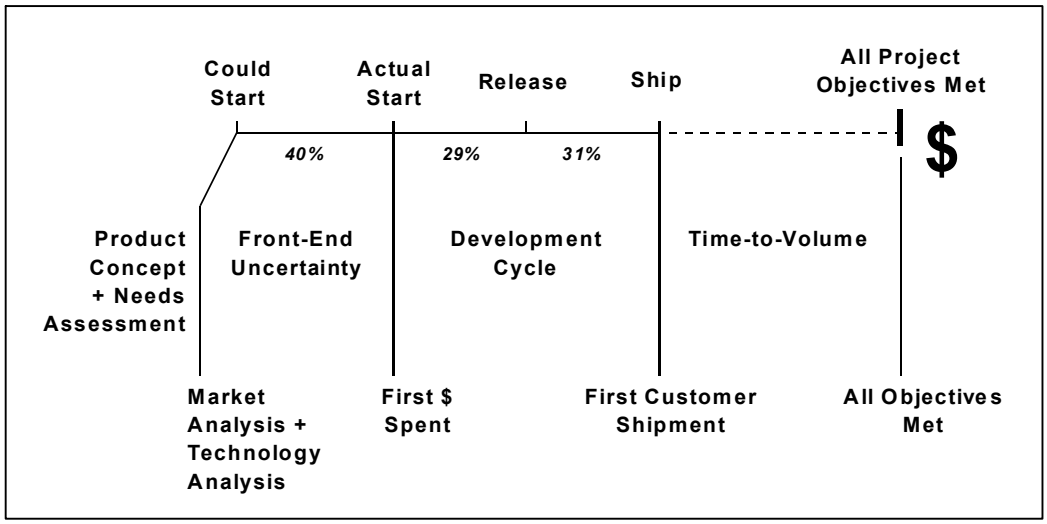


Figure 6b. Measuring the Cycle



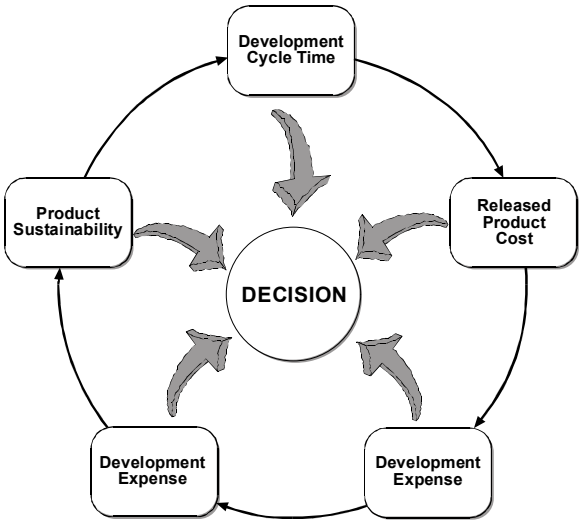
2. Evaluating Trade-offs

Any product development effort is confronted with making some hard decisions. Making the right decision quickly involves an evaluation of the trade-offs between at least four significant economic objectives (see Figure 7):

- *Development Cycle Time:* This represents the time from the moment a development program could have been initiated to the time the first product was made available to the customer. This includes the time between the birth of an idea through the start of the design effort, viz. what is commonly known as the "front-end" of the process
- *Released Product Cost:* The design to unit production costs (DTUPC) taken in the context of the total cost to the organization of design, manufacturing and support activities related to the specific product being developed. All non-recurring start-up costs also must be considered inclusive of marketing, sales, and manufacturing prior to product launch
- *Product Features and Performance:* This is a measure of how well a product meets the Customer-In requirements. It includes the broader definition of quality—the specification to market needs and the conformance of the product to the specifications—with the further concept of delighting the customer with unexpected features and benefits
- *Development Expense:* Because this is a non-recurring cost, it gets less attention. However, because all programs have a budget to work within, it will clearly be a focus of the program manager and the management team

- *Product Sustainability:* This addresses the ability to support and service the product after delivery to the customer. Testability, ease of problem diagnosis, ease of maintenance, field durability and reliability, are all features that can be designed in to reduce recurring costs to both the product manufacturer and the customer

Figure 7. The Five Economic Objectives



The skills required by the program manager and team members include a disciplined approach to using the above critical objectives in making good trade-off decisions. This is a quantification of the net economics of the situation, given conflicting impacts. An example of a complex trade-off is shown in Figure 8. An eye-opening discovery is that accelerating development cycle time is better than the cost penalty incurred to product development expense. For example, selecting a different but responsive supplier partner can be a better decision than rigidly controlling the product budget because of the recurring benefits that accrue when the product gets to market sooner.

Figure 8. A Complex Trade-Off

- Decision to add a performance feature to differentiate the product from the competition
- This entails a two-month delay, a cost increase of 2.0%, and expense of an extra $100K for a 12% increase in sales

Benefit	Cost
Revenue 12 percent = $1.2 million	• Delay 2 mos. = $500K • Cost 2.0 percent = $200K • Expense = $100K
$1.2 million	$0.80 million

A model may be developed which consists of a set of decision rules, which can be used repeatedly. This helps make faster, better decisions. Figure 9a illustrates the assessment of total impact of each of the evaluation criteria. Figure 9b converts that assessment into a re-useable formula when presented with a similar trade-off in the future. The appropriate multipliers would be used to determine total impact. For example, if there were a 10% expense overrun, the total impact would be $100,000.

Figure 9a. Calculate Total Impact

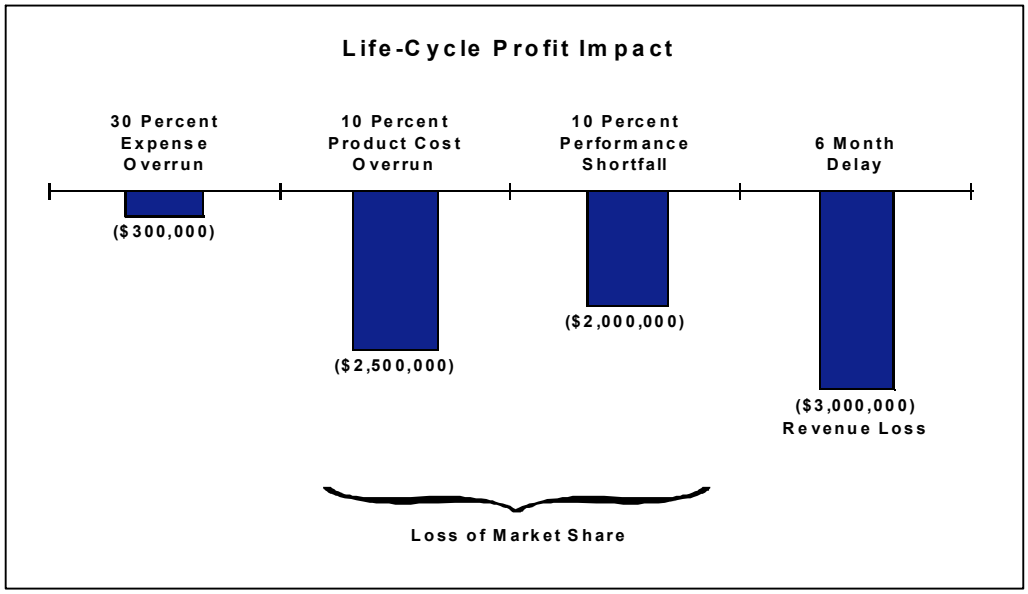
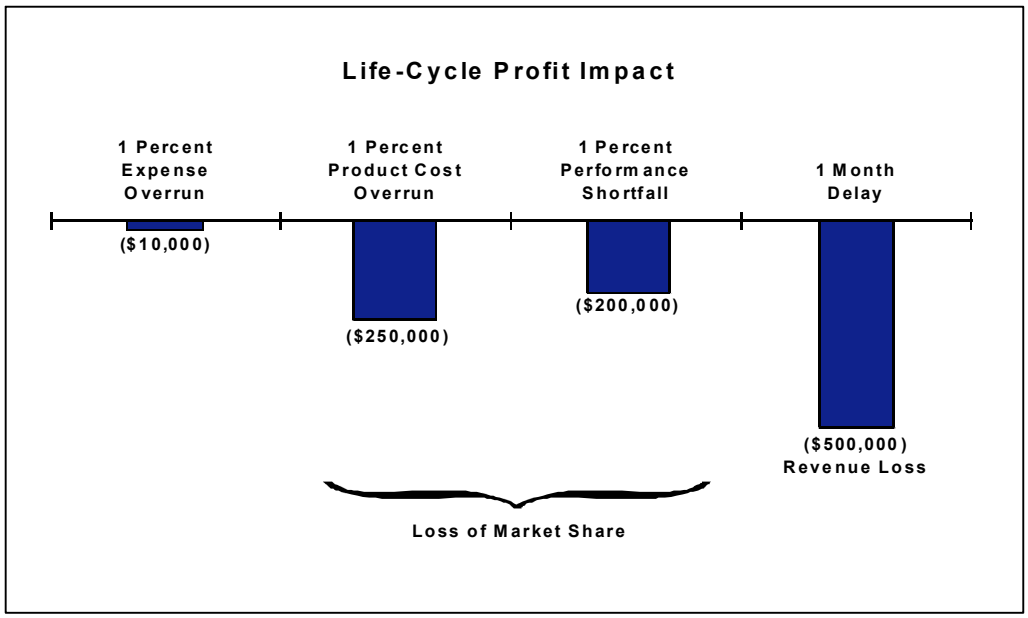


Figure 9b. Convert to Decision Rules



3. Set-Based Concurrent Engineering

Set-Based Concurrent Engineering (SBCE) described by Likert et al, begins by broadly considering sets of possible solutions and gradually narrowing the set of possibilities to converge on a final solution. SBCE underlies Toyota's development process. Toyota considers a broader range of possible designs and delays certain decisions longer than other automotive companies do, yet has what may be the fastest and most efficient vehicle development cycle in the industry.

Traditional design practice, whether concurrent or not, tends to quickly converge on a solution space, and then modify that particular solution until it meets the design objectives. As the design passes through critiques, every change causes further changes and analysis, resulting in rework.

Compared to traditional design practice, SBCE casts a wider net at the start, and then more gradually eliminates weaker solutions. Design participants develop sets of solutions in parallel and relatively independently. As the design process progresses, they gradually narrow their respective sets of solutions based on additional feedback from product and manufacturing engineers, testing, customers, and others. For every major component, development participants update a product and production checklist, which represents current capabilities—the set of feasible designs and production constraints.

SBCE has several benefits. First is that reasoning and communicating about sets of ideas leads to more robust, optimized systems and greater overall efficiency than working with one concept at a time. Another is the flexibility to respond to a changing environment, because convergence to a final solution occurs closer to market introduction. Finally, taking time up front to explore and document feasible solutions from design and manufacturing perspectives leads to tremendous gains in efficiency and product integration later in the development process and for subsequent development cycles.

4. Lean Production Preparation

Many companies have adopted lean production. Those that have must prepare for lean production during product development.

Lean production is doing more and more with less and less by systematically identifying and eliminating waste. The identification of waste is based on five principles described by Womack and Jones: precisely specify *value* by specific product, identify the *value stream* for each product, make value *flow* without interruptions, let the customer *pull* value from the producer, and pursue *perfection*.

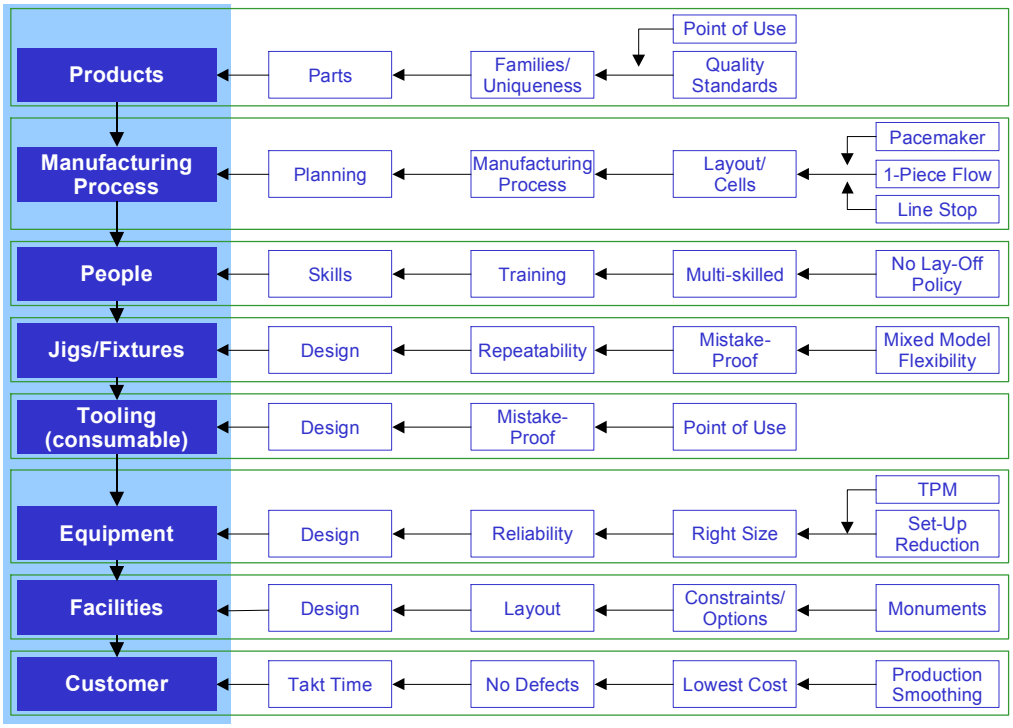
The principles of lean production manifest themselves in production techniques such as:

- Production designed for continuous one-work-piece flow (cells)
- Precisely choreographing the work sequence, the rate of production based on customer demand, and work-in-process (standard work)
- Work flow controlled by a pull system (kanban)
- Orderly layout of work area (5S)
- Visual controls

Preparing for lean production calls for designing how the product actually flows through the production process. It rejects traditional thinking that complex equipment running batches improve productivity. Instead, the goal is to enable continuous one-piece flow at and between processes. Equipment becomes “right sized” to just accomplish the required job and enable easy reconfiguration, the shape is configured to minimize walking distance within the production cell, and the design enables ease of maintenance. Production quality is assured with go/no-go gages and mistake proofing (*poka-yoke*) devices.

Figure 10 illustrates many of the considerations of lean production preparation.

Figure 10. Lean Production Preparation Process



5. Variety Effectiveness

Any business that does not actively manage and control variation in all forms places itself at a distinct competitive disadvantage. Internal policies can be developed to address the need to minimize proliferation of products, parts, materials and processes. Policies are essential to laying the groundwork for managing design, development, manufacturing operations and support costs. Variety effectiveness is a process of determining what constitutes good variety and what constitutes negative variety.

Businesses must figure out a way to satisfy and even delight their customers' growing needs without creating a complex and costly operating environment to meet those needs. It is easy for design personnel to create designs, which work well, but contain new parts and materials and require new processes. Without education on the impact that marketing and design decisions have on the ability of the organization to be cost competitive, each member of a development team may continue to contribute to negative variety. This happens as a result of not being aware of what already exists in current product offerings that can be reused in new offerings to the marketplace, or not making an effort to decide what existing modules, parts, materials, etc. can be used in new designs. Parts classification systems, if properly structured to provide that information, can be a tool that decision-makers use before deciding to add unique items to the company database.

6. Risk Management

Risk management is a key program management function requiring considerable discipline. It is a form of evaluating trade-offs, but is an extension of the considerations beyond the net cost impact of the alternatives the team must evaluate. The probability of occurrence of events plays a major role in risk assessment.

D. Product Development Tools

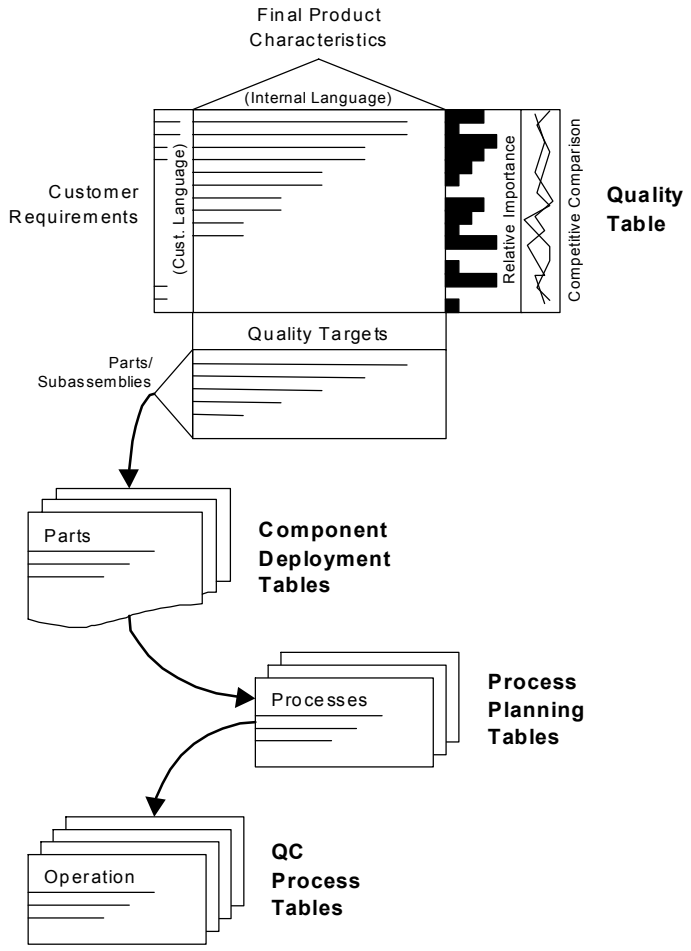
This section highlights the fourth Framework element—product development tools—by summarizing several tools or techniques that enhance a firm's development efforts.

1. Quality Function Deployment (QFD)

QFD is a tool that leverages the "Customer-In" approach to capturing customer requirements (the 'what') by systematically converting them to product requirements, features and technical characteristics (the 'how') that the product must meet. It then converts the technical characteristics into manufacturing requirements and targets that are supported by process plans and quality control plans. This is done by using a series of quality deployment tables, sometimes referred to as the "House of Quality" (see Figure 11).

QFD analysis must be multi-functional. It is one of several tools which help the product development team move through the product planning and specification steps in a more reliable and complete way, resulting in fewer engineering changes and higher product "built-in" quality. Cycle time is compressed, responsiveness to the customer's needs is increased, and the non-recurring, product development cost is reduced.

Figure 11. Quality Deployment Tables



2. Kano Methods

Capturing and documenting "real" requirements can be improved by using a structured approach. Dr. Noriaki Kano developed a technique for identifying and segregating customer requirements and inputs. Kano represented these in the diagram shown in Figure 12. The three major classifications represented in the diagram are:

1. *Performance Quality:* These are generally "known and spoken" needs stated by the customer. Product performance and quality needs that fall into this category can be captured by surveys and otherwise volunteered by the customer because they are easier to quantify. If customers do not get what they want, they are dissatisfied. If they do get what they want, they are satisfied. Examples of such needs include square footage in a house, a ranch or a two-storied house and gas mileage in a car.

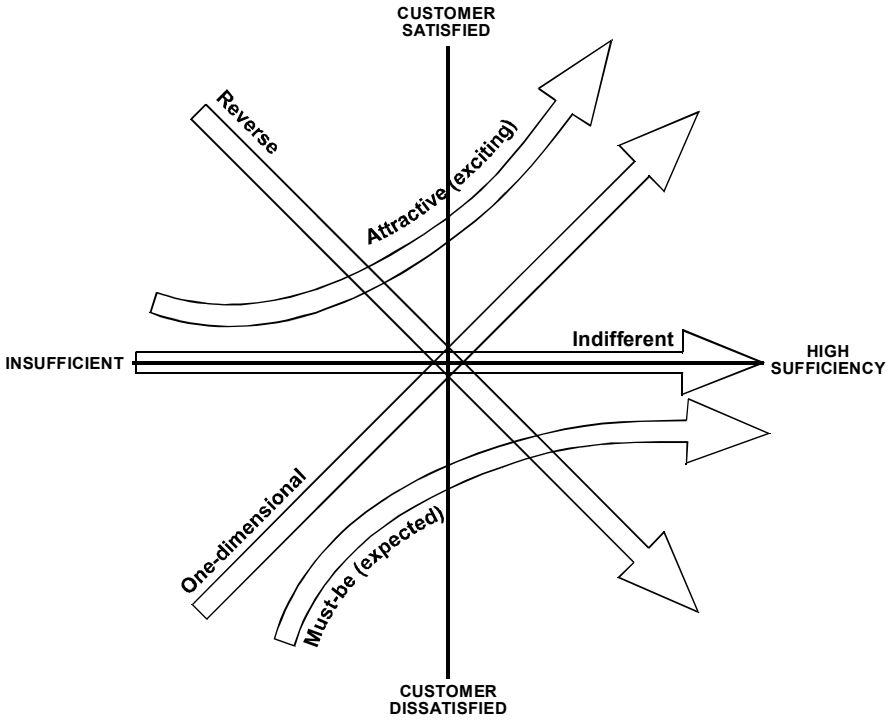
2. *Expected Quality:* There are needs that a customer will expect to be included in the product and therefore will not explicitly ask for them. They fall in the category of "known but unspoken" and the customer will be dissatisfied if they are missing. However, including these needs in the product will not further enhance the customer's satisfaction—they expect them. Examples of such needs include the reliability of being able to start a car every time, safety features such as seat belts and air bags, an instruction manual and wheels on a big screen TV.
3. *Exciting Quality:* These fall into the category of needs that the customer does not expect and therefore will not be disappointed if he/she does not find it in the product or service. This is usually because the customer does not know about the feature or believes it is hard to implement. However, this is where designers can have a significant impact by differentiating their product from the competitions by offering the unexpected but exciting feature(s) designed to delight the customer. Examples of such features include the first camera with auto-focus, the first Polaroid instant picture camera, the first automobile computer to compute instant and average mileage and TV remote control.

Two additional classifications enable the identification of undesirable features:

4. *Indifferent Quality:* In this case, customers do not care about the product characteristic and consequently just accept that fact that it is there.
5. *Reverse Quality:* This category includes features that the customer is turned off by. Examples include a mechanical voice telling the driver to put on his/her seat belt or reminding him/her that the door is open and the ignition/seat belt interlock.

Analyzing all of the above classifications of customer identified (or not identified) quality features is valuable in the early phases of product planning so that the appropriate selections can be carefully integrated into the product requirements as the design process begins.

Figure 12. Dr. Noriaki Kano's Five Classifications of Customer Perceptions

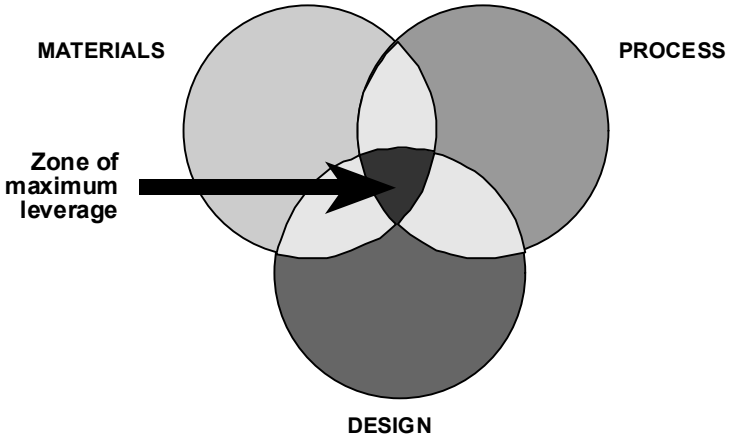


3. Design Quality Estimation

The quality of the end product is a function of the product design, material, and component selection, and the processes and equipment used to fabricate and assemble the product (Figure 13). Each has independent and interactive influences on product quality. Design Quality Estimation can be initiated soon after preliminary design is complete and be updated periodically as the product design, process development, and process improvement efforts evolve through the design cycle. Assessing the impact of the design, materials and components on the ability to produce the product is an advanced quality analysis that serves as a predictor of manufacturability. It can be expressed in a number of different ways, e.g. product sigma, defects per unit (DPU), or rolled throughput yield.

The analysis requires a good knowledge of the process capabilities of all of the process steps in the build sequence for the product. Real quality data can also be used, factored for product differences and anticipated process improvements. Leading edge quality practices such as these are employed by companies such as Motorola as part of its Six Sigma and 10X product cycle time reduction initiatives.

Figure 13. Concurrent Design and Six Sigma Quality



4. Design to Unit Production Cost (DTUPC)

DTUPC is another goal the product development team can set for itself. Just as the product development effort has a budget, the target product cost can only be achieved if the product team is allocated cost targets (cost budget) for the major architectural components of the design. These cost targets are then broken down further into the module, sub-assembly and lower levels of the product structure so that the engineers can manage the cost build up as the design selections are made.

5. Design for Manufacture and Assembly (DFMA)

Any product design that has not taken into consideration existing and planned manufacturing and assembly capabilities integral to the design process, will be at a severe disadvantage to the product design that has. As mentioned earlier, the success of a design is dependent on the organization's ability to integrate design, materials and process considerations (Figure 13) to determine the zone of maximum leverage, thereby enhancing producibility. The purpose is to produce a higher quality product with minimal rework and reduced manufacturing variation resulting in a more predictable quality output.

A powerful and proven six-step process that provides a simplified model for DFM and DFA is summarized below:

1. Identify critical customer satisfaction requirements, both implicit and explicit, for the product or system to be designed.
2. Determine the specific product or system parameters that contribute to achieving each critical customer requirement. Document these parameters.

3. Determine the manufacturing process and process steps and the component and material selection that affect the customer requirement for each product or system parameter identified in Step 2.
4. Specify a nominal value and a maximum tolerance aimed at achieving the desired quality level for each product or system parameter.
5. Determine the current capability of the contributing components and process steps for each critical parameter specified in Step 4.
6. Measure the capability indices Cp and Cpk. To achieve six sigma, the objective is Cp ≥ 2.0 and Cpk ≥ 1.5. If the indices do not meet the requirement, redesign the product and/or optimize the process to achieve Cp ≥ 2.0 and Cpk ≥ 1.5. Then implement rigid process controls.

The Design for Assembly discipline also requires the use of some basic guidelines. These include:

- Minimize the number of parts
- Utilize standard parts and materials
- Design modular assemblies
- Design parts for ease of fabrication
- Design for top-down assembly
- Design for self-alignment and self-location
- Minimize the number of fasteners, attachment devices and connectors
- Design for poka-yoke or error-proof assembly
- Minimize adjustments and physical reorientation
- Design robustness into products
- Avoid flexible/flimsy parts
- Simplify servicing

6. Design Failure Modes and Effects Analysis (DFMEA), Process Failure Modes and Effects Analysis (PFMEA)

The purpose of a Design FMEA is to identify potential failure modes and ensure that their effects are evaluated systematically. Potential safety concerns can also be identified and resolved. The DFMEA can also help identify product design verification requirements for product or system tests. For quality planning purposes, this analytic technique will help identify critical product characteristics as required by a product quality plan.

The technique uses a process that rates the failure mode by degree of severity, probability of occurrence, and ability to detect the failure. The product of these produces an index, which determines the priority of the risk and directs the evaluating team in the best use of their time.

Causes of failure are identified and an assessment made of the current control procedures. Actions are identified to help eliminate or mitigate product failure modes by making design improvements using changes, additions and deletions.

A parallel tool is a Process FMEA. The purpose is to analyze the potential failure modes inherent in a current or new manufacturing or assembly process. The steps used are similar to the above and result in the identification of critical process characteristics that then can lead to the development of the proper controls and process improvement plans to mitigate the risk of defective product.

The preparation of a DFMEA or PFMEA is a good preventive action that gives the participating team members an opportunity to make necessary changes, additions and deletions to the design or process before releasing it.

7. Value Engineering

The value methodology has been used extensively in relating cost to function. It is a systematic methodology for identifying the functions in the product or process, establishing their worth and providing the necessary functions to meet the desired performance at a minimal cost. For those functions deemed necessary, high cost implementations in a product or process can be re-engineered after assessing the alternative solutions. Value is defined as the ratio of function to cost or the ratio of customer needs to price. The larger the ratio, the greater the success in achieving maximum worth.

Value engineering defines functions at each stage of a process or for each component in a product by using a verb and noun. The need for the function is verified before determining whether the function is being provided in the most cost effective manner. Critical measures to ensure the consistent application of the process or product are also identified and implemented.

8. The Variety Effectiveness Process (VEP)

Variety Effectiveness as defined by Gwendolyn Galsworth in her book, *Smart, Simple Design,* is “a systematic process for preventing or reducing unwarranted product and parts variation while offering maximum customer selection at a least-cost sum.” Variety in the eyes of the customer is a competitive advantage if the organization that creates that variety is effective and adds value—known as positive variety—as opposed to creating variety that adds unnecessary cost—known as negative variety.

A systematic assessment process for creating and expanding customer selection while reducing the negative variety in products, parts, processes and control points is explained in Galsworth's book. The four stages of this method are:

Stage 1 Prepare for an Effective Implementation

Stage 2 Identify Valid Reduction Opportunities, Applying the Six VEP Tools

Stage 3 Coordinate and Prioritize Reduction Opportunities

Stage 4 Implement and Sustain the Improvement

The formation of a variety of cross-functional teams trained in the VEP process to assess the market, product, part and control point reduction opportunities is the underlying framework that could be viewed as extremely structured and complex. If used judiciously to target select opportunities, it can prove to be a useful approach to reducing negative variety.

The core analysis in Stage 2 uses six techniques known as the 6-VEP Analysis Tools. They are:

VAT-1 **Unique versus shared**

Analyzes parts that are unique to one product and those that are shared for maximum leverage.

VAT-2 **Modularity**

Analyzes modules and sub-systems in a similar manner to individual parts to determine whether they are being uniquely used in a single product or across several products with minor variations.

VAT-3 **Multi-functionality and synthesis**

Identifies parts and assemblies that can perform multiple functions, resulting in a reduction in the number of parts required to fulfill those functions.

VAT-4 **Ease of assembly**

Evaluates Design for Assembly.

VAT-5&6 **Range and trend**

Identifies patterns in part characteristics and relationships, which can help reduce variety within the full range covered by those characteristics. The tools highlight dispersion, clustering and trends in paired relationships, and are used to make more informed selections based on customer needs and requests.

9. Mistake Proofing

Mistake proofing or poka-yoke, eliminates inadvertent errors such as omitted processing, processing errors, missing or wrong parts, adjustment errors and improper equipment setup. Mistake proofing examples include guide pins of different shapes and sizes, error detection alarms, limit switches, counters, reliable methods and checklists. Mistake proofing assures that 100% of parts are inspected so that quality is built into the process. While commonly developed by manufacturing engineers for existing processes, it is a valuable tool in the development process, as well. Six Sigma tolerancing techniques are also a form of mistake proofing. This methodology builds on the concept of variation reduction within the design tolerances. Knowing the process capability, and therefore the extent of variation, the design tolerance can be set to achieve a very low probability of defects or vice-versa. In the latter case, if the tolerances cannot be changed, the process capability must be improved to achieve a Six Sigma product, thus requiring process improvement plans to be set in place prior to design release. This is the same as Design for Manufacturability.

10. Reliability Engineering

The ability to predict the life of a product can be used as a powerful marketing tool that can be an attractive selling point. It is also used to make informed design selection decisions for parts and materials. Knowing the Mean Time Before Failure (MTBF) and Mean Time to Repair (MTTR) of a product in the early design stages, can help designers modify the design by selecting more durable and reliable components for the environment the product must survive in. Suppliers often are able to provide reliability information on mission critical components, which can be used in this type of analysis by reliability engineers. A vast repository of such data can also be found in Reliability Handbooks.

11. Gage Reliability and Reproducibility

Measurement techniques used in design and manufacturing, are often only cursorily studied and even overlooked. A good measurement instrument or technique has certain desirable characteristics. The first characteristic is the ability to measure to the resolution needed to accurately detect parameter changes to the desired decimal level. Rule of thumb calls for the resolution to be 10 times better than the decimal level of the parameter. The other two characteristics of good measurement are accuracy and repeatability under measurement conditions, which include the measurement instrument and the person performing the measurement. Typically, the analysis will include more than one operator and piece of equipment, and will employ repeated measurements of the same parameter. Measurements will also be taken at different points in time to account for environmental variation and other factors that can influence the measurement result but cannot always be tightly controlled.

Gage reliability and reproducibility is an experimental technique that is able to quantify the above characteristics to determine whether the current or anticipated measurement technique is capable.

12. PDM/CAD/CAM

Product Data Management (PDM), Computer Aided Design (CAD), and Computer Aided Manufacturing (CAM) are powerful tools that can dramatically reduce development cycle time. These tools become particularly powerful when the organization establishes design standards and a library of parts and subassemblies that can be plugged into new designs. These standards help keep part variety within acceptable limits and enhance organizational knowledge. When these systems are linked and if the software permits, design changes are quickly and easily updated for all affected parts. Not only does this save time, but it allows more freedom in investigating alternative designs. A full discussion of these tools is beyond the scope of this paper.

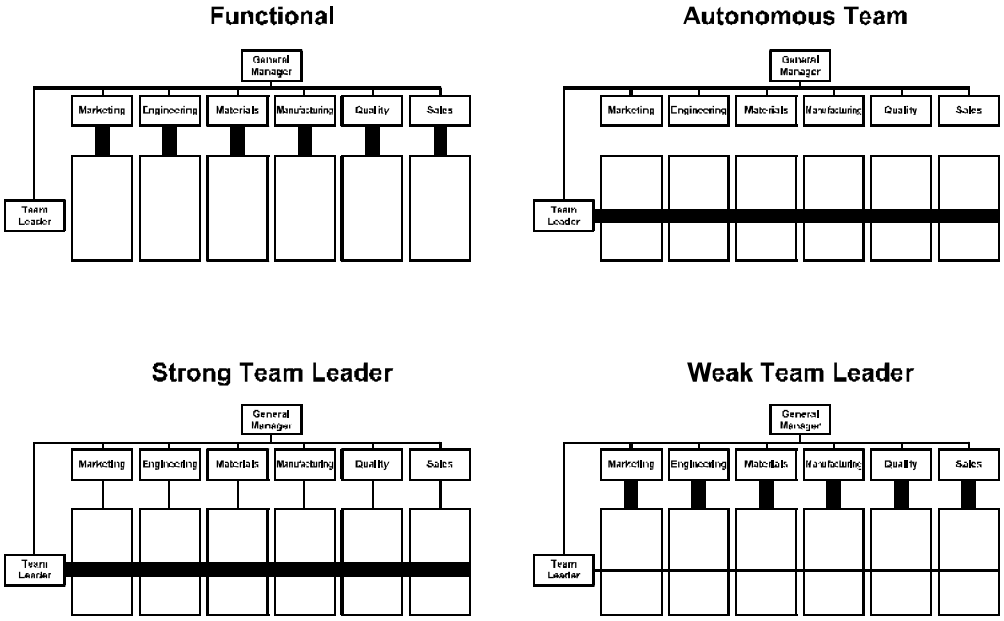
E. Organization Structure to Support Product Development

The fifth framework element—organization to support product development—includes establishing the organizational hierarchy; development teams; and roles, responsibilities and rewards that support rapid and effective product development. Concurrent engineering promotes better inter-functional dialogue and more frequent communication during the design process. A cross-functional team established during the front end of the development process is highly recommended. Getting team members involved early in the game in participating in the decisions presents the following benefits:

- Individual member skills are blended with others to bring together a wide array of talents, experiences and knowledge. Together, the quality and creativity of the solutions is greatly improved
- All members feel like they have a stake in meeting the program objectives
- Concurrency is made possible, dramatically cutting cycle time
- Team discussions result in improving the quality of input to the design
- Manufacturability issues are more readily addressed
- Communication between team members is improved and consensus decision making more easily achieved
- Team decisions are proactive and avoid having to be repeatedly adjusted for late input
- Conflict between functional areas is greatly reduced
- Increased learning and an accelerated learning curve are an outcome
- Co-location of team members further improves camaraderie, open and frequent communication, and accelerated problem solving

Figure 14 shows four forms of team organization based on the strengths of the team leader and team members, and constraints imposed by organization structure. Additionally, depending on the type of development program, the team organization could be different. For example, a team set up to develop a new platform would have greater success if either the "Strong Team Leader" organization form or the "autonomous team" structure was supported. To develop a breakthrough-type product that creates a whole new market for the business, the preference is to create an autonomous team organization for maximum leverage if such a strongly self-motivated team can be assembled, although a strong team leader can help compensate for functional organization pull on the rest of the team.

Figure 14. Organization Forms

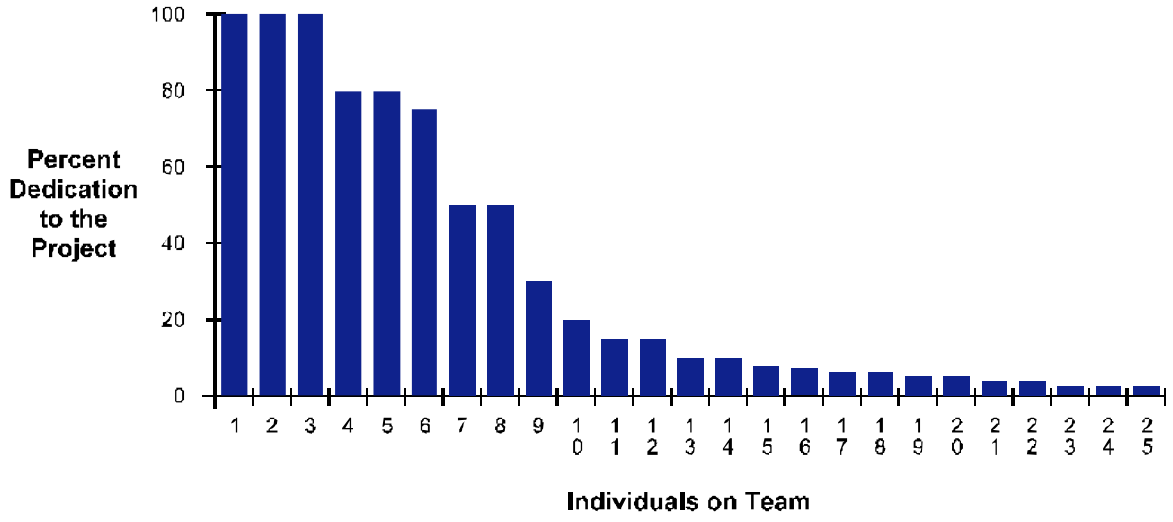


The challenge of selecting and staffing the development team is not a trivial one. Often not enough thought is given to this issue. A high-performance team tasked with new product development has to be cohesive. Considerable effort needs to go into selection, team training, agreement on goals, blend of skills (both unique talents and multi-skilled individuals), and percentage of time dedicated to team efforts. Experience suggests that the more the following criteria can be satisfied, the better the team's performance will be:

- Select an experienced and respected team leader, preferably from the senior ranks. Team leadership can be shared between a strong program manager and a technical person from the engineering organization. The former serves as the organizer and primary interface to the senior management team, as well as the team's advocate for decisions required of senior management. The latter provides the engineering leadership to achieve and exceed the program's goals and objectives within the framework provided by the program plan and schedule
- Full-time team membership should not exceed eight members, but must be able to represent marketing, sales, product design and engineering, manufacturing engineering, manufacturing, material, and quality representatives
- Roles and responsibilities must be clearly defined
- Team members are trained in high performance teaming skills
- Team members serve from product concept to shortly after the first few shipments of product
- Core team members are assigned to the team full-time if their skills are required to work critical path activities. The remaining members are assigned between 70% to 80% of the time to the project
- Team members are preferably volunteers
- Team members are given a clear mandate and objectives
- Risk taking is encouraged and not punished if things go wrong
- Team members are allowed to make most decisions effecting rapid progress, e.g. resources to be used, trade-offs, supplier selection, etc.
- Team members are responsible to the team leader and are not held to function-based goals and objectives
- Team members are co-located
- Team members are given the tools, equipment, and priorities they need to accelerate development
- All personality types are included on the team to provide diversity and balance (as indicated by a Myers-Briggs type indicator)

The real world does not usually permit some of these criteria to be fully or sometimes even partially met. Organization priorities generally prevent full-time dedication to the team, resulting in a less than ideal commitment to the product development team. Depending on the project scope (incremental vs. platform), team members may not be dedicated or may have to pull in some part-time resources to supplement the core team members. Internal politics may prevent team members from being fully committed to the team leader and the development program. Figure 15 shows how a team could be fragmented by the use of part-time membership, resulting in many more individuals with minimal commitment to the specific project.

Figure 15. Team Fragmentation



F. Management of the Development Process

The sixth framework element—management of the development framework—includes clear sponsorship and ownership of the development process, project management, and performance measurement. It also includes the support and behaviors of managers and executives.

1. Sponsorship, Ownership, and Project Management

Management participation and intervention in product development is required for the following: sponsorship of a project, management reviews, decision making which the development team members are not authorized to make, decision making which could result in a change in direction or a re-evaluation of goals or targets, and expert guidance. The level of management involvement with the team will be influenced to some degree by the team organization structure and a level of autonomy determined by team leader and member skills. Either adopting a hands-off approach once the team has been selected or imposing too much management oversight, can be detrimental to the project's success.

The Development Framework should have an assigned process sponsor, usually the Vice-President of Engineering and Development. The sponsor's roles include assigning priorities, allocating resources, managing interdependencies, and reviewing progress for all projects in development and projects in the screening process.

The Development Framework should also have an assigned process owner. The process owner's roles include ensuring that the appropriate methodology is followed, understanding best-in-class development processes, measuring and evaluating the performance of the Development Framework, and improving the Development Framework.

Project management requires a blend of technical and program management skills. Each project should have an assigned project leader, often a chief engineer. The project leader may play a dual role. However, often the project leader and a program manager are assigned to the same development project to complement each other's skills. Their roles parallel the sponsor's roles except that they are focused on a specific development project.

2. Performance Measurement

Performance measurement—the process of setting goals, monitoring progress, and rewarding good performance—provides the motive force that ensures fast development cycle times.

Setting goals that are supportive of a business strategy which encourages product innovation and rapid product development can be a great cohesive force, particularly when team members have some say in establishing the goals. It serves to get the key players pulling in the same direction and gives them and the senior management team measures of the degree of accomplishment. Goals should be set so that they are measurable; achievable but challenging; an accurate representation of the tasks that must be performed; and support the ultimate objective of rapid and cost-effective development.

Goals extend beyond the need to identify the real requirements the product has to meet and to verify the ability of the product to meet those requirements. They should be set so as to achieve a competitive edge and yet minimize any negative impact to the organization. Goals can be set to achieve a wide variety of objectives. Some typical goals designed for this purpose are:

- *Market Goals:* These take the form of market share, revenue and profitability (by market segment), revenue distribution following new product introduction through product life cycle, market share growth and distribution by product portfolio components, etc.
- *Product Portfolio:* The percentage distribution of the product development effort between products that fall into breakthrough, platform or incremental development objectives, and the change in distribution as the business strategy evolves with time
- *Design to Unit Production Cost (DTUPC):* The purpose is to challenge the design team to make cost-effective decisions. The process of setting these goals is to take the product cost target and allocate costs to the various sub-systems and modules so as to continually estimate the impact of design decisions on cost by managing to a cost budget. In this case, one must be careful not to permit other costs within the organization to increase because of the decisions made to reduce product specific costs
- *Development Cycle Time (Time to Market):* This has to be set with the goal of being first to market. The measurement of cycle time should also involve measurement of the various phases of activity starting with birth of a concept through shipment of the first product. The goal established would be progressively more difficult for succeeding products, within the context of a continuing attempt to reduce development cycle time through improvements in the design and development process.
- *Design Quality:* The objective in this case is to use information on existing process capabilities to predict or estimate the quality level at which the as-designed product can be built, through preliminary and detail design phases, and through pilot production to full production. This tool helps the team make design decisions which minimize problems in manufacturing and assembling the product, and can lead to desired improvements in product design, materials and processes needed to achieve the target. It also helps minimize the "Cost of Quality," which ultimately effects the bottom line. It reinforces the need for Design of Manufacturability (DFM) and Design for Assembly (DFA) disciplines
- *Variety Effectiveness:* These goals would be set with the intent of using parts, materials, functional modules, software functionality, etc. that already exist in other related products within the product line or across product lines. Such goals direct the organization towards greater variety effectiveness and reduced total costs as mentioned in 'Market Goals'

- *Percentage Reuse:* Several metrics could result from the desire to achieve variety effectiveness. Metrics examples, include tracking standard parts, common product modules, sub-assemblies and software modules reused in new products as a percentage of the total count of those criteria. Goals established early in the development process establish a target to be achieved by the product development team
- *Expense Budget:* In spite of its being a non-recurring cost, the expense budget is an important element in containing development costs through the management of internal and external resources applied to the development task
- *Engineering Productivity:* This can take the form of engineering hours per project tracked by project type (breakthrough, platform or incremental). Actual hours versus planned hours is another useful measure

IV. Conclusion

This paper provides a high-level overview and justification for reviewing and re-engineering the product development process to gain competitive advantage. The objective is to achieve a more responsive and flexible value stream, which maximizes value and minimizes the occurrence of errors and defects. Guidelines and recommendations have been provided along with a framework for team organization. The range of tools described for achieving a successful but rapid product design on the first attempt are adaptable by any organization willing to invest time and energy in enabling such a change and gain confidence to make the transition. The ultimate goal is to satisfy or even delight the customer base with the right product variety, at the right time, at a price the customer believes is worth the investment.

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